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Sound design: an applied, experimental framework to study the perception of everyday sounds

ABSTRACT

Mutations in late 20th-century sound design have transformed it from an empirical know-how into a full-fledged research field, with applications in the domain of everyday sound perception. This evolution leads us to propose an updated definition and a new description of the sound design process. Our updated definition, namely 'making intentions audible', is based on two types of intentions, one, essential, of function, and the other of form. We describe here three types of intentions of function, able to communicate information through an artifact. We then give a new description of the overall sound design process, as a combination of three steps (analysing, creating and testing), which articulate sound perception and sound design. Our first claim here is that the sound design process should be informed by knowledge, research and exploration of everyday sound perception; several industrial examples thereof will be presented. Our second claim is that sound design should be used to inform everyday sound perception research, both by suggesting new informative experiments and raising new methodological issues, ranging from sound design tools to

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experimental setups that need to be implemented specifically in the framework of sonic interaction design.

A MOVE TOWARDS SOUND DESIGN!

Unintentional and intentional sounds in our everyday environment

Our daily sonic environment is composed of speech and music, but also a myriad of sounds associated with environmental sources as varied as a car, a can opener or a bathroom faucet, which are now referred to as *everyday sounds*.

For a long time, this latter type of 'everyday sounds' have remained ill-defined and little studied. The work of R. Murray Schafer and his colleagues in the 1970s - reported in *The Tuning of the World* (Schafer 1977) - led to, arguably, the first classification of environmental sounds based on a combined phenomenological, sociological and artistic approach. At the same time, Vanderveer (1979) conducted experimental psychological studies in which she defined environmental sounds as:

> . . . any possible audible acoustic event which is caused by motions in the ordinary human environment. [. . .] Besides 1) having real events as their sources [. . .] 2) [they] are usually more "complex" than laboratory sinusoids, [. . .] 3) [they] are meaningful, in the sense that they specify events in the environment. [. . .] 4) The sounds to be considered are not part of a communication system, or communication sounds, they are taken in their literal rather than signal or symbolic interpretation (Vanderveer 1979: 16–17).

In other words, Vanderveer defined everyday sounds as the sonic events resulting from physical phenomena triggered by human action (for example, lighting a match, clinking glasses, crumpling a paper, slamming a door, etc.). More recently, Giordano, McDonnell and McAdams (2010) named this class of sounds 'action-sounds'. In that case, the sounds produced are 'unintentional' – even if a door can be slammed with a specific intention, but this is another story! On the other hand, it is interesting to note in Vanderveer's definition that the sounds corresponding to 'communication sounds', for example, signalling sounds such as alarms, blinkers or feedback signals, were excluded, while Schafer considered this class of sounds, which he called 'sound indicators', an integral part of what to him constitutes the 'new soundscape' of our modern era. Those latter sounds, created for the purpose of communicating information, are 'intentional'. In our point of view, both intentional and unintentional sounds form the broad category of everyday sounds. The former term shall be used for the class of sounds created and manipulated with the intention to communicate information, while the latter corresponds to sounds that are inherent to a physical phenomenon.

From sound quality to sound design

In Europe, during the second part of the 20th century, industrial design became increasingly concerned with unintentional sounds of products, inasmuch as they were not desired but rather described as objectionable noises by clients. It wasn't – and still isn't – easy to control or manipulate the sound of a product when there is no physical model to predict the corresponding sound: while characteristics of unintentional sounds can be measured from their audio recordings, making acoustic specifications in terms of the physical characteristics of the product (e.g. material, geometry, size) remains difficult. However, this hasn't deterred the industry from taking account of the sound of its products. In the automotive sector in particular, important work was conducted to improve the body structure of cars to reduce their squeaking and rattling, often to be relayed in positive advertising messages: '[...] Yet (engineers') search of silence continues - at the special Fisher Body sound laboratory ...' (LIFE Magazine 1953). In the late 1980s, the idea of active noise cancellation led to even further achievements in noise reduction. Up until that period, the ideal was that of silent products such as silent vacuum cleaners or automobiles.

However, in the 1990s, new expectations meant that the sound of a product should provide useful information about its state, quality and identity, perhaps to the same extent as its visual characteristics. Past advertisements gave way to new slogans, for example, 'Every sound has a meaning' (French car manufacturer Citroën). A new field of research in 'sound quality' emerged, based on the experimental paradigm of psychoacoustics and the technical tools of sound analysis/synthesis. It endeavoured to determine the auditory attributes of the recorded sound signal that were related to user preference and multisensory product perception (Susini, McAdams and Winsberg 1999; Spence and Zampini 2006).

The 'sound quality' approach is usually considered a post-process endeavour, aiming to improve the sound of existing products; it concerns mainly the category of unintentional sounds. In contrast, the newly emerging 'sound design' approach is conceived as a pre-step, aiming to create 'new' sounds with the intention that they will be heard in the context of use. Contrary to sound quality, sound design mainly concerns the category of intentional sounds.

Previously, the lack of tools to control, manipulate or predict the sound produced by physical objects has long limited sound design to a relatively small subset of sounds created for digital media (except for the rare cases where acoustical objects are created and used for sound installations or sound sculptures), for example, for film, computer games, branding and signalling. The particular case of signalling sounds has been a trademark of such early research attempts as such sounds are easily manipulated and integrated into software systems that can trigger sounds depending on internal or external actions. However, in a few case studies, sound was also redesigned for physical products in order to reach a target image defined in terms of robustness, comfort or luxury. Well-known examples are those of the vehicle doors for different automotive brands, Harley Davidson motorcycles, Dupont lighters, perfume bottles and chips. In those cases, the unintentional sound of the product becomes an intentional one.

Finally, recent technological development allows the combination of real-time sound synthesis and miniaturised embedded systems, for example, sensors and microcontrollers, to design new interactive sound devices. Thus, it becomes increasingly possible to design the sound aspects of an object as a constituent part of its global quality and coherence, of its ergonomics to facilitate learning and control. The sonic component of an object may also highlight the identity of a product or a brand, or even offer new aesthetic experiences. Such richly designed, multi-faceted intentional sounds soon will be integrated in the objects that we manipulate daily. A new area of play is opening up for sound designers.

SOUND DESIGN: MAKING INTENTIONS AUDIBLE

The sound dimension has not been much considered in the history of twentieth century design, and has mostly been used for theatre and film. In the 1920s, Luigi Russolo designed machines to simulate natural sounds of wind and storms, or man-made sounds such as trains or bombs, in theatre and musical performances, for example, for Eugène Deslaw and Jean Epstein in Paris's famous avant-garde cinema, Studio 28. Concerned as he was with the tradition of 'musical gesture', Russolo did not suspect at that time that the recording of these same sounds would soon replace his ingenious imitations. A few years later, the *musique concrète* of Pierre Schaeffer turned the approach on its head, and sound came to be considered for its intrinsic qualities, without regard for its meaning or context (which it often lacked, for example, the scratched record sounds of *sillon fermé*).

It wasn't before the 1970s that the term of 'sound designer' appeared in the North-American film industry, with the emblematic figure of Walter Murch for his work on Francis Ford Coppola's productions. In *The Making of 'THX 1138'*, a 1971 science-fiction motion picture, Georges Lucas described his work with Walter Murch: 'We took the sound effects and made them to be like music, and in some cases, we took the music and made it to be sound effects' (Leva 2004). Such description prefigures the future role of sound designer for the film industry. Great examples of this sound alchemy can be heard in David Lynch's and the Coen brothers' productions, such as respectively *Eraserhead* and *Barton Fink*, in which unidentified industrial whooshing or omnipresent hissing sounds are used either as sound effects, abstract music or both; the soundtrack is continuously imposing itself onto the audience's awareness and emotional response. In other words, its *intentions* are clearly *made audible*. However, in the time of *THX 1138*, Walter Murch was still credited for 'Sound Montages' (while Lalo Schifrin was credited for 'Music'). It is only in his future jobs on Coppola's movies - which were neither those of a sound editor nor musical director - that Walter Murch created a new role for himself, which he termed 'sound designer' in order to be paid and his work recognised despite restrictions on film credits imposed by the Hollywood unions. Since then, Murch is widely acknowledged as the person who coined the term 'sound designer', which rapidly became associated with the role of sound director for a movie. Nowadays, the sound designer supervises, manages and ensures the coherence of all the outputs that emanate from the many creative and technical people involved in a movie's sound production:

> Well, if an interior designer can go into an architectural space and decorate it interestingly, that's sort of what I am doing in the theater. I'm taking the three-dimensional space of the theater and decorating it with sound. I had to come up with an approach, specifically for *Apocalypse Now*, that would make that work coherently. In my case, that was where "sound designer," the word, came from. (Jarrett 2000).

In France, the term 'sound designer' still is not frequently used on credit rolls, with some confusion as to how the job should be distinguished from more traditional roles such as sound editor, Foley artist and musical director.

In Europe, sound design was first introduced in the product industry and in the fine arts. As described earlier, product sound came to be taken into account in the industry in the late 1990s, mostly on the impulse of the automotive industry. Sound design was then considered, in line with the classic Bauhaus view, as the articulation of function and form using sound. This articulation is perfectly summarised by design consultant Anne Meyer, describing the objectives of design as: 'To facilitate and improve the use, behaviour, and quality of life, finally, to embellish, as possible, the environment' (Meyer 2004). More specifically in France, Louis Dandrel and Bernard Delage developed the field of sound design for products and urban landscapes based on the work of R. Murray Schafer. At the end of the 90s, sound design started to be considered in France as an academic topic and was, for example, introduced in the research and educational departments at IRCAM (Institut de Recherche et Coordination Acoustique/Musique) in 1999, as well as in the CNAM (Concervatoire national des arts et métiers) and in the Master ENJMIM (Ecole nationales du jeu et des médias interactifs numériques) focusing on games and interactive media. In 2002 and 2004, two international symposia on sound design were organised in Paris, by Frédérique Guyot, Valérie Maffiolo and Patrick Susini, combining, for the first time, scientists in psychology and acoustics, industrial designers and artists. On the other side, nowadays, most art schools have launched their own sound creation studios; very recently, in 2011, a Master of Sound Design was created at the Le Mans Art School ESBAM (Ecole supérieure des beaux arts du Mans). Artists are now more involved in sound than in the past, for example, by creating sound installations or sculptures for open space, architectural renovation or museum exhibits. In industry, several French companies are developing methodologies and tools for the design of sound products, and other companies specialise in the creation of sound identity for brands. In addition, in the past ten years, general media attention to sound design has grown, although the role of the sound designer, and the definition and the process of sound design, often remain unclear.

WHAT ARE THE OBJECTIVES OF SOUND DESIGN?

Definition

A 'sound design' approach is implemented in order to *create 'new' sounds with the intention that they will be heard in a given context of use*. By new sounds, we mean sounds that cannot be found in existing sound databases, or cannot be recorded or, at least, cannot be directly used without being modified.

Listening, as Pierre Schaeffer emphasised, implies having an intention. Sound design can therefore be considered the reverse process of listening: *the process of making intentions audible*. To this aim, sound creation has to be taken into account from the early definition of an object, concept or system. There are two types of intention: of form and of function.

Articulation between form and function

Intention of form considers sound as part of the overall quality of a desired object, that it is coherent with the identity of the object and that it offers a new aesthetic experience of the object. Here, the notion of coherence is fundamental: for example, when several sounds are created for a human-machine interface, coherence should be maintained, regardless of the many functions that distinguish the sounds from one another, in order to keep the overall sound identity.

Intention of function considers sound as a communicator of necessary and useful information to interact with an object for a specific use. Such information needs to be clearly heard and correctly interpreted for the design to be considered successful: 'Function is essential to any object, even the most trivial' (Starck 2004). However, the result of a designed object can raise unexpected perceptions, emotions, representations and actions, all of which are also interesting to take into account (Vial 2010). It is information perceived by the user/listener that gives meaning to sound. Several kinds of functions can be considered: for example, to warn of danger or to guide towards a specific direction (sound notification), to confirm actions (sound feedback), to facilitate a user's practice and satisfaction in terms of learning and control of a device (sonic interaction).

Successful sound design should be the articulation of both form and function. Nevertheless, in line with classic design, Louis Sullivan's fundamental principle 'that form ever follows function' (1896) is still relevant: behind the formal aspects of a sound, there is always intention associated to its function. For example, both the sonic characteristics used

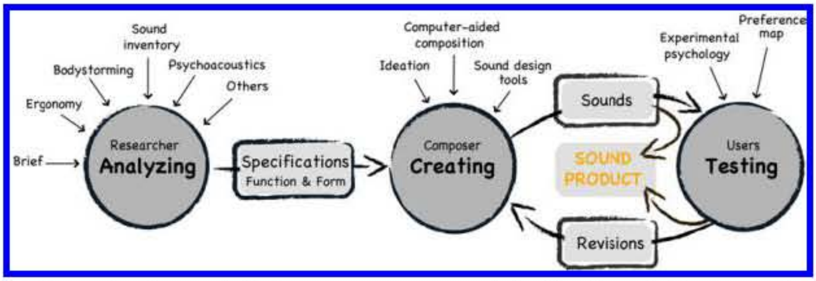

Figure 1. A sound design process proposed by the Sound Design and Perception team (IRCAM).

to make an alarm audible, as well as the characteristics of the system that broadcasts the alarm, have an influence on the design process for that sound.

The sound design process

We propose here a process for sound design that includes three successive steps: analysing, creating and testing. This 3-step iterative process, represented in Figure 1, is in line with different formats of the classic design processes that are usually proposed when designers work on a project, e.g. the brief/do/check sequence (Quarante 2001; Lidwell, Holden and Butler 2010). This 3-step sound design process involves three stakeholders, respectively the 'researcher', the 'composer' and the 'users'. This is not a strict and rigid association, but rather an analogical correspondence of the skills required for each step.

In our proposal, the analysing step aims to develop specifications for the subsequent creation step. In our view, the analysis is based on the assumption that the information required for the creation of new sounds is already partly 'available' in our sound environment. Starting from a brief of the problem to be solved, the analysing step consists, first, of using our knowledge of sound perception (informed by psychoacoustics and auditory cognition studies), and second, of exploring and exploiting a large inventory of sounds that are representative of the target product. The goal is to specify the sound product to be designed at both the acoustic and perceptual level. For example, different studies performed in our team with industrial partners, respectively for the redesign of sounds for cars (Susini, McAdams and Winsberg 1999), air conditioning units (Susini et al. 2004), car horns (Lemaitre et al. 2007), car doors (Parizet, Guyader and Nosulenko 2008) and clock watches, revealed what perceptually salient sonic features (for example, timbre) are specific to, for example, a family of sound products, a sound brand identity or are related to listeners' preferences. From a methodological perspective, the analysis step can also incorporate such complementary approaches as ergonomic analysis of everyday life or skilled activities (Tardieu et al. 2009), soundrama (Hug 2010), voice imitations (Lemaitre, Dessein, Susini and Aura 2011; Lemaitre and Rocchesso 2014), 'bodystorming' techniques (Oulasvirta, Kurvinen and Kankainen 2003; Franinović and Serafin 2007) or role-play exercises in which participants have to mimic their actions as if the product existed.

Specifications from the analysing step are used as input to the second step: creating. At IRCAM, the creation step consists of a collaboration between scientists and composers. Examples in our team include collaborations with Louis Dandrel, Emmanuel Deruty (Susini, Gaudibert, Deruty and Dandrel 2003), Andrea Cera (Misdariis, Cera, Levallois and Locqueteau 2012) and Sébastien Gaxie for industrial projects; with Hiroshi Kawakami (Tardieu et al. 2009) and Alexander Sigman (Sigman, Misdariis and Megyeri 2013) for research projects; and with Roland Cahen, Jean Lochard and Mikhail Malt for pedagogical projects and trainings. The composers that are usually involved in this process are used to taking into account industrial constraints as well as perceptual/physical specifications developed in the previous analysis phase. In line with the original art/science vision presiding over the creation of IRCAM (a 'utopian marriage of fire and water' – Boulez, 1977), our position is to combine the scientific/technical 'knowledge' of the researcher and 'know-how' of the composer (designer). In broad terms, the acoustic/perception researcher knows *what* property of sound to implement, and the composer knows *how* to reproduce these properties with her own creative singularity.

The output of the creation step typically consists of several sound specimens that are then tested (third step, testing), using listening tests, experimental psychology paradigms or preference maps, until a prototype sound is obtained that fulfils the perceptive expectations in terms of function (or aesthetics). In other words, the final sound prototype can be obtained after a selection among the sound specimens by the project's participants (the researchers, the composer and the sponsor), or after a series of perceptive experiments with listeners (users), or after a few revisions of the initial proposed sounds.

WHAT DOES AN ARTEFACT COMMUNICATE USING INTENTIONAL SOUNDS?

We move here to focus on the functional nature of sound, and especially on the sound cues we perceive when performing a task for a given purpose and context such as vacuum cleaning, driving, closing a door, cutting vegetables, using an electric drill, navigating through a menu, filling a bowl, starting a computer, etc. (Spence and Zampini 2006). In such daily, active processes, it is relevant to consider the meaning of the sonic part of an object, a human-machine interface or even a space, to communicate necessary and essential information. Three main levels of functional complexity can be defined, depending on the relation between the sound and the action of the individual perceiving the sound: sound notification, sound feedback and sonic interaction (see Figure 2).

Sound notification

Sound notification is used to warn/notify the user of an external event. Alarm sounds are good examples: they provide information about an

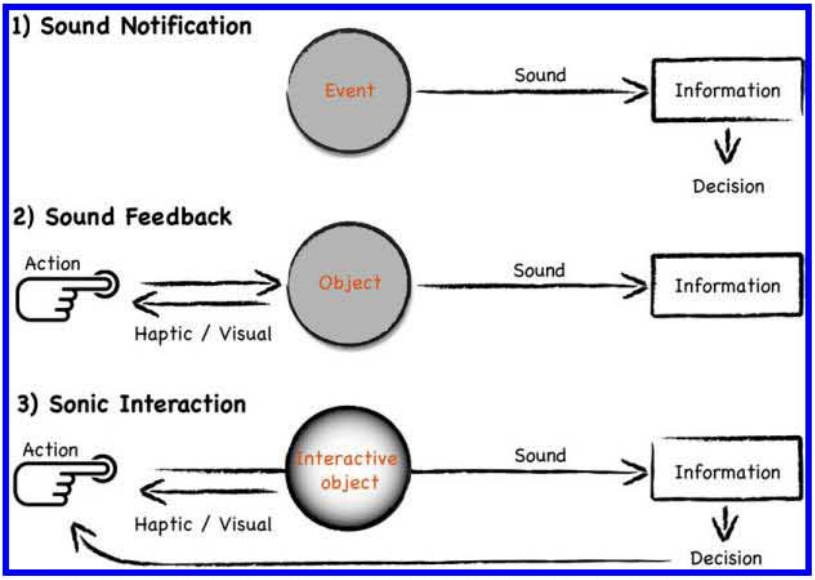

Figure 2 : What do we communicate using intentional sounds?

emergency or a warning to the individual. Auditory beacons used in audio navigation aids are another example (Walker and Lindsay 2003). Sound notification is the most simple type of intentional sound: it provides information about a specific situation but there is no relation between the sound and the eventual reaction of the individual. Several studies were conducted in order to define the acoustic and perceptive parameters of alarm sounds in order to best convey different levels of emergency or best identify the type of problem. For instance, Edworthy, Loxley and Dennis (1991) showed that a selection of parameters had clear and consistent effects on the perceived emergency of a warning sound: the faster the rate, the higher the pitch, and the more randomly irregular the harmonics, the more urgent the event is perceived. Such studies found application in the realms of the airplane, hospital and automotive industries (O'Carroll 1986; Momtahan and Tansley 1989; Edworthy and Hellier 2006; Suied et al., 2008; Suied, Susini, McAdams and Patterson 2010; Keller et al. 2011).

Sound feedback

Sound feedback is used to confirm a given action performed by a user. Feedback can be positive, when the action is performed correctly, or negative. The type of sound that is feedback, whether positive or negative, depends either on the correctness of the action or the state of the system. Validation sounds for a transportation pass on a control terminal are a good example of the latter: the type of sound depends on the validity of the pass. Feedback sounds are typically used in the realm of human-computer interface; in addition, they are often used as an illustration of an action such as in the Sonic Finder proposed by Gaver (1989), the sonified Event Os by VIPS and the ATM (Susini, Misdariis, Lemaitre and Houix 2012).

Sound interaction

Sonic Interaction Design (SID) 'explores ways in which sound can be used to convey information, meaning, and aesthetic and emotional qualities in interactive contexts' (Franinović and Serafin, 2013). In SID, the characteristics of a sound are directly related to some varying characteristics of the action performed by the individual or of the state of a system. In recent years, coupling sound to actions has become an attractive feature of a number of new objects/systems aiming to strengthen the physical reality of virtual devices and user performance with new artifacts - see e.g. the Wii control handle (Nintendo). The technological possibilities now offered by the combination of real-time sound synthesis and miniaturised embedded systems such as the Arduino system (http://www.arduino.cc) enable the design of interactive systems relevant to explore how everyday sound perception is influenced by interactive processes. Such experimental interactive devices include the Ballancer (Rath and Rocchesso 2005; Rath 2007), the Shoogle (Williamson, Murray-Smith and Hughes 2007), the Spinotron (Lemaitre et al. 2009), the Drilling Machine (Grosshauser and Hermann 2010), and the Flops (Lemaitre et al. 2012).

ARTICULATION BETWEEN SOUND PERCEPTION AND SOUND DESIGN

Claim 1: sound design should be informed by sound perception research

The sound design process proposed in the present article is based on a first analysis step consisting in the dynamical exploration of our immediate sound environment. It aims to enrich the designer's perception, to construct logical meaning and to sharpen critical thinking. We contend that this first step *would largely benefit from knowledge, research and exploration performed on everyday sound perception*. For example, imagine a sound designer who has to create a sound that comes across as an impact on a piece of wood. She could start from scratch but it certainly would be very helpful for her to know what relevant auditory clues are used in everyday life contexts to, for example, distinguish metal from wood.

Another related claim is that if one uses information already available in the world, for example, analogies with other objects or elements of nature, or rules common to a group of individuals - then the characteristics of the new object and the possible actions with this object will be more visible and intuitive (Norman 1999; Norman 2002). In the framework of sound design research, several authors have taken advantage of our daily life auditory experiences in order to define the relevant elements for the creation of sonic interactive devices (Rath and Schleicher 2008; Lemaitre et al. 2009; Susini, Misdariis, Lemaitre and Houix 2012). It is worth having good knowledge of everyday sounds!

What, then, do we know about everyday sounds?. One of the fundamental questions in auditory research is to understand what do we hear when we are listening to sounds? Pierre Schaefer explained that sound usually refers to a sound source (object, event), and that hearing a sound as a 'self-object', that is, for its intrinsic qualities, needs effort and training. William Gaver (1993a, 1993b) proposed two ways of listening mainly based on the listener's experience: 'The distinction between everyday listening and musical listening is between experiences, not sounds' (Gaver 1993b: p. 1). Recent auditory cognition studies revealed that different listening strategies do indeed exist, based for example, on a listener's capacity to identify a sound source, on her expertise (Lemaitre, Houix, Misdariis and Susini 2010) and on the context of listening (Susini et al. 2009). In particular, the results of Lemaitre and colleagues clearly revealed that poorly-identified sounds are mainly described in terms of qualitative perceptual aspects, while well-identified sounds are described in terms of the characteristics of their source and action.

In psychoacoustics, the qualitative perceptual aspects of sounds are computed thanks to models of the auditory system. The psychoacoustics features typically used are: loudness, sharpness, roughness, and fluctuation strength (Fastl 1997: pp. 754–764). They have been implemented in several commercial software packages: BAS and Artemis by Head Acoustics, dBSonic by 01dB-Metravib, PULSE by Brüel and Kjaer and LEA by Genesis. More recently, based on several studies on timbre, signal descriptors have also been proposed for different families of everyday sounds (Misdariis et al. 2010) and musical sounds (Peeters et al. 2011).

Another way to explore how we hear is to rely on quantitative verbal analysis (as it is called in psychoacoustics) or semantic analysis (as it is called in psycholinguistics) of how listeners describe sounds with words ('we hear as we speak', wrote Michel Chion, 1993). We will not do an inventory of the numerous studies based on verbal descriptions that were conducted on abstract, musical and environmental sounds, but we will report on the observations from two studies. First, work by Vanderveer (1979) showed that verbal descriptions are mainly associated with source and action characteristics, and the place where the action takes place (that is, its context). Second, in a 1960 Air Force contract, R.W. Peters acquired perceptual descriptions of different classes of sounds: pure tones, harmonic tones, white noise, voice, musical and everyday sounds. The results of the study showed that the vocabulary usually found in other studies was indeed used by the participants to describe acoustic characteristics but, surprisingly, only about a third of the participants used this vocabulary to describe everyday sounds; the other two-thirds of the participants used terms related to source and action characteristics.

Finally, recent findings in auditory cognition and neuroscience have focused on the main question related to, respectively, everyday sound identification (Lufti 2008; Houix et al. 2012; Lemaitre and Heller 2012) and perception-action loop (Kohler et al. 2002; Castellio et al. 2010; Giordano, McDonnell and McAdams 2010). Research has shown that we are better and faster when identifying actions rather than objects, and that sensori-motor reactions and controls are facilitated when we interact with objects displaying 'ecological' congruent sounds.

Implications for sound design: a wishlist of questions. Designing sounds involves several questions that can be informed by knowledge or specific studies on sound perception:

- How the listening strategy can be taken into account for the design of new sounds?
- What are the sound features that have to be modified to get a 'nice' sound?
- Which factors make us detect a sound alarm in a construction site?
- What is the most relevant sound-mapping to make sure an urgent message is attended to?
- What types of sound analogy best promote interactions with an object or an interface?
- Can sound help to learn and to control different simultaneous streams of information?
- Are there class-generic descriptors for the purpose of describing the different classes of sound product? If not, what are the specific features for each class?

Such questions, and many others, have real implications for sound design and can help sound designers to make relevant choices instead of starting from scratch.

The purpose of this article is not to provide an answer to all the questions, but rather to highlight the relevance of sound perception studies for sound design applications. For example, taking into account the different listening strategies introduced by Gaver, several strategies in terms of rules, metaphor and affordance were proposed to communicate information with sound mainly in the field of sonification (the use of non-speech audio to convey information or perceptualise data). To make more explicit the communication with non-vocal sounds in a virtual context, it was proposed to take advantage of sound analogies with the physical world (Gaver 1989) that still make sense in the virtual context. More recently, the sonification strategy has been extended in the realm of sonic interaction design (Hermann, Visell, Williamson and Brazil 2008).

Particularly important to sound design is the study of timbre perception. Indeed, a crucial aspect for sound design is to determine the relevant features to efficiently communicate information or to obtain a pleasant sound. An important corpus of studies on the timbre of musical sounds, and more recently, on timbre of different families of everyday sound products (Susini et al. 1999, 2004; Bonebright 2001; Parizet, Guyader and Nosulenko 2008; Lemaitre et al. 2007) provides perceptive and acoustic characteristics that can be linked to listeners' preferences. For example, it was shown that one sound feature, the spectral centroid (the frequency position of the centre of mass of the distribution of energy in the sound's Fourier spectrum) is of importance for all the studied classes of environmental sounds, but perceptual exploration of the different families of sound revealed that other features are specific for each family of sounds.

We see clearly how knowledge on sound perception can be used for applications in sound design, but, conversely, is sound design of any interest for studies in sound perception? Is sound design a way to elaborate new controlled stimuli that enlarge the perceptive process usually engaged in psychoacoustics experiments?

Claim 2: sound design should be used to inform sound perception research

Sound, when coupled to an action, quickly becomes an asset for interactive products as it strengthens the physical reality of virtual objects. Thinking about future products in terms of their possible sound reveals a new framework to explore sound perception, namely how sound communicates information to a user in order to accomplish a specific task. It is in this context that we can consider the functional intention, defined earlier, that gives a meaning to the sound.

A new framework for studying sound perception in active processes. It has been shown that depriving tennis players of the sound of the ball affects the actions performed and produces more errors (Takeuchi 1993); modifying the sounds that result from gestures made with an object disrupts the haptic experience of the listener/performer (Zampini et al. 2003, 2004; Spence and Zampini 2006); using sounds congruent with a specific gesture facilitates the training of athletes (Eriksson and Bresin 2010). Sound clearly communicates information that is processed in the context of the activity carried out by the individual.

The manipulation of a sounding object engages a direct sonic interaction without physical separation between the action that is made and the sound that is produced. The characteristics of a given sound directly depend on the action that produced it: the sound produced by a musical instrument is directly dependent on how it is excited, the sound of a slamming door is directly related to the particular way it is slammed. In other words, sound is perceived in a loop that combines action and perception: the sound is the result of an action which is in turn adjusted in real-time according to the perceived characteristics of the sound.

Few studies have focused on everyday sound perception engaged in active processes, perhaps because they were judged not technologically feasible in terms of real-time sound control, motion capture and experimental setup (see 3.c for a list of interactive devices recently proposed). However, such sonic interaction systems are increasingly common in a variety of fields of application, such as industrial products (to promote manipulations with an object), sports (to improve an athlete's performance), health (to assist in the rehabilitation of a patient), robotics (to control the movement of an operator) and games (to strengthen a multi-sensory immersion of a player), etc.

Implications for sound perception. We claim that the aforementioned applications provide extremely fruitful case studies to research sound perception as an active and contextual process. In that new framework, sound perception studies have to be redesigned in relation to gesture and to user's objectives. Indeed, sound design applications are related to more realistic task-context situations, compared to the usual reduced situations undertaken in usual sound perception studies. In addition, it is now possible to use sonic interactive devices – combining real-time sound synthesis and miniaturised embedded systems including sensors and microcontrollers – in behavioural experiments.

CONCLUSION

In conclusion, we have seen in this article how a good articulation between sound perception and sound design could be relevant for both fields: (1) sound perception research generates knowledge that is crucial for the emerging field of sound design and (2) sound design is a generator of new questions and interesting case-studies for research in perception.

Intention of function has been considered in the present article by considering the meaning of sounds. We have highlighted the fact that the question often asked on the meaning of sounds is fundamental, but mainly relevant when the sound dimension is involved during an interaction with an object. Indeed, we have presented studies and experimental devices in the context of sound design that addressed the functional intention of a sound in a way that extends the usual framework of sound perception studies, considering interactive devices. The different experiments and results highlight the effect of the sound dimension to improve performance, enhance learning and give a positive emotional reaction.

Intention of form has not been considered in the present article, but it is relevant for the realm of sound perception research by considering aesthetic issues in relation to emotional reactions to everyday sound objects.

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