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Cognitive structure of individuals regarding road traffic noise: considerations about their application in global noise impact assessments

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ABSTRACT

In this paper the evaluation of the cognitive structure of individuals in relation to sources of traffic noise was made by using the semantic differential technique applied to people living in urban areas. Audio recordings of the traffic noise were used as objects. 12 sample sounds were selected, and an analysis in terms of physical and psychoacoustic quantities was made. Subsequently, a principal component analysis was made in order to extract the common factors underlying the 21 pairs of considered adjectives. This analysis was conducted jointly for the 12 samples sounds and, individually, for the sounds due to road traffic, vehicle pass by, rail traffic, and air traffic. Then an association between the adjectives pairs and physical and psychoacoustical aspects was done. In the context of the results of this study, some considerations about the parameters used to quantify the impact of noise in urban areas, and the procedures to globally improve public participation in noise impact assessment are made.

Keywords: Road traffic noise, Evaluation, Environmental acoustics, Perception

1. INTRODUCTION

Charles Osgood [1] developed the semantic differential technique to verbally measure the connotative meaning of certain concepts. This technique involves the use of a set of bipolar scales, in which each item, together with its antonym, correlates with the perceptual dimension or attribute of the phenomenon that is being evaluated. The term “connotative meaning” essentially refers to the emotional components and the evaluative components that are associated with a given concept or object. Osgood even uses the term emotional meaning in order to emphasize the existence of an emotional value attached to the perception. In contrast, the denotative component of a stimulus refers to the characteristics of the object that can be targeted, for example from a physical measurement.

Another theoretical basis of the semantic differential technique is the spatial model, whereby it is assumed that a given concept is located in an area consisting of "n"dimensions or factors. From these dimensions, three of them stand out being taken as universal dimensions of the concept. They are: evaluation, potency and activity, (EPA).

Studies in acoustics reveal other dimensions, usually two or three related to the perception of sound stimulus [2].

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2. EXPERIMENT

Binaural recordings were conducted outdoors in the cities of Lisbon and Oporto. In Lisbon, binaural recordings were taken in areas like the downtown, which are characterized by narrow streets (Ouro Street, Sound 9); an open square with compact traffic (Cais do Sodré, Sound 6); and, in the vicinity of an urban main road crossing the city (2ª circular, near Telheiras, Sound 8). In Oporto, binaural recordings were taken in VCI (urban main road that circles the central area of OPorto and Vila Nova de Gaia), near the Foco area (Sound 4). Each binaural recording was edited in order to eliminate periods with major wind disturbances and unusual traffic sound, like ambulance sirens. Also binaural recordings of public transportation noise were taken. These samples integrate a train passing by (line Lisbon Cascais, Sound 3), old (Sound 5) and modern Lisbon Trams (Sound 11), modern city Bus (Sound 1), Oporto subway (Sound 10), and airplane passing by (Sound 2). Additionally, it was decided to integrate 2 samples of motorcycles passing by (a modern motorcycle with noise reduction device, Sound 12, and an old motorcycle, Sound 7) and a plane passing by.

For each of the 12 sounds, physical and psychoacoustics parameters were calculated, such as the third octave bands noise spectrum, equivalent continuous sound level, A-weighted and linear, the loudness average spectrum and percentile levels (percentiles 5%, 10% and 50%), total loudness, sharpness and roughness. In Table 1, a summary of the key issues relating to each of the 12 sounds are presented.

Table 1 – 12 sounds description (summary)

Sound 1 : City bus passing by	
The third octave sound pressure level spectrum is dominated by low frequency components (up to 250 Hz). In the loudness spectrum the region between the bands of 6 and 10 Bark (between 600 and 1000 Hz), are relevant. Total Loudness, sone 20; Sharpness: 2 acum; Roughness 2.3 asper.	
Sound 2: Airplane passing by	
The third octave sound pressure level spectrum is dominated by low and medium frequencies (up to 1250 Hz) however there are also components with higher intensity in the third octave band of 8000 Hz. This is also visible in the loudness spectrum. Sharpness: 2, 4 acum; Roughness 1.8 asper.	
Sound 3: Train passing by	
The third octave sound pressure level spectrum is dominated by low and medium frequencies, but there are also significant components in the band of 8000 Hz. Sharpness: 2.4 acum; Roughness 1.5 asper.	
Sound 4 – Road traffic noise in VCI	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency bands of 63 and 125 Hz. However, the spectrum of this signal is also rich in the band of 500 Hz. In the loudness spectrum the critical bands of 1 and 6 Bark are significant. Sharpness: 2 acum; Roughness 1.7 asper.	
Sound 5: Old Lisbon Tran passing by	
The third octave sound pressure level spectrum is dominated by components in the frequency range between 31.6 and 1500 Hz bands. Sharpness: 1.6 acum; Roughness 2.7 asper.	
Sound 6: Road traffic noise in Cais do Sodré	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency bands of 31.5 e 63 Hz, and also with the frequency bands between 125 e 1250 Hz. Sharpness: 1.9 acum; Roughness 1.3 asper.	
Sound 7: Old motorcycle passing by	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency bands of 31.5, 63 and 500 Hz. In the loudness spectrum critical bands of 2 and 5 Barks are relevant. Sharpness: 2 acum; Rougness 2 asper.	

Sound 8: Road traffic noise in 2ª circular	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency bands of 63 and 1250 Hz. In the loudness spectrum critical bands of 6 and 11 Bark are relevant. Sharpness: 2 acum; Roughness 1.8 asper.	
Sound 9 : Road traffic noise in Ouro Street	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency range between 63 and 2000 Hz bands. In the loudness spectrum critical bands of 3 Bark and then 6 and 10 Bark are relevant. Sharpness: 2 acum; Roughness 1.7 asper.	
Sound 10: Oporto subway passing by	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency range between 63 and 1000 Hz bands. In the loudness spectrum the critical band of 9 Bark is the most significant. Sharpness: 1.8 acum; Roughness 1.8 asper.	
Sound 11: Modern Lisbon Tran passing by	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency band of 1250 Hz. In the loudness spectrum the critical bands of 2 and 9 Bark is the most significant. Sharpness: 2.4 acum; Roughness 1.6 asper.	
Sound 12: Modern motorcycle with noise reduction device passing by	
In the third octave sound pressure level spectrum, the greatest intensity is associated with the frequency range between 100 and 2000 Hz bands. In the loudness spectrum the critical bands of 1.2 and 6 Bark are the most significant. Sharpness: 2.4 acum; Roughness 1.6 asper.	

There is not a tradition in applying the Semantic Differential technique with sound stimulus in the Portuguese language. So a bibliographic research was made on the words used in others countries. The words have been sorted and their respective context has been analyzed to find more detailed information on their use. Also surveys were made to people (acousticians and non experts) in order to ask them to use their own words for sound samples description. A total of 132 individuals of both sexes participated in this survey (voluntary participation), aged between 20 and 50 years. The sounds were reproduced using loudspeakers and a Power Point presentation. Before starting filling the response sheet, participants had always to perform a pre-test in order to become used with the sounds played and with the method of classification of 21 pairs of adjectives.

3. RESULTS

3.1 Data analysis

The semantic differential profile is presented in Figure 1. From the analysis of this figure, the audio recording corresponding to the city bus passing by (Sound 1), is in the point of view of connotative meaning, essentially classified as uncomfortable, annoying, but also as disharmonious, irritating, noisy, unpleasant, and strong. The corresponding scale for this assessment focuses on the intensity value equal to five. The airplane passing by (Sound 2) is identified by almost all participants, as annoying, loud and unpleasant (intensity level equal to 6.5). However, adjectives like high, uncomfortable, noisy and irritating can also be used to characterize the passage of an airplane. The train passing by (Sound 3) is more identified with the adjectives unpleasant, loud, annoying, uncomfortable, irritating and strong (intensity ranging between five and six). Regarding the audio recording associated with road traffic in the VCI (Sound 4), adjectives like unpleasant, annoying, high, uncomfortable, strong and noisy are used (intensity scale equal to six). For the sound of the old Lisbon tram passing by (Sound 5) the following adjectives were used: unpleasant, annoying, uncomfortable, loud, irritating, rough and strong (intensity scale equal to five).

The sound on the audio recording recorded at the Cais do Sodre Square (Sound 6), is mainly described by adjectives: annoying, noisy, unpleasant, uncomfortable, disharmonious, loud, irritating, strong and rough (intensity level of five). The passage of an old motorcycle (Sound 7), whose exhaust noise is significant, was essentially classified by all participants as irritating, rough and strong (intensity level equal to six). However, adjectives such as annoying, loud, uncomfortable, noisy, disharmonious, were also used to characterize this sound. Regarding the audio recording associated with the road traffic of 2ªCircular (Sound 8), in Lisbon, adjectives like annoying, uncomfortable, noisy, disharmonious, unpleasant, irritating were used.

With regard to the sound recorded at Ouro Street (Sound 9), in Lisbon, it is better identified as unpleasant, loud, annoying, uncomfortable, and strong (intensity level equal to six). However adjectives as noisy, irritating and unacceptable can also be used. The Oporto subway passing by (Sound 10) audio recording was classified as slightly uncomfortable, boring and irritating annoying (intensity level of 4). The audio recording associated with the modern Lisbon Tram passing by (Sound 11), is essentially described by the adjectives unpleasant, loud, annoying, uncomfortable and strong (intensity level close to six). Finally, the sound of a motorcycle with exhaust noise silencer (Sound 12), is essentially characterized by the adjectives dull and muffed (intensity score between 4 and 5).

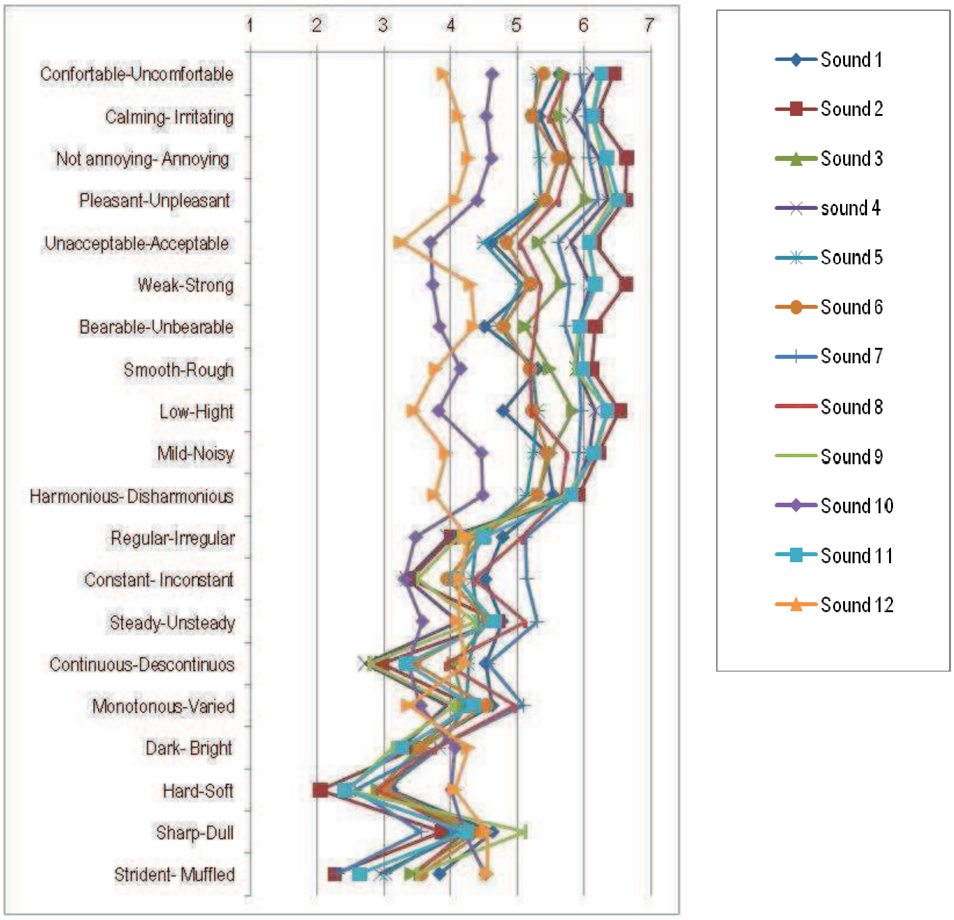

Figure 1 – Semantic differential profile

The airplane passing by is the sound for which it is associated a more depreciative assessment. It is described as the most unpleasant, uncomfortable, annoying, strong and high. Then, it follows the sounds of the Lisbon modern Tram and Old motorcycle passing by and VCI road traffic noise. At the other extreme there are the sounds associated with road traffic at Cais do Sodre, and the sound associated with the Oporto subway. Regarding the temporal structure, the sound considered as the most irregular inconstant and unstable is the sound associated with the old motorcycle passing by.

3.2 Statistical analysis

Principal component analysis was carried out using SPSS v.15 with varimax rotation (with Kaiser normalization) on the semantic differential adjective pairs in order to extract the number of factors present in the data and to identify which descriptors highly affects each factor. Table 2 presents the results of the principal components analysis for all 12 sounds, for which Kaiser-Meyer-Olkin (KMO) value is equal to 0.88, and the Bartlett test is χ2 (190) = 1612.3857, p = 0.000. In this case, four factors were extracted explaining 75% of the variance. The first factor summarizes the meanings contained in various variables among which the adjectives pairs Comfortable-Uncomfortable, Calming- Irritating, Not annoying- Annoying, Pleasant-Unpleasant have highest loadings. This factor indicates a qualitative assessment in terms of assessment and intensity, noting the inclusion of pairs like Low-Height and Weak-Strong in this factor. The Cronbach's alpha equals 0.95 for this factor. The second factor includes aspects mainly related to the scales Regular-Irregular, Constant-Inconstant, Steady-Unsteady, and Continuous-Discontinuous. A value of Cronbach alpha of 0.89 was found. The third factor, comparatively smaller than the previous ones, is mostly represented by the scales Dark-Bright and Hard-Soft (in this case the Cronbach alpha is equal to 0.79). Finally, the fourth factor is characterized by adjectives Sharp-Dull and Strident- Muffled, with a Cronbach alpha equal to 0.3.

The following names seem more appropriate for the appointment of these four factors: Qualitative Assessment (factor 1), Temporal Stability (factor 2), Power (factor 3) and Timbre (factor 4).). For this analysis the pair Exciting-Boring was taken out.

Table 2 – Component Matrix(a): 12 sounds average

Average (12 sounds)	Component			
	1	2	3	4
Comfortable-Uncomfortable	0.93			
Calming- Irritating	0.92			
Not annoying- Annoying	0.90			
Pleasant-Unpleasant	0.90			
Acceptable-Unacceptable	0.81	0.27		
Weak-Strong	0.80	0.25		
Bearable-Unbearable	0.80	0.20		
Smooth-Rough	0.80		-0.27	
Low-High	0.79			
Mild-Noisy	0.78			
Harmonious- Disharmonious	0.73		-0.23	
Regular-Irregular	0.08	0.91		
Constant- Inconstant	0.11	0.90		
Steady-Unsteady	0.15	0.86		
Continuous-Discontinues	0.06	0.79	0.20	
Monotonous-Varied	0.03	0.74		-0.37
Dark- Bright	-0.17		0.91	
Hard-Soft	-0.53		0.72	
Sharp-Dull	0.10			0.85
Strident- Muffled	-0.47			0.58

As regards the breakdown of sounds related to road traffic noise, for those audio recordings that have had a duration exceeding 30 seconds (Sounds 4, 6, 8 and 9), the same factor structure that explains 75% of the variance was found. In this case, the KMO value is equal to 0.88, and the Bartlett test χ2 (190) = 1517.3312, p = 0.000. The first factor summarizes the meanings in various scales, including the pairs: Not annoying- Annoying, Calming- Irritating, Comfortable-Uncomfortable, Unacceptable-Acceptable, and the highest loadings. As in the previous case, it is interesting to note that this factor enables a qualitative evaluation in terms of assessment and intensity. For this factor the value of Cronbach's alpha equals 0.93. The second factor includes aspects mainly related to the scales Regular-Irregular, Constant- Inconstant, Stable-Unstable, Continuous-Discontinuous, which is linked to an alpha Cronbach of 0.89. The third factor (Cronbach's alpha equal to 0.75), comparatively smaller than previous ones, is mostly represented by the scales Dark-Bright and Hard-Soft. Finally, the fourth factor is characterized by the adjectives Sharp-Dull and Strident- Muffled, with a Cronbach alpha equal to 0.3. As in the previous case, the factors were named as: Qualitative Assessment (factor 1), Temporal Stability (factor 2), Power (factor 3) and Timbre (factor 4). In this analysis, four factors extracted explain 75% of the variance.

Regarding the breakdown of sounds related to the vehicles passing by (Sounds 1,5,7,11,12), it appears that the relevant factor structure is slightly different, increasing their number by 1, which may suggest a slight difference in the evaluation of emerging sounds, from those sounds related to the background noise. In this case, KMO has a value of 0.88, while for the Bartlett test is $\chi 2$ (190) = 1447.7392, p = 0.000. These 5 factors extracted explain about 74% of the variance. The first factor (Cronbach's alpha equals 0.89) summarizes the meanings in different scales, from which the pairs Not annoying-Annoying, Comfortable-Uncomfortable, Pleasant-Unpleasant have the highest loadings. Again, this factor indicates a qualitative evaluation in terms of assessment and intensity. The second factor (Cronbach alpha of 0.8) includes aspects mainly related to the scales Constant-Inconstant, Regular-Irregular, Continuous-Discontinuous. The third factor (Cronbach's alpha equals 0.89), comparatively smaller than the previous ones, is mostly represented by the adjectives pairs Muffled-Strident and Monotonous-Varied. The last two factors are represented by one pair only, namely the factor of 4 by the pair Dark-Bright, and the factor 5 by the pair Sharp-Dull. The following names seem appropriate for these five factors: Qualitative Assessment (factor 1), Temporal Stability (factor 2), Variation (factor 3), Power (factor 4) and Timbre (factor 5).

3.3 Association between physical and perception data

Table 3 presents all the significant nonparametric associations between the pairs of adjectives (qualitative appraisal) and the corresponding physical and psychoacoustics parameters of the audio recordings associated with the 12 sounds. This nonparametric association was evaluated in terms of bivariate correlation coefficients, namely the Spearman Rho. This coefficient measures the correlation between qualitative variables (ordinal and nominal), and provides information about the intensity and direction of the relationship, ranging between -1 and 1.

Table 3 – Significative associations (p<0,01) between adjectives and physical parameters

Pairs of adjectives	Physical parameters	Psychoacoustics parameters
Acceptable-Unacceptable	SPL_A (ρ_S=0,92); SPLC (ρ_S=0,82);	S(ρ_S=0,71); LN (ρ_S=0,94);LN_5 (ρ_S=0,94); LN_{10} (ρ_S=0,94); LN_{50} (ρ_S=0,89);
Pleasant- Unpleasant	SPL_L (ρ_S=0,8); SPL_A(ρ_S=0,89); SPL_C (ρ_S=0,87)	LN (ρ_S=0,89);LN_5 (ρ_S=0,82); LN_{10} (ρ_S=0,86); LN_{50} (ρ_S=0,85);
Calming- Irritating	SPL_A(ρ_S=0,77); SPL_C (ρ_S=0,72)	LN (ρ_S=0,8);LN_5 (ρ_S=0,8); LN_{10} (ρ_S=0,86); LN_{50} (ρ_S=0,75);
Not annoying-Annoying	SPL_A(ρ_S=0,75); SPL_C (ρ_S=0,78)	LN (ρ_S=0,75);LN_5 (ρ_S=0,78); LN_{10} (ρ_S=0,78)
Bearable-Unbearable	SPL_A(ρ_S=0,75); SPL_L(ρ_S=0,73);SPL_A(ρ_S=0,92);SPL_C (ρ_S=0,86)	LN (ρ_S=0,94); LN_5(ρ_S=0,91); LN_{10} (ρ_S=0,94); LN_{50} (ρ_S=0,87)

Mild-Noisy	$SPL_A(\rho_S=0,7)$	LN_5 ($\rho_S=0,78$); LN_{10} ($\rho_S=0,78$);
Weak-Strong	$SPL_A(\rho_S=0,91)$; SPL_C ($\rho_S=0,81$)	$S(\rho_S=0,71)$; LN ($\rho_S=0,93$);LN_5 ($\rho_S=0,94$); LN_{10} ($\rho_S=0,94$); LN_{10} ($\rho_S=0,94$); LN_{50} ($\rho_S=0,89$);
Low - Height	$SPL_L(\rho_S=0,8)$; $SPL_A(\rho_S=0,96)$; SPL_C ($\rho_S=0,87$)	$S(\rho_S=0,78)$; LN ($\rho_S=0,93$);LN_5 ($\rho_S=0,96$); LN_{10} ($\rho_S=0,96$); LN_{50} ($\rho_S=0,96$);
Muffled- Strident	$SPL_L(\rho_S=-0,71)$; $SPL_A(\rho_S=-0,87)$; SPL_C ($\rho_S=-0,82$)	$LN(\rho_S=-0,87)$; LN_5 ($\rho_S=-0,79$); LN_{10} ($\rho_S=-0,83$); LN_{50} ($\rho_S=-0,81$);
Smooth-Rough	$SPL_A(\rho_S=0,91)$; SPL_C ($\rho_S=0,85$); $SPL_L(\rho_S=0,75)$	LN ($\rho_S=0,91$);LN_5 ($\rho_S=0,91$); LN_{10} ($\rho_S=0,91$); LN_{50} ($\rho_S=0,91$);
Hard-Soft	$SPL_L(\rho_S=-0,77)$; $SPL_A(\rho_S=-0,87)$; SPL_C ($\rho_S=-0,88$)	LN ($\rho_S=-0,87$);LN_{10} ($\rho_S=-0,91$); LN_{50} ($\rho_S=-0,83$);

3.4 Final remarks and conclusions

One of the sounds classified in a more depreciative way was the recording from the old motorcycle (Sound 7), corresponding to a passing by of one motorcycle with significant exhaust noise. From an opposite side, the less depreciative sound is the one related to the modern motorcycle with a noise reduction device (Sound 12).These opposite result suggests the importance of awareness campaigns and noise monitoring of vehicles. For the sounds associated with recordings of road traffic noise with a duration exceeding 30 seconds (Sounds 4,6,8 and 9), it is interesting to notice that the recordings associated with roads that crosses a compact urbanization (with buildings on both sides), are less appreciated. This is the case of Ouro Street (Sound 9), whose classification is comparable to road traffic from VCI (also with a compact urbanization structure nearby).

Regarding the principal component analysis carry out, it is interesting to notice that the second factor which emerges, is a factor related to the temporal structure of the signal. This happens when an analysis of all 12 sounds is done, as well as when carrying out a breakdown of sounds corresponding to road traffic noise. It appears that the sounds corresponding to just one passing by of vehicles are generally rated as more irregular, more inconstant and unstable. There is also an additional factor in the principal component analysis, which is appointed by variation in this study. In this context, it is possible to suggest a different mode of evaluation between sounds with a more solid structure (like background noise), from sounds related with isolated acoustic events.

Regarding the association between the perceptual (set of pairs of adjectives) and physical and psycho acoustical data, it was found that the factor qualitative assessment showed largest number of significant associations. Especially with the parameters loudness, percentiles loudness, and the equivalent continuous sound level A-weighted (C-weighted in some cases). This is the cases of the pairs: Acceptable-Unacceptable, Bearable-Unbearable, Mild-Noisy, Weak-Strong, Low-High, Smooth-Rough.

For the factor Temporal structure, there were no significant associations found between pairs of adjectives used, and the physical and psychoacoustic measures. However, for the potency factor (which is associated with the pair Hard-Soft), there is a strong negative association, because whenever "softer“ the sound is, the lower the intensity of the physical and psychoacoustics are, especially in terms of equivalent continuous sound level, A weighted, and loudness.

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