

CROSS CULTURAL STUDY OF AUDITORY WARNINGS

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ABSTRACT

Auditory human machine interfaces (HMI) are used in cars to provide the driver with information. For security reasons, sound design should respect information urgency scaling. In view of a continuous increase of Renault's sales worldwide, getting a better understanding of urgency perception of sounds is fundamental.

Scientific knowledge is not very widespread about possible cross-cultural differences for auditory alarms, but seems to indicate that people from different countries would agree more on urgency perception of abstract sounds than environmental sounds.

The aim of this study is to specify which acoustical parameters influence urgency perception of sounds, worldwide.

A experiment was conducted in six countries, representative of Renault's customers: France, Germany, Great Britain, Turkey, Korea and the USA.

Sixteen sounds were designed according to different acoustical parameters (frequency, timbre and onset of the pulses), and split into two sets depending on their tempo: one set at a fast tempo, one at a slower tempo.

The results are very similar in the six countries. The auditory HMI are perceived as urgent when the frequency is high, at both tempi. At a fast tempo, a short attack time increases urgency perception.

Abstract auditory HMI following frequency and onset guidelines should be perceived worldwide similarly along an urgency scale. These recommendations have been applied to design auditory HMI to be sounded by the instrument panel of vehicles recently released.

1. INTRODUCTION

1.1. Context

Auditory human machine interfaces (HMI) are produced in cars to provide information or warn the driver about danger. For security reasons, auditory interfaces have to match the requested urgency: an alarm used to warn about a real danger ("put on your mechanical parking brake because the automatic one can not brake the car" for example) has to be perceived as more urgent than a sound used for simple information, ("OK, the car has done what you want, you can remove your finger from the button").

As Renault's sales are expanding in new countries, the comparison of the urgency perception of sounds between countries where Renault's car are driven is vital.

As cars are not developed for a specific country, the aim is to design alarms whose urgency would be perceived similarly worldwide. As some auditory HMI are almost never emitted (for example the one emitted when major damage is detected), learning should not be taken into account.

Since The age variability of drivers is very large, another goal of this study is to check whether the urgency perception of the auditory HMI designed for cars depends on the age of the driver or not.

1.2. Bibliography

Scientific knowledge is limited about possible cross-cultural differences for auditory alarms. The principal results were collected by Osaka and Oldenburg universities between 1988 and 2000. In 1988 ([1]), the study was conducted on 41 both abstract and environmental sounds. 36 Germans and 74 Japanese participated in the experiment (semantic differences about urgency). The results for "dangerous" and "tendency to action" showed that two bell sounds were judged significantly more urgent by Japanese than Germans (the first one with a slow tempo, the other one with a fast tempo). The results were the same for two abstract sounds described as "impulsed sound 1-4kHz" and "impulsed sound 3-4kHz". The other sounds were said to be similar. The authors concluded that the existence of sound characteristics providing a similar urgency perception whatever the country is not certain.

In 1997 ([2]), some sounds from the previous study were used (the two bell sounds for example) and some new abstract sounds were added. A panel of 8 Germans and 8 Japanese evaluated the sounds. As before, the two bell sounds were perceived as more urgent by the Japanese. There was not any difference in responses between both countries for other sounds, essentially abstract sounds. According to the authors, the usage of a bell sound as an urgent alarm in train stations in Japan can explain these results. In Germany, the bell sound seems to have kept its character of a non urgent environmental sound.

In 2000 ([3]), the authors studied only abstract sounds on a group of 20 Japanese, 37 Germans and 24 Americans. The conclusion was similar: the urgency level increases with the frequency and the tempo.

These three studies highlight that some abstract sounds seem to conjure up a similar urgency level in different countries, whereas some environmental sounds loose their primitive

urgency level to attain the urgency level of the alarm they are used for.

Guillaume et al. ([4]) studied in France the urgency perception of abstract alarms created according to Edworthy et al.'s recommendations, that were obtained from experiments conducted in Great Britain ([5]), and showed that Edworthy et al.'s prediction were accurate. Guillaume et al. also tested real alarms recorded from military aircrafts. Some of these alarms did not elicit the predicted pattern of response because of a possible learnt association between an alarm and its meaning. The authors concluded that the design of alarms should take into consideration the acquisition of what they called a "mental representation".

The auditory context where we live allows us to develop our "mental representations" associated to sounds. Music belongs to auditory context, and large differences exist between occidental music on one hand, and Asiatic and oriental music on the other hand. According to Trehub et al. ([6]), both rhythmical and frequency patterns differ. On one hand, occidental music is based on regular rhythm and a restricted number of notes. On the other hand Japanese music is often irregular and Middle Eastern music divides tones into up to 9th tones.

Even if auditory context cannot be restricted to musical context, we draw from Trehub et al.'s article the conclusion that sounds containing rhythm irregularity or multiple tones could refer to "mental representations" that could highly vary from one country to another. From Guillaume et al.'s article, we expect that these different mental representations could result in different urgency perceptions.

At least two studies present contradictory conclusions concerning the influence of age on sound perception. Kawata et al. ([7], reported by Tsuchida in [8]) conducted a study on urgency perception in Japan and found no effect of age, whereas Fish ([9]) explains differences in the reaction to interior car sounds between persons below and above 40 by the reduction of sensitivity to high frequencies with age.

1.3. Goals of the study

The aim of this study is to answer two following questions:

- Does age influence urgency perception?
- Do people from different countries share the same urgency perception, and is the contribution of acoustical parameters to urgency perception similar in different countries?

The answer to these questions will help to design auditory interfaces with a similar urgency level worldwide.

2. METHOD

2.1. Participants: an international project

Six countries representative of Renault consumers were involved in the project: France, Germany, Great Britain, Korea, Turkey and the USA.

Sixty persons in each country participated in the experiment. They were all men, aged between 25 and 55. They were all car drivers, (daily use), and they did not report any hearing problem. The Korean and Turkish population (Renault employees) determined the sex and age range.

The population was split into two age ranges (50% 25-40 and 50% 40-55) to explore the age influence on sound perception.

2.2. Stimuli

This study deals with car alarms. The purpose is to know which sound characteristics have a common urgency level worldwide. As Kuwano et al.'s studies showed that the urgency level of environmental sounds vary in different countries ([2]), environmental sounds were excluded. We decided to test abstract sounds and not auditory icons.

As Trehub et al. highlighted that the use in music of rhythmic irregularity and of multiple tones highly differs from one country to another, we decided that the stimuli of the experiment would contain only one tone and that that their rhythm would be regular.

Eight sounds were designed according to these principles. Our aim was also that the differences between the sounds should be just barely perceptible (not too much).

According to Patterson's description of abstract sound ([10]), alarm design follows several steps. The first consists of creating the elementary pulse, and then the burst, where the pulses are separated by silences. The repetition of the bursts defines the alarm.

Referring to Edworthy and Hellier's studies ([5] and [11]), considered as references for this project, the duration of the pulses was set equally to 200ms. Five pulses were put per burst. Two bursts were separated by a second silence, and the alarm was composed of two bursts.

Once these choices were made, there were still many possibilities to create sounds. Hellier et al. showed ([11]) that tempo is one of the most important parameters of urgency perception. In order to avoid tempo overshadowing the influence of other parameters, two sets of sounds were created: one with a slow tempo (silence between pulses equal to 200ms), one with a faster tempo (silence equal to 50ms). The first set will be called V1, and the second V2. In order to limit the experiment duration to an average of 20 minutes, only three parameters of the burst were modified (onset, frequency and timbre). Two values were explored for each parameter:

- 20 and 175ms for the onset (attack time),
- Lower and higher frequency,
- Harmonic and inharmonic series for the timbre (a series is composed by the fundamental frequency completed by 9 partials, which are integer multiples for the harmonic series, and non integer ones for the inharmonic series).

These values are consistent with those used by Hellier et al ([11]). A pre experiment was conducted in France to be sure that the differences between the pulses were perceptible.

The acoustical parameters and their values will be called respectively factors and modalities later in the document.

The sounds were tested according to a complete experimental design ($2 \times 2 \times 2 = 8$ pulses).

As previous studies have already shown that loudness has a strong effect on urgency perception (cf. Momtahan, [12]), an experiment was conducted in France on ten people to ensure the balancing of the perceived loudness between the different pulses. Amplitude varied between 0.72 and 1.81Pa: amplitude should be larger for pulses with 175ms onset, lower frequency, and harmonic series.

The sounds were named according to the following table :

Sound name	Onset (ms)	Timbre	Frequency
Sound1	20	Harmonic	Lower
Sound2	20	Harmonic	Higher
Sound3	20	Inharmonic	Lower
Sound4	20	Inharmonic	Higher
Sound5	175	Harmonic	Lower
Sound6	175	Harmonic	Higher
Sound7	175	Inharmonic	Lower
Sound8	175	Inharmonic	Higher

Table 1: Description of the 8 pulses

The two sets of sounds were evaluated separately: the predominance of tempo on urgency perception is already known ([11]) and the aim is to evaluate the effect of the other factors. For this reason, the set with a slower tempo was presented first.

2.3. Procedure

Quantitative results of urgency perception were collected to estimate the contribution of the acoustical parameters to urgency.

The subjects were asked to evaluate urgency along a non structured scale, with two limits: “-“ and “+”. During the presentation of the experiment, the subjects were invited to use a wide range on the self-adjusting scale.

For each set, the subject was asked to listen to the sounds as often as he wanted. He could eventually change his evaluation if he wanted. When the subject finished with the first set of sounds (slow tempo), the interface let him move on to the second set.

The sounds were evaluated according to a Latin square presentation to avoid order effect.

2.4. Apparatus

The sound samples were generated with a 44.1-kHz sampling rate under the control of a PC, using Powerpoint software. The sound samples were amplified by a Head Acoustics PVA power voltage amplifier, equalized by a Head Acoustics PEQ playback equalizer and presented binaurally over electrostatic Head Acoustics HAIII headphones. The experimental sessions were run using a Powerpoint interface. The responses were recorded by Excel. All data were collected on the computer memory for further off-line analysis. The experiments took place in a quiet room.

2.5. Experiment description

The experiment was presented to the subjects by a written document. Renault and Eurosyn sent an English document to the experimenter who had to translate it into his language.

The first page of the experiment interface allowed the subject to know how to play a sound and to enter his evaluation on the self-adjusting scale.

The second page presented the first set of sounds: the subject had to listen to the sounds and to evaluate their urgency. The third page presented the second set of sounds.

The interface was simple enough to avoid the use of words and the need for translation.

2.6. Collected data

For every sound and every subject, the position of the cursor on the scale was converted to a number between 0 (lowest limit of the scale) and 100 (highest limit), that will be later called “urgency value”.

3. RESULTS

3.1. Influence of acoustical parameters on urgency perception

A repeated-measure ANOVA (later called ANOVA1) with age group and country as between-subject factors and onset, timbre and frequency as within-subject factors, was performed on the data collected. Participants were treated as random effect variables.

To account for violations of the sphericity assumption, p -values were corrected using the Huynh-Feldt method. $p < 0.05$ was considered to be statistically significant.

The same analysis was carried out on raw data collected at a faster tempo (V2).

ANOVA1 indicated that frequency and timbre had a significant effect at a slower tempo ($F=357.9$, $\epsilon=1$, $p<0.0001$ for frequency, $F=233.1$, $\epsilon=1$, $p<0.0001$ for timbre), whereas onset had none ($F=0.722$, $\epsilon=1$, $p=0.396$). At a faster tempo, frequency and timbre still had a significant effect ($F=282.8$, $\epsilon=1$, $p<0.0001$ for frequency, $F=7.81$, $\epsilon=1$, $p=0.005$ for timbre) and onset became influent ($F=88.95$, $\epsilon=1$, $p<0.0001$): the sounds perceived as urgent were those with a 20ms onset.

The interaction timbre*onset was significant at both tempi ($F=24.73$, $\epsilon=1$, $p<0.0001$ at V1, $F=145.4$, $\epsilon=1$, $p<0.0001$ for V2). The interaction timbre*frequency was also significant at both tempi ($F=46.98$, $\epsilon=1$, $p<0.0001$ at V1, $F=79.61$, $\epsilon=1$, $p<0.0001$ for V2).

Other second-degree interactions were not significant.

We will not discuss here the results of the other interactions within acoustical parameters because the aim of our study is to specify the cross-cultural influence on urgency perception. Marozeau et al.([13]) and Suied ([14]) discussed the interaction between frequency and timbre.

3.2. Influence of age on urgency perception

According to ANOVA1 analysis, age was not a significant factor, at both tempi ($F=0.001$, $\epsilon=1$, $p=0.979$ at V1; $F=0.134$, $\epsilon=1$, $p=0.714$ at V2).

3.3. Influence of country on urgency perception

ANOVA1 showed that country is a significant factor, at both tempi ($F=5.794$, $\epsilon=1$, $p<0.0001$ at V1, $F=2.413$, $\epsilon=1$, $p=0.036$ at V2). Post-hoc analysis (Tukey HSD) was performed to compare the different country conditions (France, Germany, Great Britain, Korea, Turkey, and USA).

At a slower tempo, post-hoc tests (Tukey HSD) revealed significant differences between France and Germany ($p < 0.0001$), Korea ($p < 0.0001$), the USA ($p < 0.0001$), Turkey ($p = 0.0037$) and a small similarity with Great Britain ($p = 0.115$). Figure 1 describes the mean values of urgency rating at a slower tempo, calculated on the sixty subjects in each country.

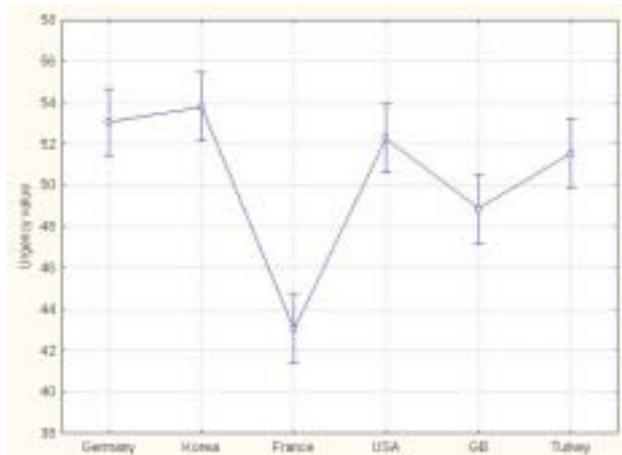


Figure 1. Mean value of the urgency rating at a slower tempo ($V1=200ms$ silence) for the six countries; vertical bars represent the SEM.

At a faster tempo, post-hoc tests (Tukey HSD) revealed significant differences only between France and the USA ($p = 0.021$). Figure 2 describes the mean value of urgency rating at faster tempo, calculated on the sixty subjects in each country. Note that the scale of figure 2 differs from the scale used in figure 1 (different amplitude, minimum and maximum).

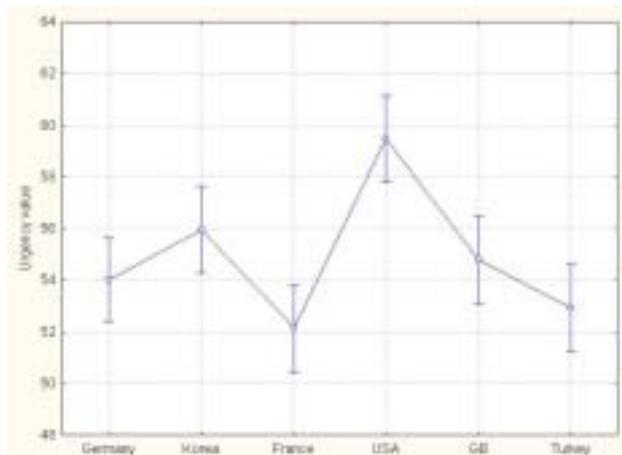


Figure 2. Mean value of the urgency rating at a faster tempo ($V1=50ms$ silence) for the six countries; vertical bars represent the SEM.

Figures 1 and 2 show that French subjects tended to use a lower part of the scale.

The country could be a significant factor because of the different grading by French subjects compared to those in other countries. To check this hypothesis, the data for all countries were centered reduced for both tempi.

A repeated-measure ANOVA (ANOVA2) was performed on these data, with country as a between-subject factor.

For both tempi, we concluded that country was not a significant factor ($F=0.000$, $p=1.000$ in both cases).

3.4. Influence of country on the contribution of acoustical parameters to urgency perception

According to ANOVA1, the interaction frequency*country was also significant at both tempi ($F=2.597$, $\epsilon=1$, $p=0.025$ for V1, $F=2.270$, $\epsilon=1$, $p=0.047$ for V2). Figure 3 shows the comparison of the mean values of urgency rating of the sounds with lower frequency and the sounds with higher frequency for the six countries, at slower tempo. It appeared that sounds with higher frequency were perceived as more urgent, and that the urgency difference was larger in Germany, Korea and France, than in Great Britain and specially the USA.

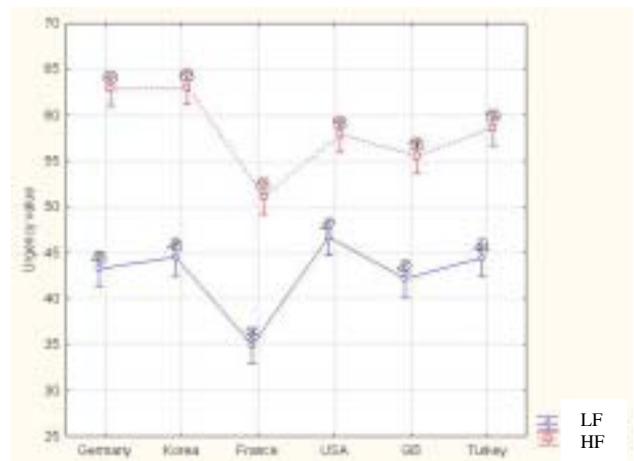


Figure 3. Mean value of the urgency rating for lower frequency sounds (LF) and higher frequency sounds (HF) at a slower tempo ($V1=200ms$ silence) for the six countries; vertical bars represent the SEM.

Figure 4 shows the same values at a faster tempo. Note that the scale of figure 4 differs from the scale used in figure 2 (different amplitude, minimum and maximum). The fact that the frequency*country factor was significant seemed to be here mainly due to the USA where the difference between urgency values at lower and higher frequency was smaller than in other countries.

4. DISCUSSION

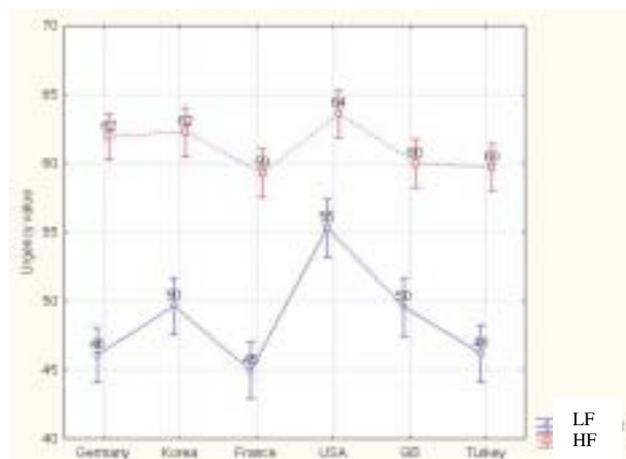


Figure 4. Mean value of the urgency rating for lower frequency sounds (LF) and higher frequency sounds (HF) at a slower tempo ($V2=50\text{ms}$ silence) for the six countries; vertical bars represent the SEM.

We concluded from the repeated-measure ANOVA1 performed on raw data, with age group and country as between-subject factors and onset, timbre and frequency as within-subject factors that timbre and frequency had a significant effect on urgency perception at a slower tempo, and that timbre, frequency and onset influence on urgency perception was significant at a faster tempo.

To further understand the contribution of the different parameters, to compare them and to check if their hierarchy is similar or not in the different countries, a repeated-measure ANOVA (ANOVA3) with onset, timbre and frequency as within-subject factors was performed for every country. The R^2 coefficient was calculated for the significant factors. This coefficient indicates the percentage of total variance accounted for by each parameter, as explained by Marozeau et al. in [13]. Results in five countries are shown in Table 2:

Country	V1=200ms		V2=50ms		
	Timbre	Freq.	Onset	Timbre	Freq.
France	8,34	9,69	2,09	0,16	6,70
GB	9,56	9,73	2,70	0,37	6,18
German y	15,76	13,11	4,11	0,27	8,63
Korea	10,53	18,92	1,81	0,50	7,97
Turkey	6,31	7,53	1,62	0,09	7,34

Table 2: Percentage of total variance (R^2 in %) accounted for by each significant parameter in five countries, for V1 and V2 tempi ($V1=200\text{ms}$ between the pulses, $V2=50\text{ms}$ between the pulses). Freq.: Frequency.

The comparison of the percentage values in the different countries indicated that, at a slower tempo, timbre and frequency had a similar influence on urgency perception (except in Korea where frequency effect is higher). At a faster tempo, frequency had a larger influence than onset in all countries, and timbre had the lowest contribution.

4.1. Influence of acoustical parameters

According to the study, the perception of urgency increases when frequency gets higher, for both slow and fast tempi. This result is similar to those already published, for example by Hellier et al. ([11]) or by Guillaume et al. ([4]).

At a fast tempo, the study shows that the onset has an effect on urgency: Hellier et al. also showed that urgency gets higher when the onset is shortened ([11]).

Interestingly, the onset influences urgency at a fast tempo but not at a slow tempo. The following explanation can be proposed for this result: when the tempo is fast, the temporal characteristics of the pulse should play a role; one of these characteristics is the onset. Its duration is equal to 175ms for one modality versus 20ms for the other one; the difference between both modalities is equal to 155ms, which is close to the inter pulse duration ($200+50=250\text{ms}$). When the tempo is slow, this difference of 155ms becomes too small compared to the inter pulse duration ($200+200=400\text{ms}$) to let this factor influence urgency perception.

4.2. Influence of age and country

Age does not seem to have any influence in any country at any rhythm on the tested sounds. These results are coherent with those reported by Tsuchida ([8]).

To generalize this result to any abstract auditory warning, one should be sure that the frequency of the auditory warning is located in a frequency band where presbycusis does not have an effect. The perception of loudness would indeed be weaker in older subjects, which could reduce urgency perception, according to Momtahan ([12]) who showed that less loud sounds are perceived as less urgent.

The experiment shows that the urgency scaling of the tested abstract sounds is similar in the six countries. This conclusion comes from the analysis on centered reduced data. This data standardization was necessary to correct the effect generated by the use of the lower part of the scale in France. To extend these results, it could be interesting to perform an experiment using a reaction time protocol. With this protocol, one can get an objective measure of urgency perception (see Suied et al., [15]).

From the results about age and country influence, one can draw the conclusion that the urgency perception of abstract sound is shared by all drivers worldwide.

The analysis of the contribution to urgency perception of acoustical parameters shows that there is a remarkable agreement between countries about urgency perception that can be explained by the agreement concerning the effect of acoustical parameters on urgency.

5. CONCLUSIONS

This study confirms results already obtained about the influence of acoustical parameters on urgency, and gives additional insights by specifying how tempo modulates the onset

influence. We confirm that the higher the frequency of the auditory interface, the higher the level of urgency. This result is valid at any rhythm, whereas onset plays a role only at a faster tempo (inter onset interval equal to 250ms): a smaller onset gives a higher urgency level to the sound. At that tempo, the frequency is by far the most influential parameter.

Another specific result of this study is the similar influence of acoustic parameters in the six countries of the study: France, Germany, Great Britain, Turkey and the USA.

In quantitative studies conducted worldwide, the most common result is that different countries do not share same tastes. Preferences are usually evaluated (on taste or smell for example), whereas this study focuses on functionality. It could explain why our conclusions differ from the other studies dedicated to cross-cultural differences.

It can be concluded that abstract auditory HMI following frequency and onset guidelines should be perceived worldwide similarly along an urgency scale. These recommendations have been applied to design auditory HMI that are emitted by the instrument panel of vehicles recently released.

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