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AUDITORY PERCEPTION OF ROAD TRAFFIC NOISE

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ABSTRACT
Our perceptual spatial representation of road traffic noise is revealed in this study by a dissimilarity factor analysis, on a corpus of 14 loudness equalized stimuli, representative of urban and suburban environments. A cluster analysis is carried out too, to gather these sounds into homogeneous classes according to the aroused stress. First dimension reveals a perception in accordance with categorization results, the stimuli being separated into two groups: suburban noises and typical urban sounds. In each group only, listeners perceive physical properties of the signal. Suburban stimuli dissimilarities are based on the number of identified sources. They explain the second factor, but the third dimension which seems to be a spectral one, concerns the other group.

1 - INTRODUCTION
This paper focuses on road traffic noise and tries to reveal our perceptual spatial representation. The most salient dimension, for these sound objects, is the perceptive loudness [1]. It can be correlated with objective measures such as the A-weighted equivalent level, Zwicker's loudness pattern, or better in the case of non stationary stimuli, a percentile loudness [2]. To avoid prominence of noise level, and to investigate further factors, stimuli loudness is equalized [3]. In our study, 14 stimuli (about 12 seconds each) are chosen to represent a large sample of urban and suburban traffic sounds.

Stimulus	Description of the traffic noises
1	Highway with heavy traffic
2	Highway with light traffic, two passbys
3	Highway with heavy traffic, behind a barrier
4	Bus departing
5	Typical urban sounds: truck and motorcycle passbys
6	Continuous sounds of vehicles in a large street
7	Car horns and vehicle accelerations
8	Traffic jam with horns
9	Cross-roads with vehicles stops and departings
10	Expressway but only one passby
11	One vehicle passing in city street
12	Highway, quite a heavy traffic, but with bird songs
13	Highway with cars, trucks and motorcycles
14	Highway, continuous traffic, behind a mound

Table 1: Description of sounds.

2 - EXPERIMENTAL METHOD

Stimuli have been stereo recorded with a pair of microphones in an ORTF configuration and presented through headphones. The perceptive loudness of each sample is equalized, compared to a pink noise reference, by a corpus of 12 subjects. All the signals are filtered by the transfer function of the headphones. The acoustic and psycho-acoustic parameters are calculated on the average signal of the left and right signals.
A dissimilarity experiment was conducted with 21 subjects. They had to rate the dissimilarity between two sounds on a scale from 0 (very similar) to 10 (very dissimilar). After a rating trial of five representative pairs, the 91 pairs of stimuli were presented in random order. The dissimilarities are averaged among listeners. An additive constant is used to transform dissimilarities into Euclidean distances. A Principal Components Analysis is carried out on the scalar product matrix.
Another experiment was conducted with 18 subjects. The categorization test consisted in gathering stimuli into homogeneous classes according to the aroused stress. Each subject was free to form as many groups as he wanted. From the subjects' answers, a dissimilarity matrix is built and a hierarchical cluster analysis is carried out with average linkage option.

3 - RESULTS

The tree structure of cluster analysis reveals two groups of noises. Group G1 is gathering typical urban sounds, group G2 suburban or highway noises. This last group can be separated into two subgroups: group G2-a which gathers the continuous road traffic sounds and group G2-b which gathers the passing of vehicles. Subjects' comments allow to qualify clusters. G1 is the most stressful class, with *harsh, jerky, impulsive* sounds. The stress is also very strong with the G2-a group because of the *continuous background* noise of the traffic. The less stressful scenes are gathered into the G2-b class: the feeling of *breaks* into the traffic noise (between vehicles) makes the sounds more bearable. It is noticeable that groups are formed with noises which sound alike. Even if groups G1 and G2-a are equally stressful, they are not gathered in a same cluster. Subjects gather sounds in respect of their meaning and not only in respect of the aroused stress as proposed.

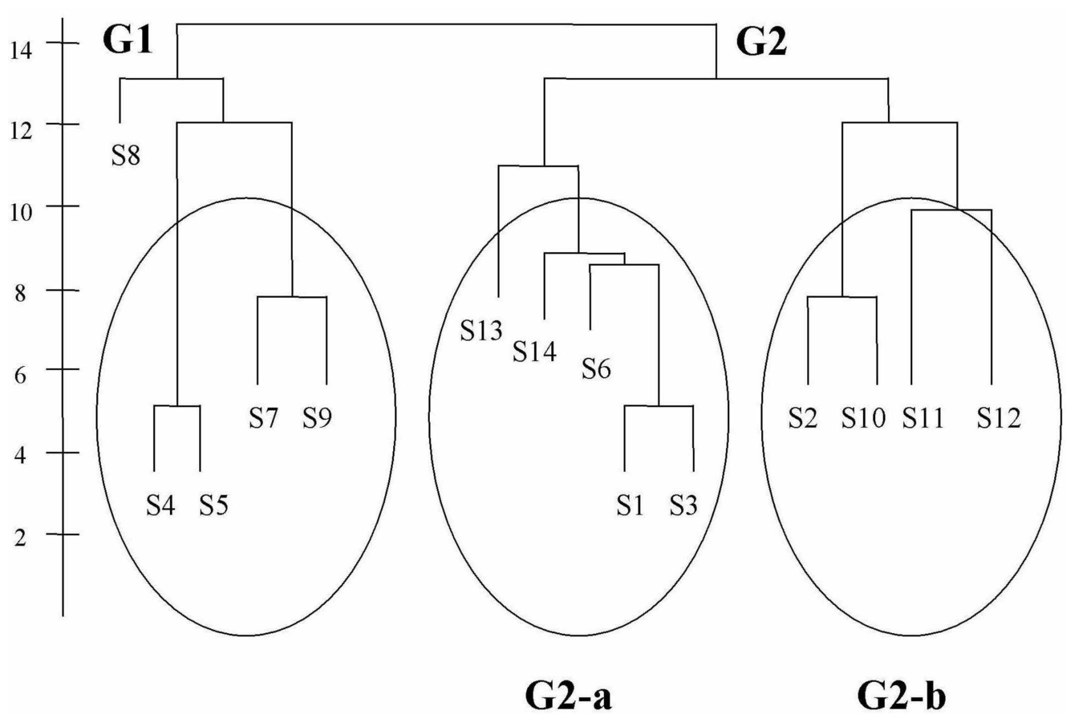

Figure 1: Hierarchical cluster analysis from a corpus of fourteen road traffic noises.

4 - DISCUSSION

The perceptual space of the multidimensional approach proposes three auditory factors which explain respectively 34,6%, 14,3% and 13,1% of the variance. The first dimension seems to discriminate typical urban sounds and high speed road traffic. Though, the stimulus 11 has been judged quite similar to

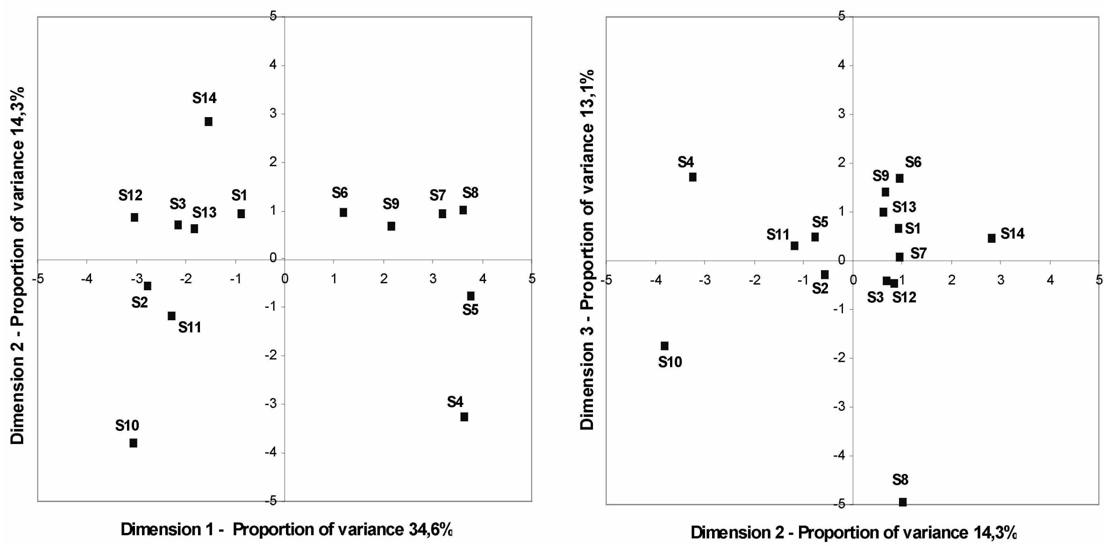

Figure 2: Perceptual space of the 14 sound objects, representative of road traffic environment.

highway noises but was in fact recorded in a city street. Could the smooth character of the stimuli better explains this first factor? Anyway, it seems that this dimension is not continuous as opposed to the multidimensional model. The cluster analysis explains the discrimination between the positive (G1) and negative (G2) coordinates of sounds along this dimension. The correlation coefficient between this factor and these two groups confirms a categoriel perception (R=0,92; p=0,000). Is it due to the choice of stimuli, with a lack of intermediate sounds, or is it due to cognition?

Moreover, listeners can only characterize urban sounds with physical parameters if they have identified the meaning of sounds [4]. It orientates the following analysis of the two other dimensions. If it is not possible to find statistically significant correlation coefficients with all the stimuli coordinates and acoustic parameters, the correlation coefficient will be calculated only with group G1 or G2 which gather more homogeneous stimuli. It is important to listen the auditory variations between stimuli along the dimensions to understand the perceptual space. To predict these variations, it is useful to objectively characterize them. Therefore, physic parameters have been systematically correlated with the three factors.

Oddly, the first dimension is correlated with statistical values L_A10 or N10. It can be explain by the loudness equalization. For the same type of sounds, L_A10 or N10 are quite constant, but the subjects have decreased this statistical measure for stressful stimuli (group G1) to adjust the global perceptive loudness. The meaning of the stimuli influences the perceptive loudness.

	L_A10	N10	L_A90		N90		Standard deviation	
	All	All	All	G2	All	G2	All	G2
Dimension 1	-0.77**	-0,56*	0,38	0,43	0,55*	0,55	-0,61*	-0,62
Dimension 2	-0.19	-0,22	0,68**	0,88**	0,64**	0,85**	-0,64*	-0,94**
Dimension 3	-0,42	-0,37	0,10	0,56	0,04	0,62	-0,21	-0,71*
	Roughness		Fluctuation strength		Sharpness			
	All	G2	All	G2	All	G1	G1 except 8	
Dimension 1	0,42	0,37	0,69**	0,57	0,65	0,37	0,35	
Dimension 2	0,51	0,82**	0,31	0,67**	0,55*	0,45	0,28	
Dimension 3	0,08	0,51	0,04	0,56	-0,28	-0,98**	-0,75	

Table 2: Correlation coefficients between stimuli coordinates and parameters for all stimuli, for group 1 and for group 2; (**) indicates probability $p<0,01$, (*) indicates $p<0,05$.

The second dimension illustrates the number of recognizable sources. Therefore, it is very difficult to find a physical parameter which explains the position in the perceptual space. If the different sources

can be discriminate in the temporal evolution, like in the G2 group, some temporal parameters could work. Standard deviation calculated on the A-weighted equivalent level evolution seems to be a good predictor for this factor. Roughness and Fluctuation strength are also correlated with G2 sounds on the second dimension. This is a consequence of the temporal variation of the stimuli level. But the auditory variation listened between stimuli along this second dimension is not perceived as roughness. The number of identified sources is not easy to count with acoustic measures. Another consequence of the equalization based on percentile loudness L_A10 or N10, is that the background level L_A90 or N90 is correlated to this factor. The more traffic there is, the more background noise there is.
The third dimension is a spectral one. The timbre effect is more perceptible with group G1. But is it only due to the specificity of the stimulus 8 which is sharper than the others? If the stimulus 8 is eliminated from the G1 group, the sharpness is no more significant. As the stimulus 8 was too specific, it is not possible here to conclude clearly that sharpness is a good estimator for this factor.
More investigations, with very careful selection of stimuli, might confirm the temporal and spectral nature of perceptual dimensions. 3-D visual representations could be examined.

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