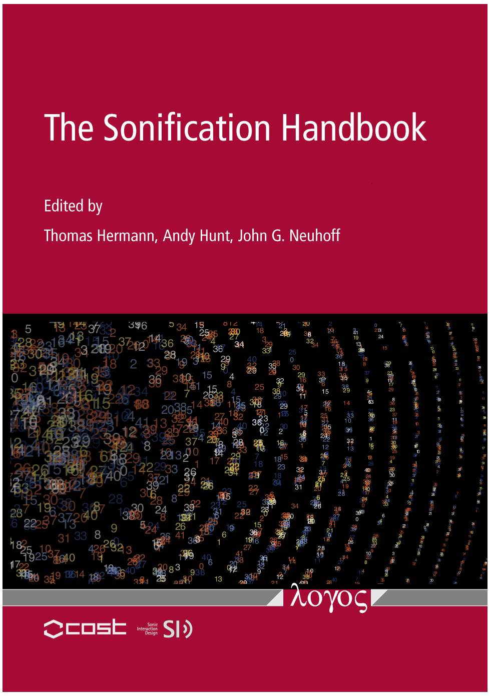

The Sonification Handbook

Edited by
Thomas Hermann, Andy Hunt, John G. Neuhoff

Logos Publishing House, Berlin, Germany
ISBN 978-3-8325-2819-5
2011, 586 pages

Online: http://sonification.de/handbook
Order: http://www.logos-verlag.com

Reference:
Hermann, T., Hunt, A., Neuhoff, J. G., editors (2011). *The Sonification Handbook*. Logos Publishing House, Berlin, Germany.

Chapter 5

Sonic Interaction Design

Stefania Serafin, Karmen Franinović, Thomas Hermann
Guillaume Lemaitre, Michal Rinott and Davide Rocchesso

This chapter introduces the emerging discipline of sonic interaction design (SID). SID is the study and exploitation of sound as one of the principal channels conveying information, meaning, and aesthetic/emotional qualities in interactive contexts. Sonic interaction design lies at the intersection of interaction design and sound and music computing.

Reference:
Serafin, S., Franinović, K., Hermann, T., Lemaitre, G., Rinott, M., and Rocchesso, D. (2011). Sonic interaction design. In Hermann, T., Hunt, A., Neuhoff, J. G., editors, The Sonification Handbook, chapter 5, pages 87–110. Logos Publishing House, Berlin, Germany.

Media examples: http://sonification.de/handbook/chapters/chapter5

Chapter 5

Sonic Interaction Design

Stefania Serafin, Karmen Franinović, Thomas Hermann, Guillaume Lemaitre, Michal Rinott, Davide Rocchesso

5.1 Introduction

Sonic Interaction Design (SID) is an interdisciplinary field which has recently emerged as a combined effort of researchers and practitioners working at the intersection of sound and music computing, interaction design, human-computer interaction, novel interfaces for musical expression, product design, music psychology and cognition, music composition, performance and interactive arts.

SID explores ways in which sound can be used to convey information, meaning, aesthetic and emotional qualities in interactive contexts. One of the ultimate goals of SID is the ability to provide design and evaluation guidelines for interactive products with a salient sonic behavior. SID addresses the challenges of creating interactive, adaptive sonic interactions, which continuously respond to the gestures of one or more users. At the same time, SID investigates how the designed gestures and sonic feedback is able to convey emotions and engage expressive and creative experiences.

SID also aims at identifying new roles that sound may play in the interaction between users and artifacts, services, or environments. By exploring topics such as multisensory experience with sounding artifacts, perceptual illusions, sound as a means for communication in an action-perception loop and sensorimotor learning through sound, SID researchers are opening up new domains of research and practice for sound designers and engineers, interaction and interface designers, media artists and product designers, among others[1].

SID emerges from different established disciplines where sound has played an important role. Within the field of human-computer studies, the subtopics of auditory display and sonification have been of interest for a couple of decades, as extensively described in this

[1] When talking about designers, we use the definition proposed by [66]

handbook.

In sound and music computing, researchers have moved away from the mere engineering reproduction of existing musical instruments and everyday sounds in a passive context, towards investigating principles and methods to aid in the design and evaluation of sonic interactive systems. This is considered to be one of the most promising areas for research and experimentation [61]. Moreover, the design and implementation of novel interfaces to control such sounds, together with the ability to augment existing musical instruments and everyday objects with sensors and auditory feedback, is currently an active area of exploration in the New Interfaces for Musical Expression (NIME) community [13].

Among scholars in perception and cognition, there has been a shift in attention, from the human as a receiver of auditory stimuli, to the perception-action loops that are mediated by acoustic signals [43]. Such loops have become an important topic of research also in the sonification domain, where the topic of interactive sonification has emerged. This topic is described in Section 5.5, as well as in chapter 11 of this handbook.

Several efforts in these research areas were unified under the Sonic Interaction Design umbrella thanks to a European COST (CoOperation in Science and Technology) action which started in 2006 [1][2]. The different areas of exploration of SID, which are reflected in this action, are described in the following.

5.2 A psychological perspective on sonic interaction

Before addressing sonic interaction design from the perspective of product design, interactive arts and sonification in the next sections, the next paragraphs will consider some basic psychological phenomena involved in sonic interactions. To do so, they will examine a specific type of sonic interaction: closed-loop interactions. During such interactions, the users manipulate an interface that produces sound, and the sonic feedback affects in turn the users' manipulation (see Chapter 11). Such interactions have been used in applied [57, 19] and experimental settings [41, 50][3]. In fact, the design of these interactions brings under a magnifying glass a phenomenon that has recently received a great deal of attention on the part of psychologists interested in perception: the tight coupling between auditory perception and action [3].

Let us first consider a recent example of such an interaction: the real-time sonification of a rowing boat aiming to improve the athletes' performance [57]. In this design, the athletes' movements modulated the auditory feedback in real time. In turn, the sound helped the athletes to adapt their movements. Sounds had a great advantage in this case, because auditory perception and action are naturally and tightly coupled. Therefore, the intention was that the rowers would not be expected to consciously "decode" the information conveyed by the sounds, nor to think about how modifying their action would modify the sound. The sound-action loop was supposed to be intuitive. After all, this is what happens in "natural" interactions through sound. A user filling a vessel with water does not need to understand the relationship between pitch and volume to fill a recipient without overflowing [9]. Nor does

[2] http://sid.soundobject.org

[3] The ISon conferences provide a useful repository of such approaches http://www.interactive-sonification.org

a beginner violinist need to be aware of the physics of the bow-string interaction to avoid squeaky sounds (at least after a bit of practice).

In a designed sonic interaction, the richness of the added auditory feedback has the potential to let the users explore the complex patterns, and discover how their actions can modulate the sound. In turn, the auditory feedback guides the actions. As such, sonic interactions have a great potential to help a user become more proficient at the fine movements required in sports, as illustrated by the rowing example, but also in music, dance, surgery, and the complicated manipulation of tools [7]. As discussed later in this chapter, there are also other aspects of sounds to consider. The next section shows how recent research in psychology sheds light on the phenomenon of action-sound coupling.

5.2.1 The auditory perception-action loop

This section covers the importance of action, perception and multimodal feedback when designing interactive sounds.

The brain specifically processes the sounds of actions

Recent neuropsychological research has consistently suggested that the brain processes the sounds of actions made by an agent differently from other sounds. This line of research was initiated by the identification of audio-visual mirror neurons in monkeys' brains [36]. These are neurons that react both when the monkey subject does, sees, or hears the action.

Some recent experiments on human subjects led scientists to hypothesize the existence of two different brain mechanisms processing sounds caused by a human action (e.g., the sound of someone walking) and non-action sounds (e.g., thunder) [48]. They suggested that, on one hand, action-related sounds activate the mirror system, together with a specific motor action program. This system represents "how the sound was made". On the other hand, non-action sounds rely solely on the acoustic and perceptual properties of the sound itself, without the possibility of activating any action-related representation. This is for instance illustrated by the results of Lahav and co-workers [37] who showed that non-musician subjects had their brain premotor areas activated while they were listening to a piano piece they just had learned to play. When they listened to pieces that they had not learned, the motor area was not activated: for these latter sounds, they had no motor representation available.

Listening to sounds might not only activate a representation of how the sound was made: it might also prepare the listener to react to the sound [14]. Cognitive representations of sounds might be associated with action-planning schemas, and sounds can also unconsciously cue a further reaction on the part of the listener. This is exactly the principle of a closed-loop sonic interaction. Since the mirror system is also activated when the subject is seeing the action, some scientists introduced the idea of an abstract representation of the meaning of the actions, parallel to the activation of the motor plans [23]. And it might be that this abstract representation integrates multimodal inputs, and particularly audition and vision [4].

Multimodality and naturalness

During any interaction, users receive visual, haptic, and proprioceptive information in addition to sound. Even in the case of “passive” auditory displays, sounds influence the identification and interpretation of visual images [10]. With regard to the perceived quality of products, there are many cases (e.g., potato chips, electric toothbrushes) where the sound of a product affects the perception of its quality [63]. In the example of the iPod clickwheel described in section 5.3.1, a sound feedback may create pseudo-haptic sensations. Such a phenomenon has also been used to create pseudo-haptic interfaces [20].

Sonically augmented interfaces offer the psychologists the possibility of exploring the relationships between different modalities (audition, vision and touch). Important issues are those of the temporal synchrony between stimulations of different sensory modalities, and the related perception of causality[4] [30]. For example, whether two moving discs with crossing trajectories are perceived as bouncing or overlapping is heavily affected by the presence, timing and nature of a sound occurring at the contact instant [26].

Synchrony between sounds and gestures is important for sonic interactions because it influences the perception of causality. And the perception of causality is important for sonic interaction, because designers often choose to use a causal or iconic representation, rather than an arbitrary one, based on the hypothesis that sonic interactions should not require excessive cognitive effort on the part of users. In other words, by using the sounds that users could commonly expect as a result of their gestures, the designer assumes that users will intuitively understand how their gestures influence the sonic feedback. Such commonly expected sounds which result from gestures (e.g., the sound of an impact arising from the striking of an object) are here referred to as “natural". The natural relationships between a sound and a gesture are those driven by the laws of physics.[5]

The use of causal sonic feedback was explored in two recent studies. In the first study, an arbitrary (e.g., a bicycle bell) or causal (the sound of keystroke) feedback sound was added to a numerical keypad of an ATM cash machine [64]. Subjects judged the causal sounds as natural, and the arbitrary sounds as being less natural, and found that using the keypad with arbitrary sounds was more unpleasant and less efficient than with the causal sounds (for an example of different kinds of sonic feedback, see video **S5.1**). In another study [41], the researchers designed a tangible interface (the Spinotron, see Figure 5.1) based on the metaphor of a child’s spinning top. When the users pumped the Spinotron, they drove a physical model of a ratcheted wheel that produced a characteristic clickety-clack sound. The participants were required to pump the interface and to reach and maintain a precise and constant pace. By using sonic feedback which modeled the dynamic behavior of a spinning top the users’ performance was improved significantly compared to more arbitrary feedback.

The design of sonic interactions based on the physical modeling of natural interaction seems to have two advantages. Firstly, the listeners find the interaction more pleasant, natural and engaging. Secondly, it seems that the interfaces are easier to use because the subjects already know, from their previous experience with everyday objects, how sound and gesture

[4] As discussed later, the sense of agency - the perception that one is causing the sound - is a particular and very important case of causality.

[5] Note that using a natural or causal relationship may have its own drawbacks - e.g., users having an overly deterministic vision of the feedback model based on prior expectations from the “natural" situation.

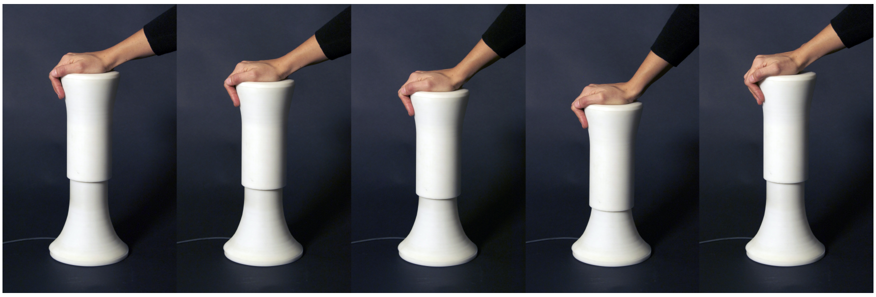

Figure 5.1: When a user pumps the Spinotron, a physical model of a ratcheted wheel produces a characteristic clickety-clack sound.

are related. It is unclear if interactions based on the modeling of natural interaction work well because they use a sound-action relationship pre-learned by the users, or because they provide rich, complex and redundant information that users just have to pick up. Maybe interactive interfaces based on natural interaction are easier to learn and master. However, natural sounds are in most of the cases preferred by users over artificial ones.

The evaluation of performance in sonic interactions

The evaluation of sonic interactions has a lot in common with what is done in product design. Laboratory studies enable the designer to evaluate the effectiveness of the interaction. As illustrated by the example of the Spinotron, the evaluation of the success of a sonically augmented interactive interface requires the designer to measure how the sound influences the user's interaction with the interface. This paradigm is therefore different from that of the sonification of passive auditory displays, where the evaluation consists in assessing whether the user is capable of consciously decoding the information conveyed by the sounds. In the case of closed-loop sonic interactions, what is important is not that users are consciously aware of the information, but that they can successfully adapt their movements and gestures.

The study of human-computer interaction offers an interesting point of comparison. Many of the methods that have been developed in this discipline measure reaction times, movement times or other chronometrical measurements. But what is probably more important is how well and fast users can learn to manipulate an interface, or successfully modify their actions. The quality of the design becomes indexed by the users' performance, and by the speed of their learning.

In the case of the Spinotron, the participants were required to pump an interface and to reach and maintain a precise and constant pace (indicated by a visual target). Half of the participants were provided with a continuous auditory feedback (the sounds of a virtual spinning top set into motion by their pumping gesture), half with a discrete visual feedback only. Only the participants who were provided with the auditory feedback were able to improve their performance across trials. The speed of learning was the actual measure used to quantify the success of the auditory feedback. However, when asked to describe their appraisal of the sonic feedback, the subjects reported two interesting comments. First, they were not aware that the sound actually helped them improving their performance. Second, they found the sound very irritating.

Therefore, evaluating the functional aspect of a sonic interaction is only one side of the coin. Designers should not forget that sounds create strong aesthetical and emotional reactions in users.

5.2.2 Affective and emotional reactions to sonic interactions

In fact, the sounds of interactive interfaces have the power to influence the users' emotions, as it is the case with any artificially added sound. The "pleasantness", "aesthetic", and "annoyance" of the sonic interaction are an important part of their appraisal by the users, and require investigation.

What are emotions?

The study of emotions is the subject of intense debate. Most modern emotion theorists agree that an emotion episode is a dynamic process consisting of coordinated changes in several cognitive, neurophysiological, and motor components [55, 59]. Among these components, feelings have a particular status: they serve as a monitoring function, and are consciously accessible. Feelings thus represent the component of an emotion episode that a subject can report. And, importantly, it is the component that the researcher can observe. Physiological measures (heart rate, skin conductance, facial EMG, startle reflex, etc.) can indicate neurophysiological activities, action tendencies and motor expressions. Self-reports can provide insights into the feelings of the subjects. The results of many studies have very often suggested that the feelings observed in, or reported by subjects can be accounted by a few principal dimensions. Furthermore, these dimensions can be related to different types of appraisals [58]:

- *Valence* results from the appraisal of intrinsic pleasantness (a feature of the stimulus) and goal conduciveness (the positive evaluation of a stimulus that helps reaching goals or satisfying needs).
- *Arousal* results from the appraisal of the stimulus' novelty and unexpectedness (when action is needed unexpectedly).
- *Dominance* results from the appraisal of the subject's coping potential.

Therefore, concerning the sounds of interactive interfaces, the appraisal of the features of a sound may have an influence on the valence (appraisal of pleasantness) and arousal (appraisal of novelty) dimensions of the feelings. Possibly, if the sound has a function in the interaction, it may also have an influence on the appraisal of the goal conduciveness (imagine an alarm clock that does not sound loud enough to wake you up).

Emotions and auditory feedback

Sound quality studies[6] provide, indirectly, some insights into the relationships between acoustic features of product sounds and emotions. For example, it has been reported that attractive products are perceived as easier to use [46]. Emotional reactions to the sounds of everyday products have been studied in terms of pleasantness or annoyance [29] or preference [65].

Sounds are also used in many forms of human-computer interfaces. And, because computer interfaces (and more particularly computer games) have the potential to induce emotions through different types of appraisal, they can also be used as an experimental technique to elicit emotions in subjects in a laboratory setting, and to enable the study of emotion processes [51].

In a recent study, the emotions felt by users manipulating a computationally and acoustically augmented artifact were assessed [40] (see interaction video **S5.2**). The artifact consisted of an interface similar to a glass (the Flops, see Figure 5.2), that the users tilted to pour a number of virtual items, that they could only hear. The task was to pour exactly a predetermined

Figure 5.2: When a user tilts the Flops, a number of virtual items, that can only be heard, are poured out.

number of items. Both the sound design (making more or less pleasant sounds), and the dynamics of the interaction (making the manipulation more or less difficult) were manipulated, and users had to report their feelings. The difficulty of the task, obstructing or

[6] We refer here to academic studies that explore the quality of everyday sounds: e.g., air-conditioning noises, transportation noises, vacuum cleaners, car horns, etc. - see [42] for an overview.

facilitating the users' goal conduciveness, modulated the valence and dominance dimensions of their feelings. However, the acoustic qualities of the sounds also influenced the feelings reported by participants. The quality of the sounds (indexed by their sharpness and their naturalness) systematically influenced the valence of the users' feelings, independently from the difficulty of the task. These results demonstrate that sonic interactions have the potential to influence the users' emotions: the quality of the sounds has a clear influence on the pleasantness of the interaction, and the difficulty of the manipulation (which, in some cases, results directly from the quality of the sound design) influences whether the user feels in control or not.

5.2.3 Summary of the psychological perspective

Closed-loop sonic interactions are different from *passive* auditory displays in that they involve users in actively manipulating an interface (or performing some action). The action modulates the sound, and the sound informs the users on how to modify their actions.

From the design perspective, the main question is how to create a multimodal interface that engages users in active manipulation, that provides them with auditory feedback complex enough to discover new patterns, and intuitive enough to successfully modulate their actions and gestures.

However, as with other forms of auditory interfaces, sonic interaction also affects the users' emotions. This is true partly because sounds can be more or less pleasant, but also, in the case of sonic interaction, it is the sound that can make the interaction successful or not.

The next section describes how sonic interactions have already been designed and implemented in real products, and discusses the issues that these examples highlight.

5.3 Product sound design

When we interact with physical objects in the world, these interactions often create sound. The nature of this sound is a combined product of our actions and of the physical attributes of the objects with which we interact – their form, materials and dynamics, as well as the surrounding environment. People possess a natural capacity for deriving information from sound: we can infer, from the sound arriving at our ears, rich information about its source [24].

Today more and more sounds for products are being designed. This includes both sounds that are produced through physical phenomena, and sounds that are digitally created. As an example of both types, the physical manipulation of materials and fine-tuning of internal components have been used to create the distinct sound of the Harley Davidson engine, a sound that the company tried to protect as a trademark[7]. With the recent advent of electric cars that create very little noise [53], digitally produced sounds have been introduced into cars both for pedestrian safety and for driver experience [38]. The long-awaited Fisker Karma, the first hybrid sports car, is said to have external speakers that generate "a sound somewhere between a Formula One car and a starship", but can be configured by the owner[8].

[7] http://articles.latimes.com/2000/jun/21/business/fi-43145
[8] http://www.popsci.com/cars/article/2010-04/price-karma

Obviously, these corporations realize the impact of sound on the perception of the product quality.

The field of sound design for products – specifically the design of non-speech, non-musical sounds – is quite young. A main source of knowledge on which it builds is the domain of film, where sound has been used extensively and in complex ways to affect the viewer's experience. Michel Chion, a researcher of film sound, has referred to two types of added value of sound in film: informative and expressive [11]. These are useful in thinking about sound for products as well: sound can add information in the use of a product, and can enhance its perceived quality and character. The development of the field of sound design is such that sound designers today use their skills to create auditory logos and signals (such as the attention-getting tone – or attenson [32] – that precedes an announcement in a train station), sound effects for website navigation and for computer games, and more.

Interactive physical products bring a new level of potential and challenge into this field. The lack of an inherent relation between form and functionality, as found in many consumer-electronics products, makes feedback a prominent factor. The complexity of functions makes the dialog between user and system more critical. Fortunately, these products are embedded with technological components and can be equipped with micro-controllers and sound producing elements Thus there is great potential for rich responsive sound in interactive products.

When we think of the sounds of products, we may still think about the beeps and bleeps of our household appliances, or the "ding" of the PC error. However, things are changing. Our input methods for digital products are no longer limited to pressing or pointing, and continuous interactions such as finger gestures and body movements are those for which sonic feedback may be the most beneficial [52]. Knowledge from the realm of interaction design, sound design and software development is needed to tackle continuous interactive sound projects.

The next section reviews a few examples of existing products and prototypes with informative and expressive sound, with an emphasis on the continuous nature of the interaction.

5.3.1 Key issues in designing interactive sonic products

Not surprisingly, some of the best examples of continuous sound for interaction come from the world of mobile devices. The reasons are twofold: the price and positioning of these products make the embedding of high quality audio components most feasible, and also the fact that these devices are used "on the move" motivates the provision of information in a non-visual way.

The iPod Clickwheel

The first iPod "Classic" model (see Figure 5.3) used a mechanical scroll wheel as an input device: a wheel that turned to allow scrolling between menu items. Consequent iPod versions replaced the mechanical wheel with the click wheel: a round, touch sensitive surface on which users slide their finger clockwise and counterclockwise, as if on a moving wheel.

One element that was introduced to the click wheel is the clicker: a clicking sound that

Figure 5.3: The first iPod “classic" with its mechanical scroll wheel.

Figure 5.4: The Apple Mighty Mouse, the Apple Magic Mouse, and the Microsoft Arc Touch Mouse, all viewed from top.

provides feedback for the movement between menu items. This feature gives a tactile feel to the click wheel (a pseudo-haptic illusion), somewhat similarly to the rotary dial on old phones, making the scrolling more expressive and more informative. Since the scrolling reacts to acceleration – the more you scroll the faster menu items move per rotation – the clicker provides information that is not evident from the scrolling action per se. The click sound is the only sound made by the iPod outside of the headphones, and is generated via a small, piezoelectric speaker inside the device.

Sonic, silent, and purring mice

The Apple Mighty Mouse (see Figure 5.4), introduced in 2005, contained an embedded speaker that gave sonic feedback to scrolling gestures. Apple seemed to abandon this line completely in 2009, when the Magic Mouse was introduced. This symmetric, uniformly smooth, and perfectly silent object supported multi-touch gestures and contained no apparent usability clues. Interestingly, despite the success of the Magic Mouse, Microsoft decided to go the other way and in 2010 unveiled the Arc Touch Mouse, that includes both haptic and sonic feedback to scrolling gestures over a central capacitive scroll strip.

Nintendo Wii Controller feedback

The Wii remote is the primary controller for Nintendo Wii game console, introduced in 2006. A main feature of the Wii Remote is its motion sensing capability, which allows the user to interact with and manipulate items on screen via gesture recognition and pointing through the use of accelerometer and optical sensor technology. The Wii Remote has basic audio functionality, via its own independent speaker on the face of the unit. This audio is used in different games to enhance the experience of the gestures through tightly coupled sound. Sonic and vibro-tactile feedback can be experienced, for example, in the Wii Tennis (a swish sound when swinging the racket), or in The Legend of Zelda: Twilight Princess (the sound is altered as the bow is shot to give the impression of the arrow traveling away from the player).

The sonified moka

The moka coffee maker is an Italian household accessory, composed of a bottom water chamber, a middle filter and a top container. To make coffee, the water chamber needs to be filled with water and the filter with ground coffee; the three parts then need to be connected by means of a screw connection. In a prototype [52], the screwing action was sonified to inform the user of the right degree of tightness. Sound dynamically changes its timbral quality as the coupling becomes tighter, starting from the sound of glass harmonica for loose coupling, assuming a rubber quality for the right tightness, and resembling the sound of a squeaking hinge when the coupling becomes too tight. This example shows a possible future direction of designed sonic feedback in consumer products, a direction that goes against an otherwise increasing clutter of beeps and bleeps[9].

5.3.2 Key issues in designing interactive products with sound

In the following we examine the different elements which relate to the design of interactive products with a salient sonic behavior.

Sounds and behaviors

One of the main challenges in creating sound for products is finding the design language – the selection of sound type and sound character to fit the product and the interaction. Now that we are no longer limited by piezoelectric buzzers in our products, the wealth of possible sound is great; which sounds should we choose? From which category? Musical sounds, speech sounds and everyday sounds all hold benefits. If our microwave wants to tell us that

[9] In the same category of coffee makers, the Bialetti Moka Sound incorporates a musical auditory alert that, given its poor sound quality, gives a significant contribution to lowering the quality of domestic soundscapes.

the meat is defrosted, should it moo? Play a tune? Emit clicks? Call out to us in words? And how should simple objects sound, as compared to complex products such as robots?

Thinking and sketching

Creating sounds for continuous interaction, where the sonic behavior changes rapidly and dynamically, is a challenging task. To the designer, thinking and sketching in sound is not as readily accessible as pen and paper, whiteboards and Post-its.

A number of methods have been proposed to help designers think and sketch sound. Different ways to increase designers' sensitivity to the auditory domain include, for example, sound walks [67, 2]. Vocal sketching [18] is simply the practice of describing sounds using the voice while operating a prop; the idea being that with the right setting, designers can easily and intuitively communicate sonic ideas through non-verbal vocal sound. It has been shown that people spontaneously use vocal imitations in everyday conversations, and that imitating a sound allows a listener to recover what has been imitated [5, 39]. Methods from interaction design, mostly focused on the visual domain, have been adapted to the sonic domain. Sonic Overlay refers to video prototypes in which sound is designed and overlaid over the video footage at a later time, to create a "fake" sonic interaction for the viewer. The "Wizard of Oz" technique[10] [27] has been useful for sound behaviors, and methods of developing narrative through sound, inspired by film sound, have been used to develop narrative interactive objects [35].

Creating functional prototypes, which enable the direct experience of interaction firsthand, is of great value in iterating and improving designs. Microcontroller kits such as Arduino[11] and Phidgets[12], which enable the easy connection of sensors to sound-producing software such as Max/MSP[13] and PureData[14], together create a way to embed (at least part of) the electronics inside objects and to prototype sound behaviors. Parameter-based sound models such as the Sound Design Toolkit [15] help to link between sensor input and dynamic output.

Challenges of evaluation

There is much work to be done in assessing the value that sound brings to interactive products. Evaluation can be performed through laboratory experimentation, or via analysis of products in the market. Both paths have their own challenges, since products have complex behaviors and usage patterns, and discerning the role of sound is not obvious. Some initial work shows promise, and can draw knowledge from existing research in interaction design [34, 60].

The laboratory experimentation with the Spinotron, for example, has shown that sonic feedback may aid users in learning to control the object [41]. In particular, as stated in section 5.2 the controllability of the interface and pleasantness of the sonic feedback are two important factors which need to be taken into consideration when evaluating interactive

[10] This techniques refers to a computer system which is apparently autonomous, but where infact a human is operating it.
[11] http://www.arduino.cc/
[12] http://www.phidgets.com/
[13] http://cycling74.com
[14] http://puredata.info/

products with a salient sonic behavior.

As an additional challenge, sound does not exist in isolation. Sound has the potential to intrude and annoy when wrongfully designed. Designers of sonic artifacts need to scrutinize closely the context in which their product will be used, considering both the direct user and the indirect, unintended users around. The existing soundscape also needs to be considered since it will determine whether the added sounds will be heard and how they will be perceived.

5.3.3 Summary of Product Sound Design

Digital technologies and scale economies have enabled new possibilities in using sound in interactive products. Interaction can be coupled with feedback in the auditory domain, potentially benefiting objects and use-situations in which the auditory channel is superior to the visual one, such as with users who are mobile. The degree to which this potential will be achieved depends on the value sound will have for the users. This is to some extent cyclical, since this value will depend on good sound quality and good interaction design, which, especially in small objects, is still a technological challenge and a costly endeavor. Good processes for working with sound, and research directed at showing the value of sonic interaction, will help designers to push forward sonic interactions. Most importantly, designers must create interactions that, through sound, enhance the beauty and utility of experiences.

An important source of inspiration and knowledge comes from the worlds of art and music, as described in the next section.

5.4 Interactive art and music

Visionary inspiration and aesthetic experimentation in art and music have always been valuable for design. Artistic projects working with interactive sound expand the notions of interactivity, performance and participation which have become an integral part of our everyday life. Artists question our own sonic agency in everyday life [6], involve non-expert users in sound creation [45], deal with mobile music making [25], explore collaboration through sound [21], experiment with interactive metaphors [31] and overall enable novel sonic expressions. These projects not only exemplify novel approaches to designing interactive sound, but also situate and probe possible social and phenomenological sonic experience within everyday contexts.

5.4.1 Listening and Doing with Sound

“Impression is only half of perception. The other half is expression”, wrote the father of soundscape research Murray Schafer, reminding us that sonic acting is as important as listening [56]. In sonic interaction design, the involvement of art and music researchers focuses mainly on “exploiting the role of enactive engagement with sound-augmented interactive objects.”[15]. The enactive approach challenges the dominant models of sound

[15] Memorandum of Understanding of the COST Action on Sonic Interaction Design, 2007: http://w3.cost.esf.org/index.php?id=110&action_number=IC0601

reception in which users' activity is limited to listening only. Rather, working with sound is an active multisensory experience which bridges the gap between perception and action. Sound making is considered to be a meaningful aesthetic experience not only for musicians but also for users who do not posses expert musical skills. This shift from reception-based to performance-based experience brings new challenges to sound design and sonification practices. Although "doing with sound" has been sparsely researched outside of the realm of professional music performance, examples of audience involvement in sound manipulation have been present since the 1960s, for example in certain experiments with audiotape.

In the Random Access Music installation by Nam Jun Paik (1963), visitors could generate sounds by moving the audio recorder head over the audiotapes arranged in abstract shapes on the wall. By changing the control of the head from an automatic mechanism to the human hand, a functional piece of technology was converted into an expressive instrument. The rearrangement of a technological device offered the visitors a rich sonic experience through their direct engagement with sound material. The unpredictability of visitors' gestures created sounds that the artist could not compose or predict. Abandoning the traditional listening role of the audience meant that the artist was giving up control by making his artifact accessible to all. Today, audience engagement is an integral part of many sound installations as well as social and participatory media projects.

5.4.2 Molding Sound: Ease or Virtuosity?

Sonic interaction has been challenged and shaped by the tension between the ease of interaction and virtuosity of musical expression.

Although highly expressive, many interfaces demand musical virtuosity and are not suitable for non-expert users (e.g., The Hands by M. Waisvisz, 1984). However, molding sound may be an experience as natural as pouring water [22] or bending a flexible tube [62]. Intuitive interaction can be facilitated through everyday objects such as the kitchenware used in the Crackle Family (Waisvisz, 1976) and the Gamelunch [49]. In the AudioShaker project, for example, [31] an ordinary cocktail shaker is used to mix sounds rather than liquids. Users can open the object, speak into it to record sounds, shake it to mix them and then literally pour out the sound mix. The sounds keep the reference to the recorded sound but are transformed according to intensity and repetition of shaking gestures. The project shows that the close coupling of body movement and sonic responses of an object plays an important role in increasing the malleability of sound. The design affordances of the AudioShaker invite familiar manipulation, letting the sonic material be molded under the force of users' physical gestures.

The use of everyday, rather than expert musical movements creates the potential for intuitive interaction without the need for instruction and learning. However, the balance between expression and effortless interaction remains to be explored beyond the triggering of habitual movements. Understanding the learning processes that underlie familiarization and exploration is a key issue in opening new possibilities for sound design [17].

5.4.3 Embodying Emotions

The emotional power of sound is often harnessed in artistic projects. When embodied in an object, interactive sound may be associated with the object's behavior and identity. For example, Blendie [16] is a blender that a user can control by vocally imitating its motor sounds. Such conversation based on the interplay between the artifact's machine sounds and the user's vocal expressions creates an emerging identity of the object which appears to respond emotionally. Blendie shows that objects can acquire an emotional character not simply by using the semantic qualities of sound, but rather by activating its relational potential.

The vibrotactile sensations caused by being in contact with a sounding object can also amplify its emotional power. While researchers are working with vibratory feedback to explore audio-haptic and sensorymotor interplay [47], artists are imagining worlds in which such responses could gain new meanings. For example, the ScreamBody (Dobson 1998-2004) is a wearable object which silences, stores and reproduces its user's screams. The user wears it on the chest and can replay his or her recorded screams by a strong and sudden squeeze of the object. This gesture and the vibrational feedback on the user's body help the user to re-enact the actual screaming movements, hopefully relieving the user of associated and unexpressed emotions. The ScreamBody excites the users' auditory, tactile and kinesthetic senses in multiple ways, allowing them to play, express and share emotional states, both in an intimate (when offering the scream to another person) and social (when performed in front of others) manner.

5.4.4 Contextualizing

A range of artistic projects are challenging and criticizing our sonic behaviors in everyday contexts, as well as probing our possible sonic futures. The SoMo5 phone by Ideo and Crispin Jones challenges the annoying uses of mobile phones in public spaces by allowing the user to virtually hurt a person who is talking too loudly on the phone. The user pulls a catapult-like device mounted on their phone, aiming and releasing it towards the offending person in order to activate an abrupt warning sound emitted from the other person's phone. The catapulting gesture's spatial directness and sonic consequences create the feeling that something physical has been thrown at the annoying person. The physical release of anger is thus expressed and enacted through a sonic gesture that exploits a new malleability of sound material.

Other artists explore collaborative composition and play as a means of encountering strangers in public space. For example, projects by the Zero-Th group aim to bring the transient sonic information floating in urban locations into the hands of passers-by [21]. In the Recycled Soundscapes project (see Figure 5.4.4), the sculptural interfaces enable citizens to intuitively capture, transform and compose soundscapes, thus bringing awareness to their own sonic actions and contributing to the ever-evolving urban compositions. Sound is once again treated as material which can be caught within public objects as well as liberated and transformed through physical action. Such experiments in phenomenology and sociality reveal existing social behaviors, question sonic privacy in public space, challenge the composition strategies and engage the playful relations among strangers in urban locations through sound.

Figure 5.5: The Recycled soundscape installation.

5.4.5 Sonic Awareness

Designing sound for action requires a shift of perspective from unconscious hearing or even ignoring one's sonic agency to becoming aware that one can shape one's sonic contributions in the world.

As Murray Schafer suggested, the awareness of our sonic contributions may be the key to re-shaping the quality of our everyday surroundings [56]. The problem is that during ergoaudition, the term that Michel Chion uses to describe the experience of hearing the self-produced sound, we are often less conscious of the sounds we make than of those that others produce [12].

In digitally-augmented artefacts, our agency is often "schizophonically"[16] displaced from the sound that is produced, not allowing us to be aware of the sonic effects we generate. In such context, our interpretation of the cause of the sound event is challenged, and, due to the blurred relationship between action and sound, this may decrease the responsibility for the sound we produce. However, in our cacophonic world, taking responsibility for self-produced sound is an ethical issue and the transparency between our actions and their sonic effects must be considered within sonic interaction design.

Learning from artistic and musical creations may help sonic interaction designers to raise awareness of human agency in everyday life. However, many questions and challenges remain. Artworks are often temporary experiments or imaginary narratives that cannot probe the evolution of interactive sonic systems on a long term scale. Although artists borrow from ethnography and psychology to bring insights to design and technology, the transfer of

[16] Schafer coined the term "schizophonia" to describe this phenomenon of separating sound from its source through technological means [56].

knowledge often remains hidden as tacit knowledge or may be reduced to dry facts using scientific methods. This challenge of abstracting and sharing knowledge has begun to be addressed by the community of sonic interaction design through the development of tools, methods and strategies accessible to designers and artists.

5.5 Sonification and Sonic Interaction Design

The previous sections in this chapter have provided an overview of the emerging field of sonic interaction design, which is situated at the intersection of interaction design and sound computing. This section addresses more specifically the relation between this field and sonification, discusses some examples and proposes a research agenda of relevant scientific questions.

Sonification, as defined in [33] and in chapter 1 and 2 in this volume, provides *information* in an auditory, typically non-speech, form. When looking at interaction with objects in everyday contexts we can pose questions about (a) what information the sound conveys, (b) how exactly sonic interaction depends on relevant variables and (c) when and how the sounds occur and structure the overall interaction. This analysis may give us inspiration as to how new technical devices, or normally silent artifacts or interfaces, can better profit from auditory display.

5.5.1 Examples of sonic information in everyday contexts

Let us consider two everyday examples where we probably underestimate the information value of sound: (a) walking along a corridor, and (b) filling a kettle with water.

When walking along a corridor, we generate a contact sound with each footstep. This sound not only provides us with the information that we have touched the floor as acknowledgement to proceed to the next step, but also gives detailed information about the material of the shoe sole and the floor, the impact energy and velocity, etc. [44]. In the sequence of these sounds we can attend to the walking speed, walking style, eventually even gender, emotion or gait problems to some extent. Beyond that we also obtain a sonic response from the reflections of these sounds from the walls and other objects, even allowing visually impaired pedestrians to stay in the middle of the corridor without other cues [54]. Normally we are not aware of this information since our sensory-motor system integrates them so seamlessly into our overall behavior programmes.

The second example shows that we may also profit more explicitly from interactive sounds to direct our actions. When filling a kettle with water, we typically attend to the accompanying water sounds which systematically change with fill level. The pitch rises during filling the kettle and thereby suggests a time until task completion [9]. Also, the sound depends on the water speed, kettle material, jet shape, etc., conveying even more detail beyond our primary interest. Often people explicitly make use of the resonance sound and only look to the fill level when the pitch starts to rise quickly.

These two examples make clear that there is much information in sound, and particularly in interaction sound, and we often exploit it effortlessly, and even without being aware of it. Only when a problem or a change occurs, for instance if electrical car indicators are installed where the usual “tick-tack” sound from the relays is missing, do we become conscious of the missing information.

How can we explicitly profit from sound and establish interaction sounds so that they support and enhance the interaction with task-relevant information? How can objects sound even without interaction so that we can keep peripheral awareness of relevant information without interference with verbal communication? Sonification provides the answer and the following sections shed light on the functions that are supported by information-carrying sound.

5.5.2 Functions of informative components in object sounds

The following functions of information-loaded everyday interaction sounds, and also of sonification-based additional interaction sounds, can be identified:

- Sound provides an *acknowledgement* of the completion of an action step, supporting us to structure more complex actions. The information is basically binary and conveyed by the mere occurrence of the sound. An everyday example is that of closing a door until you hear the “click” sound of the latch which indicates that it is now firmly closed. A sonification example is the “file deleted” sound when dragging and releasing a file icon onto the trashcan icon on a computer desktop (see **S5.3** for an example using parameterized auditory icons).
- Feedback sounds allow users to refine their actions. An everyday example has already been given above with “filling a kettle with water”. A good sonification example is the sonification-enhanced drilling machine [28] which indicates by pulsing sounds how far the actual orientation of the drilling axis deviates from intended vertical and horizontal angles to the surface, in other words: a parking aid for the drilling machine (see interaction video **S5.4**).
- Sound can lead to characteristic sonic interaction *gestalts* which allow us to compare repeated instances of interactions. For instance, the sound of a gait becomes a pattern from which a person can be identified. For sonification of body movements, a complex movement such as a pirouette in dance or a racket serve in tennis may be turned into a sonic contour which can be compared to an ideal movement execution in timing and expression (see interaction video **S5.5**, which shows movement sonification in a sensor augmented German wheel).
- Sound can enhance awareness of certain information of interest: traffic sounds or environmental sounds (birds, cafeteria noises) are “passive sound” examples where we are not interacting. An interactive everyday example is the reverberant response following any sound (e.g., contact sound, footstep, verbal utterance) by which we become aware of the size, depth, wall/surface materials in a room or place. This latter principle inspired auditory augmentation, a sonification type where the real physical structure-born sound of real-world objects such as a keyboard or table is recorded and modified in real-time. This enables us to perceive - on top and tightly coupled to the original sound - the sonification which keeps us in touch with any information of interest. In [8] this is demonstrated with a modification of keystroke sounds by weather data (as shown in example video **S5.6**).

For SID, the inclusion of sound for the normally unhearable bears the potential to enable novel functions currently unavailable. For instance, a cooking oil bottle could sonically communicate how many millilitres have been poured out, making it easier for the chef to follow the recipe without using spoons or scales.

5.5.3 Interaction design consequences for sonification design

Sound in interaction is certainly a multi-faceted phenomenon which can be understood on various levels including the aesthetic, emotional, affective, coordination, information and even social and cultural level. In everyday interaction with objects, sound is mainly the result of the object properties and the interaction details, so sound design mostly operates on the level of the design of object properties. There are basic bindings between the interaction and sonic response which are fully determined by the laws of physics: the more energy is put into a system, the louder is typically the sound signal, the higher the tension, the higher the pitch, etc..

For sonifications, however, more freedom exists on how exactly to connect information with sound. Mapping data variables to sound parameters is a common approach for that. The designer here needs to take many decisions which influence the effectiveness of the system. If, for instance, the energy during interaction is a critical variable, it may seem sensible to map it to pitch, a sonic variable where we have a much higher sensitivity to perceive changes compared to sound level. However, such a mapping would be highly counterintuitive in the light of natural bindings, and this could increase learning time and even cause misunderstandings.

Therefore the designer needs to balance various factors and adjust designs to find an optimal working point. Learnability versus effectiveness is just one example. There may be sound categories with very salient sonic parameters which are perhaps very intuitive, yet the sound would be less pleasant for long-term use, or even irritating or provoking an unwanted emotional reaction.

A possible procedure would be (a) to sort all factors according to their importance for the given application context, (b) to optimize the sonification in light of the most important factor, (c) to refine the sound design within limits in light of the secondary factors, and (d) to iterate this until no further improvement can be made. Ideally this procedure needs to be followed with different seed designs, and user studies and questionnaires are the only way to compare their acceptance, utility and effectiveness.

Sonification within SID brings into the focus of attention that sound, and particularly sound in interaction contexts, can carry a large amount of information, which designers can shape and refine. This information-carrying aspect should not be underestimated only because we obviously do not pay so much conscious attention to it in everyday situations. For sonic interaction design, sonification can offer powerful tools and know-how about how to shape sounds according to measured or available information to generate additional benefits. The experiences in interactive sonification can furthermore inspire “classical” sound design where the information level has not yet been developed. What if car horn sound level and direction depended on the car’s velocity? Or if the urgency level of the alarm clock depended on the time until the first appointment in the user’s calendar? The sounds of technical products could possibly be enhanced in most cases if an information-based view would be taken to the sound.

5.5.4 Research topics in sonification for sonic interaction design

There are many open research questions on how best to integrate sonification in sonic interaction design, which are brought together in this section as a research agenda. Starting backwards from the perspective of the application, perhaps the most difficult question is how to evaluate the characteristics of complex sound in interaction. What questionnaires are to be used to gather information about the relevant factors? Are questionnaires at all a valid tool for evaluating sonic interactions? Can we investigate an interaction at all in experimental settings where an ecological acoustic context is missing? How can we make general statements about the utility of mappings from observations or studies with specific data-to-sound mappings, given the fact that users are so highly adaptive to accept and learn even inconvenient mappings? How to extrapolate the interaction data in light of the users' adaptivity to learn even inconvenient mappings?

From the other side there are questions such as: How can designers weigh the factors (perceptability, pleasantness, intuitiveness, long-term acceptability, etc.) for a specific application?

From the side of the sonification itself, the most important question is how to create metaphors that are convincing to the user, need little explanation, are in unison with the user's expectation and create sounds so rich in complexity that users are not bored or annoyed by them. A promising way is to adopt ideas from physical modelling, or directly to use Model-Based Sonification (see chapter 16) and trust that with learning the user will discover the relevant bindings between data variables and sonic characteristics.

5.5.5 Summary of Sonification in sound design

Sonification addresses the information level in sound, how information can be conveyed with sound. Thereby sonification provides a distinct perspective on the design process in sonic interaction design, which complements other perspectives such as aesthetic or emotional qualities of sound or branding/identification aspects. Sonification and its techniques are extensively introduced, described and characterized throughout the whole of this volume. A particular recommendation to the reader is to observe interaction in everyday contexts with a fresh and unconditioned mind, attending to how sound reflects and conveys a fantastic richness of information in real-time. Since our human sensory-motor systems are so well optimized to effortlessly make sense of this information, these observations can offer much inspiration on how to shape technology, and technical interaction sounds in particular, to be useful from a functional perspective. While starting from such a functional and information-oriented perspective will hopefully lead to interesting interaction design ideas, later these need to be refined to be in balance with the other relevant design criteria.

5.6 Open challenges in SID

This chapter has introduced the novel discipline of SID, outlining different applications. The importance of multimodality in SID has been underlined by presenting different examples of commercial products, artistic applications and research projects where the tight connection between sound and touch has been exploited. The different examples presented all have in common the presence of an action-perception loop mediated by sound, together with the need of creating aesthetically pleasurable sonic experiences, which might be of an exploratory and artistic nature, or possibly providing some new information.

The development of SID follows the trends of the so-called third wave of human-computer interaction, where culture, emotion and experience, rather than solely function and efficiency, are included in the interaction between humans and machines [46].

From a methodological point of view, this requires novel perspectives that move away from the rigid guidelines and techniques which have been traditionally adopted in the auditory research community. Strict engineering guidelines and formal listening tests are not valid as such in SID, but need to be replaced by design and evaluation principles which are more exploratory in nature. These include participatory workshops and active listening experiences, which support the importance of an ecological approach to SID, together with the need to investigate sound in an action-perception loop. This distinguishes SID from most previous efforts in auditory perception and cognition research, where the role of sound has merely been connected to the investigation of basic psychophysical phenomena. It also represents one of the biggest challenges in SID, i.e., how to evaluate the characteristics of a complex sound in interaction. Different possibilities have been proposed, ranging from using questionnaires, to measurement of user behavior to informal observations of users.

Together with the issue of evaluation, another open question is how to design the sound themselves, balancing between pleasantness versus annoyance, artistic expression or ability to understand the message conveyed by sounds as in the case of interactive sonification. The design challenges proposed by SID are no longer predominantly of a technical nature. The wide availability of sound design, synthesis and processing tools, together with physical computing resources, allows practitioners who are not technically trained to easily produce sonic interactive artifacts. Instead, the challenges are mostly focused on the ways in which designers may successfully create meaningful, engaging and aesthetically pleasing sonic interactions. To come closer to reaching the ambitious goal of becoming an established discipline, the field of SID will benefit from advances in knowledge in many related areas, including the perceptual, cognitive, and emotional study of sonic interactions, improved sound synthesis and design methods and tools, a better understanding of the role of sound while performing actions, and finally design and evaluation methods addressing the objective and subjective qualities of sounding objects, especially in active settings. For a new generation of sound designers to be capable of addressing the interdisciplinary problems the field raises, a more solid foundation of methodologies in those related disciplines needs to be developed.

Bibliography

[1] D. Rocchesso. *Explorations in Sonic Interaction Design*. Logos Verlag, Berlin, 2011.

[2] M. Adams, N. Bruce, W. Davies, R. Cain, P. Jennings, A. Carlyle, P. Cusack, K. Hume, and C. Plack. Soundwalking as a methodology for understanding soundscapes. In *Institute of Acoustics Spring Conference*, Reading, UK, 2008.

[3] S. M. Aglioti and M. Pazzaglia. Representing actions through their sound. *Experimental Brain Research*, 2010. Published online 04 July 2010. DOI 10.1007/s00221-010-2344-x.

[4] K. Alaerts, S. Swinnen, and N. Wenderoth. Interaction of sound and sight during action perception: Evidence for shared modality-dependent action representations. *Neuropsychologia*, 47(12):2593–2599, 2009.

[5] K. Aura, G. Lemaitre, and P. Susini. Verbal imitations of sound events enable recognition of the imitated

sounds. *Journal of the Acoustical Society of America*, 123:3414, 2008.

[6] M. Bain. Psychosonics, and the modulation of public space on subversive sonic techniques. In J. Seijdel and L. Melis, editors, *OPEN Sound: The Importance of the Auditory in Art and the Public Domain*. NAI, 2005.

[7] S. Barrass and G. Kramer. Using sonification. *Multimedia Systems*, 7(1):23–31, 1999.

[8] T. Bovermann, R. Tünnermann, and T. Hermann. Auditory augmentation. *International Journal on Ambient Computing and Intelligence (IJACI)*, 2(2):27–41, 2010.

[9] P. Cabe and J. Pittenger. Human sensitivity to acoustic information from vessel filling. *Journal of experimental psychology. Human perception and performance*, 26(1):313–324, 2000.

[10] Y. Chen and C. Spence. When hearing the bark helps to identify the dog: Semantically-congruent sounds modulate the identification of masked pictures. *Cognition*, 114(3):389–404, 2010.

[11] M. Chion. *Audio-vision: sound on screen*. Columbia University Press, 1994.

[12] M. Chion. *Le Son*. Editions Nathan, 1998.

[13] P. Cook. Principles for designing computer music controllers. In *Proceedings of the 2001 conference on New interfaces for musical expression*, pages 1–4. National University of Singapore, 2001.

[14] M. De Lucia, C. Camen, S. Clarke, and M. Murray. The role of actions in auditory object discrimination. *Neuroimage*, 48(2):475–485, 2009.

[15] S. Delle Monache, P. Polotti, and D. Rocchesso. A toolkit for explorations in sonic interaction design. In *Proceedings of the $5^t h$ Audio Mostly Conference: A Conference on Interaction with Sound*, pages 1:1–1:7, Piteå, Sweden, 2010. Association for Computer Machinery.

[16] K. Dobson. Blendie. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques*, page 309. ACM, 2004.

[17] H. L. Dreyfus. Intelligence without representation – Merleau-Ponty's critique of mental representation: The relevance of phenomenology to scientific explanation. *Phenomenology and the Cognitive Sciences*, 1(4):367–383, 2002.

[18] I. Ekman and M. Rinott. Using vocal sketching for designing sonic interactions. In *Proceedings of the 8^{th} ACM Conference on Designing Interactive Systems (DIS 2010)*, pages 123–131, Aarhus, Denmark, 2010. Association for Computing Machinery.

[19] M. Eriksson and R. Bresin. Improving running mechanisms by use of interactive sonification. In *Proceedings of the 3^{rd} Interactive Sonification Workshop (ISon 2010)*, Stockholm, Sweden, April 2010.

[20] M. Fernström, E. Brazil, and L. Bannon. HCI design and interactive sonification for fingers and ears. *IEEE Multimedia*, 12(2):36–44, april-june 2005.

[21] K. Franinović and Y. Visell. New musical interfaces in context: sonic interaction design in the urban setting. In *Proceedings of the 7^{th} International Conference on New Interfaces for Musical Expression (NIME 2007)*, pages 191–196. Association for Computing Machinery, 2007.

[22] K. Franinović and Y. Visell. Flops: Sonic and luminescent drinking glasses. In *Biennale Internationale du Design*. Cité du Design, Saint-Étienne, France, 2008.

[23] G. Galati, G. Committeri, G. Spitoni, T. Aprile, F. Di Russo, S. Pitzalis, and L. Pizzamiglio. A selective representation of the meaning of actions in the auditory mirror system. *Neuroimage*, 40(3):1274–1286, 2008.

[24] W. Gaver. What in the world do we hear?: An ecological approach to auditory event perception. *Ecological psychology*, 5(1):1–29, 1993.

[25] L. Gaye, L. E. Holmquist, F. Behrendt, and A. Tanaka. Mobile music technology: report on an emerging community. In *Proceedings of the 6^{th} International Conference on New Interfaces for Musical Expression (NIME 2006)*, pages 22–25, Paris, France, 2006. IRCAM Centre Pompidou.

[26] M. Grassi and C. Casco. Audiovisual bounce-inducing effect: When sound congruence affects grouping in vision. *Attention, Perception, & Psychophysics*, 72(2):378, 2010.

[27] P. Green and L. Wei-Haas. The rapid development of user interfaces: Experience with the Wizard of Oz method. In *Human Factors and Ergonomics Society Annual Meeting Proceedings*, volume 29, pages 470–474. Human Factors and Ergonomics Society, 1985.

[28] T. Grosshauser and T. Hermann. Multimodal closed-loop human machine interaction. In R. Bresin, T. Hermann, and A. Hunt, editors, *Proceedings of the* 3^{rd} *Interactive Sonification Workshop (ISon 2010)*, Stockholm, Sweden, 2010.

[29] R. Guski, U. Felscher-Suhr, and R. Schuemer. The concept of noise annoyance: how international experts see it. *Journal of Sound and Vibration*, 223(4):513–527, 1999.

[30] R. Guski and N. Troje. Audiovisual phenomenal causality. *Perception & Psychophysics*, 65(5):789–800, 2003.

[31] M. Hauenstein and T. Jenkin. Audio shaker. http://www.tom-jenkins.net/projects/audioshaker.htm.

[32] E. Hellier and J. Edworthy. The design and validation of attensons for a high workload environment. In N. A. Stanton and J. Edworthy, editors, *Human Factors in Auditory Warnings*. Ashgate Publishing Ltd., 1999.

[33] T. Hermann. Taxonomy and definitions for sonification and auditory display. In P. Susini and O. Warusfel, editors, *Proceedings 14*th *International Conference on Auditory Display (ICAD 2008)*, Paris, France, 2008. Institut de Recherche et de Coordination Acoustique Musique.

[34] D. Hong, T. Höllerer, M. Haller, H. Takemura, A. Cheok, G. Kim, M. Billinghurst, W. Woo, E. Hornecker, R.J.K. Jacob, C. Hummels, B. Ullmer, A. Schmidt, E. van den Hoven, and A. Mazalek Advances in Tangible Interaction and Ubiquitous Virtual Reality. *IEEE Pervasive Computing*, 7(2), pages 90–96, 2008.

[35] D. Hug. Investigating narrative and performative sound design strategies for interactive commodities. In S. Ystad, M. Aramaki, R. Kronland-Martinet, and K. Jensen, editors, *Auditory Display*, volume 5954 of *Lecture Notes in Computer Science*, pages 12–40. Springer Berlin / Heidelberg, 2010.

[36] C. Keysers, E. Kohler, M. Umiltà, L. Nanetti, L. Fogassi, and V. Gallese. Audiovisual mirror neurons and action recognition. *Experimental brain research*, 153(4):628–636, 2003.

[37] A. Lahav, E. Saltzman, and G. Schlaug. Action representation of sound: audiomotor recognition network while listening to newly acquired actions. *Journal of Neuroscience*, 27(2):308–314, 2007.

[38] B. Le Nindre and G. Guyader. Electrical vehicle sound quality: customer expectations and fears - crucial NVH stakes. In *Proceedings on the International Conference on Noise, Vibration and Harshness (NVH) of hybrid and electric vehicles*, Paris, France, 2008.

[39] G. Lemaitre, A. Dessein, P. Susini, and K. Aura. Vocal imitations and the identification of sound events. *Ecological Psychology*. in press.

[40] G. Lemaitre, O. Houix, K. Franinović, Y. Visell, and P. Susini. The Flops glass: a device to study the emotional reactions arising from sonic interactions. In F. Gouyon, Álvaro Barbosa, and X. Serra, editors, *Proceedings of the 6*th *Sound and Music Computing Conference (SMC 2009)*, Porto, Portugal, 2009.

[41] G. Lemaitre, O. Houix, Y. Visell, K. Franinović, N. Misdariis, and P. Susini. Toward the design and evaluation of continuous sound in tangible interfaces: The spinotron. *International Journal of Human-Computer Studies*, 67(11):976–993, 2009.

[42] G. Lemaitre, P. Susini, S. Winsberg, S. McAdams, and B. Letinturier. The sound quality of car horns: designing new representative sounds. *Acta Acustica united with Acustica*, 95(2):356–372, 2009.

[43] M. Leman. *Embodied music cognition and mediation technology*. The MIT Press, 2008.

[44] X. Li, R. Logan, and R. Pastore. Perception of acoustic source characteristics: Walking sounds. *The Journal of the Acoustical Society of America*, 90(6):3036–3049, 1991.

[45] D. Merrill and H. Raffle. The sound of touch. In *CHI '07 extended abstracts on Human Factors in Computing Systems*, pages 2807–2812, San Jose, CA, 2007. Association for Computing Machinery.

[46] D. Norman. *Emotional design: Why we love (or hate) everyday things*. Basic Books, 2004.

[47] S. O'Modhrain and G. Essl. An enactive approach to the design of new tangible musical instruments. *Organised Sound*, 11(3):285–296, 2006.

[48] L. Pizzamiglio, T. Aprile, G. Spitoni, S. Pitzalis, E. Bates, S. D'Amico, and F. Di Russo. Separate neural systems for processing action-or non-action-related sounds. *Neuroimage*, 24(3):852–861, 2005.

[49] P. Polotti, S. Delle Monache, S. Papetti, and D. Rocchesso. Gamelunch: forging a dining experience through

sound. In M. Czerwinski, A. M. Lund, and D. S. Tan, editors, *CHI '08 extended abstracts on Human Factors in Computing Systems*, pages 2281–2286, Florence, Italy, 2008. Association for Computing Machinery.

[50] M. Rath and D. Rocchesso. Continuous sonic feedback from a rolling ball. *IEEE MultiMedia*, 12(2):60–69, 2005.

[51] N. Ravaja, M. Turpeinen, T. Saari, S. Puttonen, and L. Keltikangas-Järvinen. The psychophysiology of James Bond: Phasic emotional responses to violent video game events. *Emotion*, 8(1):114–120, 2008.

[52] D. Rocchesso, P. Polotti, and S. Delle Monache. Designing continuous sonic interaction. *International Journal of Design*, 3(3):13–25, 2009.

[53] L. Rosenblum. Are hybrid cars too quiet? *Journal of the Acoustical Society of America*, 125:2744–2744, 2009.

[54] L. D. Rosenblum. *See what I'm saying: the extraordinary powers of our five senses*. W W. Norton & Company, Inc., New York, 2010.

[55] J. A. Russell and L. Feldman Barrett. Core affect, prototypical emotional episodes, and other things called emotion: dissecting the elephant. *Journal of personality and social psychology*, 76(5):805–819, 1999.

[56] R. M. Schafer. *The Soundscape: Our Sonic Environment and the Tuning of the World*. Destiny Books, 1994(1977).

[57] N. Schaffert, K. Mattes, and A. O. Effenberg. Listen to the boat motion: acoustic information for elite rowers. In R. Bresin, T. Hermann, and A. Hunt, editors, *Proceedings of the* 3^{rd} *Interactive Sonification Workshop (ISon 2010)*, pages 31–37, Stockholm, Sweden, 2010.

[58] K. Scherer, E. Dan, and A. Flykt. What determines a feeling's position in affective space? A case for appraisal. *Cognition & Emotion*, 20(1):92–113, 2006.

[59] K. R. Scherer. What are emotions? And how can they be measured? *Social Science Information*, 44(4):695–729, 2005.

[60] P. Sengers and B. Gaver. Staying open to interpretation: engaging multiple meanings in design and evaluation. In *Proceedings of the 6th conference on Designing Interactive systems*, pages 99–108. ACM, 2006.

[61] X. Serra, M. Leman, and G. Widmer. A roadmap for sound and music computing. *The S2S Consortium*, 2007.

[62] E. Singer. Sonic banana: a novel bend-sensor-based midi controller. In F. Thibault, editor, *Proceedings of the* 3^{rd} *International Conference on New Interfaces for Musical Expression (NIME 2003)*, pages 220–221, Montréal, Québec, Canada, 2003. McGill University, Faculty of Music.

[63] C. Spence and M. Zampini. Auditory contributions to multisensory product perception. *Acta Acustica united with Acustica*, 92(6):1009–1025, 2006.

[64] P. Susini, N. Misdariis, O. Houix, and G. Lemaitre. Does a "natural" sonic feedback affect perceived usability and emotion in the context of use of an ATM? In F. Gouyon, Álvaro Barbosa, and X. Serra, editors, *Proceedings of the* 6^{th} *Sound and Music Computing Conference (SMC 2009)*, pages 207–212, Porto, Portugal, 2009.

[65] D. Västfjäll and M. Kleiner. Emotion in product sound design. In *Proceedings of the Journées du Design Sonore*, Paris, France, 2002.

[66] Y. Wand. A Proposal for a Formal Definition of the Design Concept. *In Design Requirements Engineering: A Ten-Year Perspective*, 14, 2009.

[67] H. Westerkamp. Soundwalking. *Sound Heritage*, 3(4):18–27, 1974.