TOWARD A SOUND DESIGN METHODOLOGY: APPLICATION TO ELECTRONIC AUTOMOTIVE SOUNDS

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ABSTRACT

In the field of Human Machine Interfaces (HMI), there is a potential to convey numerous different messages by non-verbal-sounds. In the eighties, different approaches to the design of information-bearing sounds were proposed. These approaches and corresponding guidelines focused on the acoustical properties of auditory displays. In particular, psychophysical approaches to urgency perception have identified relationships between acoustic parameters and different degrees of urgency perception. We performed an experiment with sounds currently used in automotive HMI. It was found that these sounds are not satisfactory and do not fulfill their intended function, even though some of them match the existing guidelines. Thus, we propose that a new methodology should be used to design more adequate HMIs. This methodology draws on two different theoretical frameworks: acoustics and semiotics (science of signs). In order to investigate the important hypotheses on which the methodology is based, we describe specific experiments that can be used to validate or invalidate the method, when applied to a specific sound design problem. Finally, we discuss the potential use of our new methodology.

1. INTRODUCTION

How to convey a message or a function using a non-verbal sound? This question could be a definition of "sound design". In this paper, we will address this question within the restricted framework of electronic automotive sounds.

In the Eighties, the most common use of non-verbal sounds related to alarms. At the end of the Eighties, these ideas were extended and several studies proposed that sound messages could convey more complex information. These information-bearing sounds, called "earcons" by analogy to visual icons, can be divided into two groups: "representational earcons" and "abstract earcons". We will discuss this distinction in the paper.

Among the different areas of application of auditory displays, we can find the car. Cars are employing an ever increasing number of Human Machine Interfaces (HMI). Auditory warnings may signal an imminent or potential danger, or inform us about something happening in the car or its environment. More precisely, in order to define the message to be conveyed, three criteria are distinguished: the reason for the sound (a technical failure, an oversight of the driver or a voluntary action of the driver), the general message function (to alert to a danger, to announce something or simply to inform) and the reaction expected from the driver (immediate reaction, delayed reaction, or no action necessary). To decide on the type of reaction to adopt, the listener must understand the message function as well as the reason for the sound. This paper is not about the listener's reaction. We first aim to study the acoustic properties that can convey the reason for the sound and its function.

A first experiment we performed on existing automotive sounds pointed out shortcomings about the comprehension of the current sound HMI. Auditory warnings were generally poorly understood and poorly interpreted, which could induce potentially dangerous situations.

Thus, a sound design methodology is required. With this goal in mind, we will introduce a theoretical framework: Semiotics. As the "science of signs", semiotics allows us to understand how to build meaning, and to establish internal relations between signs.

This theoretical framework leads to several assumptions about the link between the sound HMI classification and the various sound representations (earcons, for example). With four experiments, we propose how to test these assumptions resulting from semiotics, and other assumptions resulting from existing auditory display work.

This paper will be presented in five parts: first, a review of non-verbal sounds used to convey information (§2); second, an oriented-categorization experiment using a selected automotive sounds corpus (§3); third, the theoretical (§4) and the methodological (§5) approaches of the present study; then, a first experiment based on our methodology (§6); and finally, the conclusion (§7).

2. ABOUT ALARMS, EARCONS AND AUDITORY ICONS

Historically, the design of auditory displays was related to alarm sounds (e.g. [1]). Then, auditory messages that can be used to transmit information in general were introduced (e.g. [4]). These auditory messages are traditionally divided into two classes: "auditory icons", which are literally the sounds of the objects themselves; and "earcons", abstract sounds that involve the development of an arbitrary audio pattern. Traditional alarm sounds are generally abstract sounds: earcons. The first part will deal only with alarm sounds, a great number of studies having been devoted to them. In the next sections, we will attempt to clarify the differences between auditory icons and earcons.

2.1. Alarms

Many studies were carried out on auditory warnings. Their general aim was to establish relationships between acoustic

parameters and different degrees of perceived urgency. In 1982, Patterson ([1], quoted in [2]) proposed to build auditory warnings by repeating sequences (called bursts) of harmonic sounds (called pulses). In particular, he specified the level of signal compared to background noise, pulse duration, inter-pulse interval, and other temporal and spectral characteristics of the sounds. He also recommended that the sound pulses should have onsets and offsets lasting 20-30ms in order to avoid startle reactions.
The article published by Edworthy, Loxley and Dennis [3] was also used as a basis for a whole series of publications. Among the signals they tested, the ones considered to be the most urgent were those with a high fundamental frequency, with a brief onset envelope, those whose partials series had random frequencies, and those that were the most irregular from the rhythmic point of view.

2.2. Auditory icons

Since this work and first guidelines on alarms, other proposals were made in order to convey information by non-verbal sound messages. By analogy with visual symbols, traditionally called "icons", Blattner and al. [4] defines auditory messages as "earcons". Earcons are used in transmitting information to system users. A first class of earcons are the "representational earcons", also called "auditory icons". The notion of auditory icon was developed by Gaver in 1988 ([5]). They are environmental, natural sounds that represent actions, processes or objects by similarity.
However, problems can appear when the objects or processes to be represented do not have an equivalent in everyday life (for example, sending an e-mail). In this case, Gaver proposes using "sound effects", as is the case in cinema. To carry out a non-arbitrary choice of auditory icons intended to represent a specific process (a technical failure, for example), Barrass [6] proposes a method: the idea is that everyday use of sounds might serve as design examples in auditory display by collecting stories about listening experiences. The analysis of these stories allows deduction of the characteristic features of sounds that are common to all the stories.

2.3. Earcons

Earcons were introduced in 1989 by Blattner, Sumikawa and Greenberg [4]. They are abstract, synthetic sounds, musical motives that are used to provide information and that create non-verbal sound messages. There is no intuitive correlation between the earcon and what it represents. It has to be learned, unlike the auditory icons for which only minimal training is required. In comparison with auditory icons, the earcon approach is more musical.
In [4], earcons are described by motives, themselves defined according to five criteria: rhythm, pitch, timbre, register and dynamics. The authors extracted these five criteria from an article by Bernstein & Picker, 1966. They describe a motive as a "brief succession of pitches arranged to produce a rhythmic and tonal pattern sufficiently distinct to allow it to function as an individual, recognizable entity".
Rhythm is described as the most prominent characteristic of a motive, timbre as one of the most easily recognizable characteristics of sounds, and register as likewise easily differentiable. It is recommended to choose pitches of a single motive in the same octave. The optimal number of pitches in a motive is two to four. Then it is possible to create a compound earcon by combining one or more elements with different construction principles. One of these principles is to place two or more elements in succession. Repeating elements eases identification by the user.
Brewster [7] refined these guidelines. He recommends using musical timbres (with multiple harmonics whenever possible) with pitches in the range 125-5000 Hz to have great differences in register between earcons in order to differentiate them, using rhythms as different as possible with different number of events for each earcons, and finally, when playing earcons one after another to use a gap between them so that users can tell where one finishes and the other starts.
Moreover, we can add to this list of earcon parameters another parameter proposed by Kramer in [8]: polyphony. Kramer distinguishes two types of "sonification" (or sound representation): simple and complex sonification. To obtain a "complex" sonification, which would make the sounds more understandable, one of his recommendations is to use polyphony.

3. EXISTING CAR'S HMI EXPERIMENT

3.1. Purpose of the study

The goal of this first study is to examine existing car HMIs, i.e. to know if the sounds really convey the message for which they were designed. Traditionally, these car HMIs are simple earcons. Does a listener well understand a danger sound as such, an oversight sound as such, and an information sound as such? These three functional categories are to be considered in a hierarchical order, according to their level of seriousness: the first one signals a danger, the second announces an oversight without risk, and the third simply informs. According to the methodology developed in [9] and used in [10], an oriented categorization experiment was used to answer this question. We consider the recognition score for each category and a functional representation of the HMI.

3.2. Experimental protocol

The sounds used in this experiment were recorded on various vehicles, using a dummy head. All available sounds were recorded, with the car stopped or moving (some sounds cannot be triggered when not moving). Among all the sound samples, many of them were identical or strongly similar. 39 different sounds were thus retained: 15 danger sounds, 11 oversight and 12 informational. The recorded sounds differed essentially by rhythmic criteria, such as the number of pulses, or the various durations (pulse durations, inter-pulse interval durations, total duration). According to [1], there is a strong link between certain acoustic properties of the signal, like the rhythm, and the perceived urgency.
The 39 sound samples were amplified by a Yamaha P2075 stereo amplifier and presented binaurally with a Sennheiser HD 250 linear II headphone. The listeners were seated in a double-walled IAC sound booth. The experimental sessions were run using a Matlab interface running on an Apple computer.
42 subjects were recruited for this experiment. None of the subjects reported having hearing problems. An instruction text explained the goal of the experiment and gave a description of the 3 various functions. Subjects were asked to classify each sound in the most suitable category.

3.3. Results

The recognition scores for each function were calculated. They showed that the existing sounds are not, in their majority, associated with the function for which they were designed. Only 32% of the subjects recognized sounds of danger as such, 41% of the subjects recognize sounds of oversight as such, and 37% of the subjects recognized sounds of information as such.
A hierarchical cluster analysis was performed on the data to give the perceptual representation of the 39 sound samples. This analysis provided a hierarchical tree that can be optimised by a bootstrap method [11]. Three categories were obtained. In these three categories, corresponding to the sounds of danger, oversight and information, some of the sounds had an acoustic description that matched Patterson's guidelines (in terms of pulse number, pulse duration, and inter-pulse interval duration) and others not. The hypothesis that allows us to explain this result is that some of Patterson's parameters are dominant whereas others are only secondary. Another hypothesis is that the degree of seriousness is probably more an interaction between several parameters. These assumptions will be tested in further experiments.
Another possible explanation could be that "traditional" alarms, i.e. earcons, are not adapted to the task. As we mentioned, among the different sound representation approaches, the choice of one or the other depends on the message to be conveyed.

4. THEORETICAL CONTEXT: SEMIOTICS

4.1. Definition

We propose to introduce a theoretical framework for sound design - semiotics. The first definition of semiotics is the "science of signs". More exactly, it is the "science of the meaning processes". The question is to understand how to build meaning and to establish internal relations between signs.

4.2. Premises of semioacoustics

This term was introduced in 1992 by Blauert ([12]). The principal idea consists of regarding the sound as a sign; "it conveys meaning" ([13]). Moreover, the authors underline the fact that the relationship between signifier (the sound) and signified (the message) does not exist as such, but is assigned by the listener ([14]). This triadic relation between form, content and interpreter defines the semiotic triangle ([13]). The authors recommend considering it in any sound quality study.
They also describe the different types of triadic relation: indexical relation, iconic, and symbolic. The distinction between the three is based on the different relations between form and content (causal relation, similarity or arbitrary).
However, even if these definitions are useful in sound quality analysis, they are not enough to give concrete recommendations for sound design.

4.3. The fundamental about the Peirce's triadic semiotics

4.3.1. The phenomenology

Phenomenology is one of the prerequisites for the understanding of the semiotic introduced by Peirce. He defines the phenomenon as "what is present at the spirit, here and now, that it is about something of reality or not" [15]. The phenomenon's elements can be treated on a hierarchical basis according to three categories: *firstness*, *secondness*, and *thirdness*. The typical ideas of firstness are qualities of feelings, or mere appearances. The idea of secondness encompasses the experience of effort; it is the mode of being that is related to facts. Thirdness is the mode by which the phenomenon is related to significance. If an element belongs to the third category, then it also inevitably belongs to the second and the first, and if it belongs to the second category, it also inevitably belongs to the first. It is the complexity of the message, its abstraction, which is organized into this hierarchy. An element of thirdness is more abstract, more complex than an element of secondness, which is itself a degree of abstraction higher than an element of firstness. This degree of abstraction can also be seen as a degree of learning. Indeed, an element of firstness is understood intuitively, it does not require training (or very little), contrary to an element of thirdness, with a high level of abstraction, which inevitably requires preliminary knowledge necessary to comprehension.

4.3.2. The triadic sign

In addition, Peirce defines the triadic sign as the co-operation of the *Representamen*, the *Object* and *Interpretant*. The Representamen is "what represents": in our case, the sound we heard. The Object is "what is represented": in our case, the reason for the sound. The Interpretant produces the relation between the Representamen and the Object: in our case, the function of the sound, i.e. the interpretation of the sound as a danger, an oversight or an information, for example. The Interpretant shouldn't be confused with the interpreter: the Interpretant is at the same time the social convention, or the collective *habitus*, and the determination of a mind that interiorizes this convention. The social being is differentiated from the particular individual. For example, the interpretation of the horn as a "warning of danger" is a shared cultural convention.

4.3.3. Link between phenomenology and triadic sign

Each one of these elements of the triadic sign can be seen as a phenomenon, and can thus be considered as elements of the three phenomenological categories; each element can be described as an element of firstness, secondness, or thirdness.
We will only focus here on the decomposition of the relation between the Sign and its Object; the two other decompositions (concerning the Representamen and the Interpretant) are not useful in the present paper. According to this decomposition, the relation between sign and object considered at the level of firstness is an iconic one; at the level of secondness it is an indexical one; on the level of thirdness it is a symbolic one.
According to [15], an icon is "a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not". An index is "a sign which refers to the Object that it denotes by virtue of being really

affected by that Object". A symbol is "a sign which refers to the Object that it denotes by virtue of a law, usually an association of general ideas, which operates to cause the Symbol to be interpreted as referring to that Object".
The sound of ruffled paper is an iconic sign if it means that a document is thrown in the basket on a computer interface. The relationship between the sound and the object is obvious; it is just a synthesised real-life sound. Comprehension is immediate. A sound with a progressively increasing pitch indicating the sending of an email is an indexical sign; there is a direct link between the sound and the object it represents, the evolution in time. A musical and abstract sound indicating that the computer is powered-on is a symbolic sign; there is no obvious link between the sound and the object represented. Here, the link between sound and object has to be learned in order to be understood.

5. METHODOLOGY. APPLICATION TO SOUND HMI

The concrete application of the concepts presented above requires firstly a precise redefinition of the functions to be conveyed by the sounds.

5.1. Definition and organization into a hierarchy of the studied HMIs

5.1.1. Criteria of Definition

5.1.1.1 Definition

During the creation of an electronic sound, three steps can be identified. The first is just before the emission of the sound; it raises the question of why the sound is produced. The second specifies what information is conveyed by the sound; what is its function. The third step takes place after the sound's interpretation by the listener and addresses the reaction the sound must induce.
Thus, three criteria can be useful to define the various HMIs:

1. The reason for the sound,
2. The function of the sound,
3. The awaited behaviour of the driver.

5.1.1.2 Values of the criteria

Each one of these criteria can take three different values; the association of the values of these three criteria gives the precise definition of the message that each HMI must convey.
The reason for the sound is either related to the driver or to the vehicle itself. In the first case, the driver can cause the sound voluntarily by an action or in an involuntary way by forgetting to perform an action. In the second case, the sound is caused by a technical failure of the vehicle.
Thus, the reason for the sound can be:

- A technical failure of the vehicle
- An oversight of the driver
- An action by the driver

After listening to the sound, the driver must understand the function of the sound: the sound can alert (to a danger), announce (something) or inform (about something).
The criterion "function of the sound" also takes three values:

- Signal a danger
- Announce
- Inform

Following the sound's emission and its interpretation by the driver, a certain behaviour is expected on the part of listeners (here, the driver): they can react or not. If they react, their reaction can be immediate or delayed.
Thus, the criterion "behaviour expected" can also come in three values:

- Immediate reaction
- expected action (not necessarily immediate)
- No expected reaction.

5.1.2. Organisation into a hierarchy

It is the combination of the values of the criteria which gives the precise definition of the message to be conveyed by the sound. Each of the three criteria can take three values, so 27 messages are possible in theory. For this study, four of these 27 possible crossings are retained.
Table 1 presents the four categories, in a descending hierarchical order according to the level of seriousness.

	Function	Reason for the sound	Awaited behaviour
1	Signal a danger	Oversight of the driver	Immediate reaction
2	Signal a danger	Technical failure of the vehicle	Expected action
3	Announce	Oversight of the driver	Expected action
4	Inform	Action of the driver	No expected action

Table 1: *The four HMI categories*

5.1.3. First step: reduced definition

Before reacting to the sound, the listener has to understand the sound. For this reason, the first two criteria that must be studied are the function and reason for the sound. Once these two criteria are understood, the reaction induced by the sound in the listener can be studied.
Thus the four types of messages studied in the paper are:

- Signal a danger related to an oversight of the driver
- Signal a danger related to a technical failure of the vehicle
- Announce an oversight without risk
- Inform

5.2. Sound design methodology

5.2.1. The semiotic hypothesis

5.2.1.1 Link between semiotics and HMI's classification

From the semiotic point of view, the reason for the sound is the relation between the sign itself and the Object, it can be an icon, an index or a symbol. The less foreseeable the reason for the sound is, the less arbitrary the relation between the sign and the object must be to be comprehensible as soon as possible. The least foreseeable cause is the failure of the vehicle: the relationship between the sign and the object must thus be iconic to be most comprehensible and as soon as possible. With the same reasoning, the cause "oversight of the driver" must be an indexical sign, and the cause "action by the driver", obviously foreseeable (because voluntarily provoked), is a symbolic sign, i.e. it can have the most arbitrary relationship between sign and object.

Reason for the sound	Relation sign / object
Failure of the vehicle	Iconic
Oversight of the driver	Indexical
Action by the driver	Symbolic

Table 2: *Link between semiotics and HMIs*

5.2.1.2 Link between semiotics and the different approaches to sound representation

The various approaches to sound representation, auditory icons or earcons, are various manners of establishing a link between an object and the final sound. We can also define these approaches on a hierarchical scale of abstraction. This scale allows us to go from auditory icons, which truly have a similarity link with the object, to earcons, which have an arbitrary link with the object. The scale on which the various approaches are classified can be associated with the semiotic scale of the various relationships between sign and object. Thus, an iconic sign which represents a resemblance with the object is associated with auditory icons; an indexical sign which represents a direct link with the object is associated with "simple earcons"; a symbolic sign which represents an arbitrary link with the object is associated with "complex earcons". To obtain a "complex" earcon, we use polyphony as recommended by [8], whereas simple earcons are monophonic.

Sound's representation	Relation sign / object
Auditory icons	Iconic
Simple earcons	Indexical
Complex earcons	Symbolic

Table 3: *Link between semiotics and sound representation*

5.2.1.3 Link between HMI and sound representation: the semiotic assumption

Considering the link between semiotics and HMI's classification, and the link between semiotics and the different approaches of sound representation, we can establish a direct link between HMI and the different sound representation approaches. We call this link the semiotic assumption.

Reason for the sound	Sound's representation
Failure of the vehicle	Auditory icons
Oversight of the driver	Simple earcons
Action by the driver	Complex earcons

Table 4: *The semiotic hypothesis*

5.2.2. The acoustic hypothesis

The "acoustic hypothesis" regroups various assumptions that describe the link between the sound's acoustic parameters and the message to be conveyed by this sound. Several authors already studied some of these parameters (cf. §2), and have shown which ones are interesting and which value they can assume to convey a message. However, the results of the first experiment (cf. §3) showed that it would be interesting to cross all these parameters together, in order to study the prevalence of some of them on the one hand, and of possible interactions between these parameters, on the other hand.

5.2.3. Checking of the various hypotheses

In order to check the two important hypotheses, semiotic and acoustic, four experiments can be proposed. We present below the objectives of the four experiments, to make the global process clear and understandable.
Presentation of the four experiments:
Experiment 1: the aim of the first experiment, called "Earcons 1", is to examine which parameters or which configurations of earcon sound design parameters can be associated with each of the four categories. It is a question of determining the intra-categorical similarities and the inter-categorical discontinuities. In addition, Experiment 1 allows us to examine a part of the semiotic hypothesis: a simple earcon is better suited than a complex earcon to convey the concept of an oversight, and a complex earcon is more adapted than a simple earcon to convey the concept of information (see Table 4).
Experiment 2: the aim of the second experiment, called "Earcons 2", is to specify the values of the parameters revealed by Experiment 1.
Experiment 3: the aim of the third experiment, called "Auditory icons", consists of determining a group of auditory icons adapted to convey the concept of failure. The selection of the auditory icons makes use of Barrass' method [6], described in the §2.2 and supplemented with an experimental validation.
Experiment 4: the aim of the fourth experiment, called "Auditory icons vs. Earcons" is to compare the selected auditory icons (Experiment 3) with earcons created following the experiments "Earcons 1" and "Earcons 2". This last experiment tests part of the semiotic hypothesis, which consists of saying that icons (whatever they are) are more adapted than earcons (whatever they are) to convey the concept of technical failure.
The aims of Experiments 3 and 4 consist of testing in two steps the assumption concerning the association of an auditory icon to a "failure" (see Table 4). Indeed, the driver must understand the concept of failure immediately and without ambiguity. The semiotic assumption (concerning the signs' hierarchy) leads us to consider a sign belonging to the firstness category, and thus an iconic relation more than an indexical or symbolic one.

6. EXPERIMENT "EARCONS 1"

6.1. Goal of this study

The goal of this experiment is to understand how to convey the HMI's categories messages using earcons. More precisely, what parameters have an influence on the four concepts: danger related to an oversight of the driver, danger related to a technical failure, oversight without risk and information? These concepts are hierarchically organized, according to the level of seriousness, but it is also necessary to distinguish them without ambiguity and by there, to reveal intercategorical sound discontinuities.
An oriented-categorization experiment (i.e. categories are predefined) will help us to answer this question.

6.2. Experimental protocol

Stimuli

Patterson ([1] quoted in [2]) and Edworthy ([3]) described the acoustic properties and psychoacoustics of an auditory warning. We defined four parameters based on these recommendations. In 1987, Sanders and McCormick (quoted in [2]) proposed guidelines on a more general basis; we note from these guidelines the recommendation to use a modulated signal. We add a parameter resulting from the semiotic assumption to this parameter list: the polyphony, which allows distinguishing simple earcons from complex earcons (cf. §2).

Thus, a set of six parameters is defined. Five of them permit to define a “motive”. The sixth one concerns the motive repetition. The five parameters describing the motive are "signal/silence" - including three others parameters (pulse duration, inter-pulse interval, pulses number) - timbre, pitch, polyphony and modulation.

In order to test the effect of all these parameters and their possible interactions, we use an experimental design. It is impossible to have a complete one, which would correspond to all the possible crossings between all the selected values of all the parameters. We choose here a resolution 4 experimental design, called HGLG26, which precise construction is explained in [16]. This plan is defined by 4 factors in 2 levels and 2 factors in 4 levels resulting in 32 tests. In our case the factors are the various acoustic parameters, their levels correspond to the various values that parameters can take, and the 32 tests are thus the 32 sounds defined by these parameters. A resolution 4 plan allows the analysis of all the factors and a part of the order 2 interactions (i.e. with two factors), those forming packages, we can use only one interaction in each package. A plan of resolution 5 would have allowed the analysis of all the interactions of order 2. These kinds of plans tend to be time consuming because of the rapidly growing of number of samples if one wants to take into consideration the whole set of interaction between parameters.

Table 5 indicates the construction of some of the 32 sounds following the six parameters. Parameters “signal/silence” and “repetition” can take four values each one; the others take two values.

The values of signal/silence are defined by a pulse number (NP), a pulse duration (PD) and an inter-pulse interval duration (IPD). Signal/silence=0,625 corresponds to NP=5, PD=200ms, IPD=400ms; Signal/silence=5 corresponds to NP=5, PD=200ms, IPD=50ms; Signal/silence=200 corresponds to NP=1, PD=200ms, IPD=1ms; Signal/silence=2000 corresponds to NP=1, PD=2000ms, IPD=1ms. These four values allow us to test the Patterson assumptions concerning the pulse number, the pulse duration and the inter-pulses interval duration.

The four values of the parameter “repetition” are: “no”, - i.e. no repetition, 2.5s - i.e. 4 signal repetitions with a 2.5s interval silence, 0.6s - 4 signal repetitions with a 0.6s interval silence, and 2.5+1.2+0.6 S - i.e. an interval between repetition of decreasing duration, 2.5s, then 1.2s and 0.6s.

The two timbres were created using Modalys, a software based on the physical modeling ([17]). “String” and “Plate” describe the basic elements used for the sound creation. These two timbres respect the spectral recommendations of Patterson.

The two different pitches are A1 and A3. We choose two pitches separated by two octaves to be differentiable easily.

The parameter “polyphony” take the value "No", i.e. no polyphony or "yes", which corresponds to a 3 pulses chord.

When the parameter “modulation” takes the value “yes”, it corresponds to: m=0.8 and Fm=60Hz.

	signal/silence	repetition	timbre	pitch	polyphony	modulation
1	0,625	no	String	A1	no	no
10	5	no	Plate	A3	no	no
11	5	2.5s	String	A3	yes	no
21	200	0.6s	String	A3	yes	no
23	200	2.5+1.2+0.6 s	String	A1	yes	yes
29	2000	0.6s	String	A3	no	yes
32	2000	2.5+1.2+0.6 s	Plate	A3	yes	yes

Table 5: experimental design of the sound's parameters: some examples

6.3. Test procedure

As a preliminary, the sounds were equalized in loudness, using a loudness equalization experiment. Indeed, in this study, we want to make sure that all the sounds are heard, whatever the background noise, as proposed by several authors such as which Patterson [1]. That is why this parameter is not considered here. In practice, the auditory warnings will be the appropriate level, according to existing recommendations.

The listening conditions are the same that those described for the principal test. 10 subjects were recruited for this experiment. They were asked to adjust each of the 32 sounds compared to a reference sound (one pulse of 1000ms, based on the String timbre, without polyphony or modulation).

For the principal experiment, the 32 sound samples were amplified by a Yamaha P2075 stereo amplifier and presented binaurally on a Sennheiser HD 250 linear II headphone. The listeners were seated in a double-walled IAC sound booth. The experimental sessions were run using an interface Psiexp running on an Apple computer.

60 subjects were recruited for this experiment and were remunerated. None of the subjects reported having hearing problems. The experimental instruction explained the 4 categories (the definition of each category with examples as well as the hierarchy between categories). They were asked to classify each of the 32 sounds in the most suitable category: signal a danger related to an oversight of the driver, signal a danger related to a technical failure of the vehicle, announce an oversight without risk, inform.

6.4. Results and discussion

A first descriptive analysis of the data was carried out in order to make sure that the subjects had well understood the suggested categories. The correspondence analysis allows us to see the distribution of the subjects responses compared with the various sounds. The parabolic form along the first axis of the graphs obtained highlighted a traditional Guttman effect. In other words, the four categories are ordered: the different levels of seriousness were well understood. We can also notice that the difference between category 4 and the 3 others is very clear; informational messages seem to be considered by the subjects less serious than the three other types of messages between them.

With explanatory and predictive ends, a logistic regression was made. The goal of this analysis is to establish the link between a qualitative variable (the answer given by the subjects) and a whole of qualitative explanatory variables (acoustic parameters that define the sounds). Thus, we could answer the question: which are the parameters (or

interactions between parameters) used by the subjects to differentiate the categories?
In order to give a response, we built several statistical models: the first one analyzes the data according to each parameter separately; then a second type of models gather some parameters (2, 3, 4 and all together); finally other models allows us to gather some parameters with interactions between some of them. Results provided by these models are analyzed according to two criteria: significativity of each parameter and the quality factor of the model.
Seven principal results can be drawn from this first analysis:

- Signal/Silence parameter prevalent on all the others, whatever the studied model
- Repetition parameter also appears as a dominating factor, considered alone or in interaction with Signal/Silence parameter.
- The interaction between Signal/Silence parameter and Repetition one is more significant than Repetition parameter alone
- The interaction between Signal/Silence parameter and Repetition one is the only significant one
- Pitch parameter is really significant only when it is considered in models with other parameters
- Polyphony and Timbre parameters are not very significant
- Modulation parameter is not significant, whatever the model

These results show that Signal/Silence parameter is most significant: as expected, that confirms results of [1] and [3]. Moreover, the importance of Repetition parameter appears especially in its interaction with Signal/Silence parameter.
Although the significativity of Pitch and Timbre parameters is confirmed, they are only secondary compared with parameters Signal/Silence and Repetition. In the same way, the parameter resulting from the semiotic assumption (polyphony) is not very significant. Other analyses will be carried out in order to quantify more precisely the influence of these secondary parameters and to understand how helpful could be the semiotic hypothesis to design guidelines. An additional experience will be necessary in order to understand the no-significativity of Modulation parameter: indeed, it is possible that its influence is not significant compared with the values chosen for the Timbres.

Then, we want to answer a second question: how to define categories according to the values taken by each parameter? To this end, we used a supervised classification method: CART (Classification and Regression Tree). Figure 6 shows these results. Once more, the prevalence of Signal/Silence parameter and its interaction with Repetition is revealed. Table 7 summarizes these results.

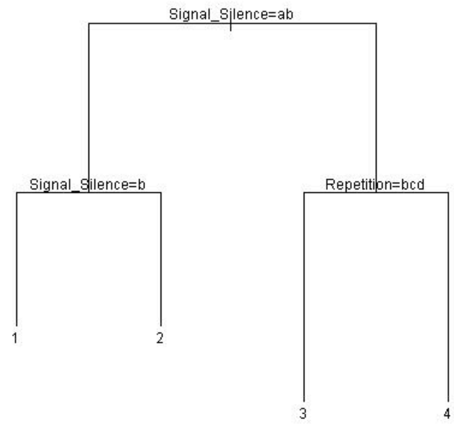

Figure 6: CART Results. Prevalence of Signal/Silence and interaction between Signal/Silence and Repetition

Function	signal a danger related to an oversight of the driver	signal a danger related to a technical failure	announce an oversight without risk	inform
Acustical definition (PD & IPD in ms)	NP=5 PD=200 IPD=50	NP=5 PD=200 IPD=400	NP=1 PD=200 or 2000 Repetition=yes	NP=1 PD=200 or 2000 Repetition =no

Table 7: summary of the CART results

- NP allows us to differentiate categories of danger from the others: a danger sound is characterized by 5 pulses, others sounds by one pulse
- Inside the danger category, an IPD<100ms characterised the most serious sound
- An oversight is characterised by the repetition of a motive, whatever the nature of the repetition
- An informational sound is characterised by one pulse, whatever its length.

7. CONCLUSIONS

Current sounds used in automotive HMIs are not satisfactory. Existing car HMIs experiments indicate that the important concepts of danger, oversight and information are not understood by listeners when listening to these sounds. We propose that a new methodology should be used to design more adequate HMIs. This methodology is based on two important hypotheses: acoustic and semiotics. The acoustic hypothesis regroups various assumptions, which describe the link between the sound's acoustic parameters and the message to be conveyed by this sound. The semiotic hypothesis defines a link between HMI and the different sound representation approaches. Moreover, we have designed experiments intended to test directly these two new hypotheses. First experimental results about the acoustic one are presented; the potential use of our new methodology will be discussed during the conference.

Thus, semiotics and acoustics will be combined, applied to a practical problem, and evaluated experimentally.

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