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Relation between perceived urgency of alarm signals and psychoacoustic parameters

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ABSTRACT

Many alarm signals can be experienced in ordinary situations (e.g. in a car). Knowing the relation between signal parameters and perceived urgency is important for manufacturers, because the severity of the reported events may be very different. Many studies on this subject have found a correlation between some physical parameters of the signal and the perceived level of urgency. For physical parameters, most of these studies focused on elementary construction parameters such as fundamental frequency, sound level or number or duration of repeated bursts. But it may be asked whether conventional psychoacoustic criteria can be used to evaluate urgency. In this study, this question was addressed by studying the possible links between perceived urgency and two psychoacoustic criteria: sharpness and roughness. To do this, a listening test was conducted using stimuli for which these two parameters could have different levels. 46 people were selected to that experiment. Results showed that both roughness and sharpness could have an influence on the perception of urgency. However, the link between these criteria and perceived urgency can be different from one listener to another one. While 71% of the participants showed a strong positive correlation between only sharpness and perceived urgency, the other ones showed a inverse correlation between these two features and also between roughness and perceived urgency.

1. INTRODUCTION

According to Patterson [1], an alarm signal can be designed from one to three levels. The primary level, called the pulse, is the basic sound signal brick. A pulse is characterized by its pitch, its attack and release times, and its timbre. Several identical or similar pulses can be arranged as a burst according to a rhythmic and possibly a harmonic and dynamic structure. The third level of composition consists of burst repetition. From these different levels of design, several authors have sought to establish links between perceived urgency and the acoustic characteristics of an alarm signal [2-6]. In particular, working from repeated pulses composed of a small number of partials, Hellier and Edworthy [2-4] identified three primordial parameters: the fundamental frequency of the pulse, the tempo of the burst and the number of pulses repetitions. This work has since been

taken up and continued by several authors who considered other acoustic features such as harmonic regularity or duration of silences between pulses. Using simple signals these studies verified Hellier and Edworthy's conclusions [5-6]. Among these more recent works, Marshall *et al.* [6] have also highlighted the existence of a positive link between the perceived urgency of an alarm sound and the annoyance induced by the sound itself. On the basis of this finding, and because audible discomfort is a field of investigation widely studied by psychoacoustics, it may be relevant to know whether indices often used to characterize the level of discomfort induced by a sound [7] can also be used to quantify the level of alert induced by the same sound used in an alert context. To this objective, this paper proposes to study the possible links between perceived urgency and two psychoacoustic criteria: sharpness and roughness.

In the first part of this paper, a short discussion on the criteria of sharpness and roughness is conducted, leading to the methods of calculation of these indices used in the present study. Experimental conditions are then presented, including a description of the test signals, the experimental conditions, the participants' corpus and the requested task. The analysis of the test results is then presented. A search for clusters of listeners according to their responses, an individual analysis for each listeners and a global analysis by cluster of the links between perceived urgency and the two psychoacoustic parameters studied were carried out.

2. SHAPNESS & ROUGHNESS

2.1 Sharpness

Sharpness is a perceptual sensation of the timbre of a sound related to the presence of high frequencies in a sound signal [8]. It is relatively independent of loudness for average listening levels. Zwicker and Fastl [8] have proposed to include it in a general criterion of sensory pleasantness. Sharpness is expressed in *acum* (ac), 1 acum corresponding to the sharpness produced by a narrow band noise centred at 1kHz, one critical band wide and having a level of 60dB. The just noticeable difference seems to be around 3% for sharpness levels of about 1.5 ac [9].

There are several models [9-11] proposed to compute sharpness, one of which has been the subject of a DIN standard [10]. However, these methods are all based on multiplying the specific loudness function by a weighting

function emphasizing the influence of high frequencies. For our study, the model proposed by Zwicker was chosen [7].

2.2 Roughness

Roughness is a perceptual sensation of the timbre of a sound related to the presence of several tonal components of a sound within the same critical band creating a rapid modulation effect detectable by the ear but not as a level variation [12]. Roughness is sometimes addressed as part of an overall sound discomfort [7, 13]. Roughness is expressed in *asper* (as), 1 asper corresponding to the roughness produced by a sound of 1000Hz at 60dB modulated at 70Hz at 100% amplitude.

Compared to sharpness, roughness is a more complex quantity. Today several models exist [12-14] and can lead to very variable results depending on the sounds. None of them is truly consensual. However, because it is clearly described in the literature with a relatively easy computation, we have chosen for this study the Daniel and Weber model [12].

3. EXPERIMENT

The proposed experiment consisted in the alert judgment of 30 sounds by 51 listeners calibrated in level.

3.1 Sounds

Each sound has been constructed from the superposition of sines with varying frequencies and amplitudes. A first set of 7 harmonics with a fundamental frequency of 900Hz is created. The 6 highest components are then randomly modified in level (-20 dB to +20 dB) and frequency (-50% to +50%). A second set of 6 sinusoidal components varying in level (-15 dB to +15 dB) is added from -150Hz to +150 Hz to the 6 previously modified components. Finally, a decrease of the overall level of the components is computed between -15 dB/octave and +15db/octave. The resulting sounds are thus frequency-rich, relatively complex and inharmonic enough to eventually produce roughness. The lowest component is always at 900Hz so that the "fundamental frequency" is fixed to avoid its influence in the evaluation of alertness. The overall signal level has been adjusted for headphone listening at 16.5 sones¹. These sounds were split into 300ms pulses to which a 30ms linear fade-in and a 30ms linear fade-out were applied. Finally, a burst composed of three of these pulses was created by interposing 150ms of silence between each of them. All the sounds were produced in 16 bits PCM format at 44100Hz.

This approach of complex sound construction does not allow to know *a priori* the values of sharpness and roughness. A large set of sounds was produced within which a subset was selected. This selection was made to

¹ The broadcast loudness level was calculated from Zwicker's model taking into account the frequency response function of a Sennheiser HD650 headphone measured on a dummy head.

obtain 5 sounds for a given class of values of sharpness and roughness. Three sharpness classes and two roughness classes were selected so that they could be widely distinguishable to the ear. For sharpness, since the signals have components at 900Hz and above but within a bounded limit, the signal sharpness is greater than 1 ac and is itself bounded. Over the resulting range [1.25; ~3] ac (Fig.1). For Roughness the maximum level obtained was quite below 1 ac, probably because of the type of the signals. Thus, only two categories were considered, one for signals with no or very low audible roughness (<0.07 ac) and the other for signals with an existing and detectable roughness but with the least scattered values as possible (~0.25 ac) (Fig.2). Thus, a total of 30 sounds were selected, 5 for each category of combined sharpness and roughness (Rgh/NoRgh * Shrp1/Shrp2/Shrp3).

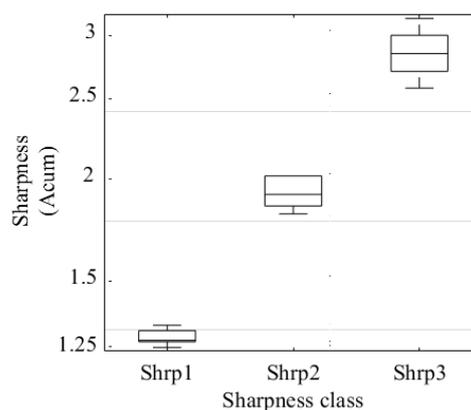


Figure 1. Sharpness (log scale) boxplot of selected signals

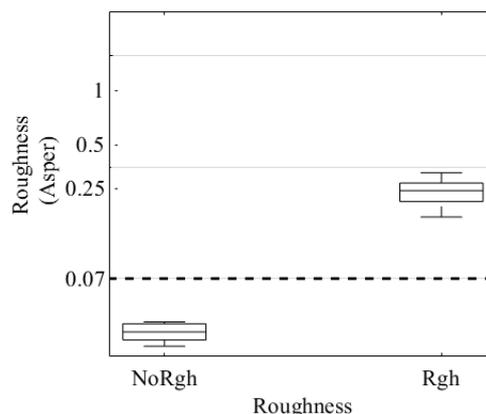


Figure 2. Roughness (log scale) boxplot of selected signals

3.2 Participants and listening conditions

51 retributed participants aged between 20 to 35 were initially selected for this study. Their hearing threshold was lower than 25 dBHL as measured by tonal audiometry between 500 Hz and 8 kHz.

Each of the 30 sounds was broadcasted through a headphone (Sennheiser HD 650) previously calibrated for a listening level of 16.5 sones for each sound. The listeners themselves were placed in a listening booth

isolated from outside noise with a measured residual noise level of 25 dB(A).

3.3 Listening task

The purpose of this study (i.e. study of the alertness level induced by alarm signals) was explained to the participants beforehand. A training phase was carried out on 5 signals in order to familiarize the listeners with the HMI (Human-Machine Interface), the alert rating scale and the type of signals proposed. During the actual test phase, 81 signals were presented in random order, 30 signals for the evaluation of the effect of sharpness and roughness presented here, to which were added 51 signals that were similar but used for a study on other criteria. After each presentation, a question on the evaluation of urgency induced was submitted to the listener: "According to you, which urgency level does this sound induce?". The proposed rating scale was a continuous scale marked with 5 items (not urgent at all, not very urgent, moderately urgent, very urgent, extremely urgent). Each assessment was made by positioning a cursor on this scale, producing a score between 0 (not urgent at all) and 1000 (extremely urgent).

4. RESULTS

4.1 Participant selection

During the listening test, 10 sound signals were subjected to the alert rating twice. This was done in order to evaluate for each subject a response stability score (SSc) measured on these 10 signals. This score is an average of the rating deviations on these 10 sounds ($|Sc_i - Sc_i|$) in relation to the width of the rating scale used by each listener ($Sc_{max} - Sc_{min}$).

$$SSc = 1 - \frac{1}{N} \sum_{i=1}^N \frac{|Sc_i - Sc_i|}{Sc_{max} - Sc_{min}} \quad (1)$$

Participants with a response stability score of less than 0.7 were excluded from the study. 46 auditors (17 females and 29 males) out of the 51 initial ones were thus retained.

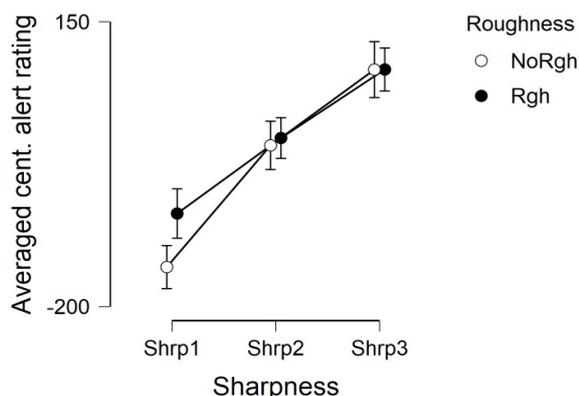


Figure 3. Descriptive plot of two-way repeated-measures ANOVA made over group 1. Error bars represent the 95% confidence interval.

4.2 Participant clustering

The first analysis made was a clustering over 2 clusters by a k-means approach for which the distance metric was the Spearman's rank correlation computed from the centred alert rating. It appears that the first cluster is composed of 33 participants and the second of 13 participants. A higher number of clusters selected for this analysis resulted in too few participants per at least one cluster. For 3 clusters, only group 2 was affected and subdivided in two groups of 2 and 11 participants. An ANOVA over 2 participants would have obviously resulted in an invalid statistical analysis.

4.3 Two-way repeated-measures ANOVA analysis

The complete factorial design of experiment with crossover between factors and the use of the same signals for all participants allows the use of a two-way repeated-measures ANOVA analysis. The results of this separate analysis for the two groups identified above were performed using the JASP software [15] (Tab. 1. to 4.).

For the first group, the analysis shows a large and positive effect of sharpness ($F(2,64) = 109.3$; $p < 0.001$). This factor explains 54% of the total variance of the model (η^2). A post-Hoc test indicates that this effect is significant across all sharpness categories tested and that the mean difference between two sharpness categories is an increase of about 10% in the alert rating. Roughness alone does not appear to be significant, but its mixed effect with sharpness is ($F(2,64) = 4.5$; $p = 0.015$). However, this effect explains less than 2% of the variance. The weakness of this combined effect compared to that of sharpness alone is also visible in Fig. 3.

For the second group (Fig. 4), the analysis shows an effect of sharpness ($F(2,24) = 6.8$; $p = 0.005$) and roughness ($F(1,12) = 7.7$; $p = 0.017$). Each of these psychoacoustics criteria explains respectively 20% and 11% of the model variance. A post-Hoc test indicates that sharpness is, however, only significant on alert judgement between the categories shrp2 and shrp3. The difference in the induced alert rating is then 10%. Both roughness and sharpness have an inverse influence on the alert ratings. Between the signals with and without roughness, the alert rating varies on average by 7%.

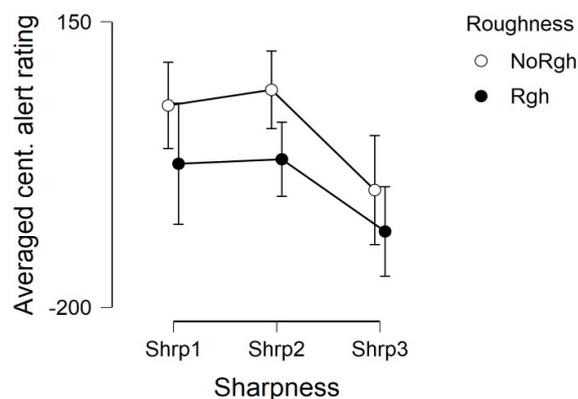


Figure 4. Descriptive plot of two-way repeated-measures ANOVA made over group 2. Error bars represent the 95% confidence interval.

	Sum of Squares	df	Mean Square	F	p	η^2
Sharpness	1.463e +6	2	731377.527	109.311	<.001	0.544
Residual	428210.118	64	6690.783			
Roughness	30922.502	1	30922.502	2.943	0.096	
Residual	336259.325	32	10508.104			
Sharpness * Roughness	41824.847	2	20912.424	4.523	0.015	
Residual	295916.326	64	4623.693			

Note. Type III Sum of Squares

Table 2. Results of the two-way repeated-measures ANOVA analysis on group 1

		95% CI of Mean Difference					
		Mean Difference	Lower	Upper	SE	t	p _{bonf}
Shrp1	Shrp2	-121.094	-160.323	-81.865	15.527	-7.799	<.001
	Shrp3	-209.700	-247.125	-172.275	14.813	-14.156	<.001
Shrp2	Shrp3	-88.606	-119.312	-57.900	12.154	-7.290	<.001

Note. Bonferroni adjusted confidence intervals.

Table 2. Post Hoc comparisons for sharpness on group 1

	Sum of Squares	df	Mean Square	F	p	η^2
Sharpness	173483.172	2	86741.586	6.793	0.005	0.204
Residual	306481.708	24	12770.071			
Roughness	93046.615	1	93046.615	7.696	0.017	0.109
Residual	145076.998	12	12089.750			
Sharpness * Roughness	3892.360	2	1946.180	0.474		
Residual	98538.067	24	4105.753			

Note. Type III Sum of Squares

Table 3. Results of the two-way repeated-measures ANOVA analysis on group 2

		95% CI of Mean Difference					
		Mean Difference	Lower	Upper	SE	t	p _{bonf}
Shrp1	Shrp2	-12.315	-92.489	67.858	28.845	-0.427	1.000
	Shrp3	93.315	-10.477	197.108	37.343	2.499	0.084
Shrp2	Shrp3	105.631	31.027	180.235	26.841	3.935	0.006
NoRgh	Rgh	69.077	14.825	123.328	24.900	2.774	0.017

Note. Bonferroni adjusted confidence intervals.

Table 4. Post Hoc comparisons for sharpness and roughness on group 2

5. DISCUSSION

Group 1, which constitutes 71% of the participants, presents an alert assessment of the proposed signals positively related to the level of sharpness. This effect is visible within the group through the ANOVA results but also at the individual level. The ANOVA also indicates an effect of roughness when crossed with sharpness. However, this effect is very small compared to sharpness alone, 54% of the alert rating can be explained by

sharpness alone, while the interaction between sharpness and roughness represents only 2% of the model variance. At the individual level, the Kendall's ρ calculated for each participant of this group between the evaluation of the alert and the sharpness is significant in 67% of the cases and 100% have a positive correlation. Kendall's ρ calculation between the alert evaluation and roughness is significant in only 9% of cases and positive in 70% of cases.

Thus, it seems that for this majority group, the increase in sharpness is directly related to the urgency conveyed by the signals. A change in sharpness from 1.25 to 2 ac or from 2 to 3 ac results in an average increase of 10% in perceived urgency for this group.

Group 2, which constitutes 29% of the participants, presents more complex and less obvious results. The small size of this group also calls for greater caution in interpreting the results. At the individual level, the correlations by rank between perceived urgency and sharpness or roughness are almost always insignificant (less than 15% of the participants for sharpness and 8% for roughness) and the ANOVA results indicate a rather low variance explained by the two parameters (~31%). According to the ANOVA, for this group roughness is also significant, and for sharpness only the higher level compared to the other two levels leads to a significant change in perceived alertness. It also appears that the links between perceived alertness and the two psychoacoustic criteria studied are reversed in group 2.

6. CONCLUSION

The present paper introduced a study about the possible relationships between the alertness of sound signals designed on the base of sound alarms and the values of two psychoacoustic parameters: sharpness and roughness. A full factorial design experiment was conducted on 46 listeners with 3 distinguishable levels of sharpness and the 2 levels of roughness (without roughness / with roughness).

For the signals studied here, an individual correlation analysis and a two-way repeated measures ANOVA analysis show that sharpness seems to be the most dominant feature on the alert rating for the most part of the subjects (71%) and for those subjects this correlation is positive. Although the majority of subjects appears to follow this rule, a minority but not negligible percentage of subjects (29%) tends to follow a rather inverse rule of alert judgement with respect to sharpness. These later subjects also appear to incorporate signal roughness into their assessment of alertness in an inverse relationship. However, for these subjects, relationships between perceived urgency and the two psychoacoustic criteria studied are less pronounced.

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