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RELATIONSHIP BETWEEN PSYCHOACOUSTIC DESCRIPTORS AND ANNOYANCE: REGARDING SOUNDS IN HOME ENVIRONMENTS

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ABSTRACT
In the field of product sound quality a huge number of psychoacoustic and physical descriptors are used. This study focuses on annoyance assessments of sounds in the home environment, namely from large household appliances, small electrical appliances and exterior background sounds. The objective is to define a relationship between psychoacoustic descriptors and annoyance. All sounds were binaurally recorded and reproduced by headphones. A total of 22 subjects participated in the listening test. The aim of the present study is to combine the results from a previous investigation where 43 sound stimuli were compared in three different sessions. The relationship between psychoacoustic descriptors and subjective assessments of psychoacoustic annoyance were evaluated by multivariate statistics. The final result is an index describing annoyance in terms of psychoacoustic descriptors.

1 - INTRODUCTION
There are numerous of variables that contribute to noise annoyance e.g., characteristics of the sound, the products' operating condition, individual personalities and mood. To reduce the number of interfering variables it is useful to use binaural technology [1]. Binaural recording makes it possible to reproduce sound events as they originally occurred. This allows direct comparison between different types of acoustic signals in a neutral environment. In such test situations it is possible to establish a relationship between psychoacoustic annoyance and various psychoacoustic descriptors [2]. A model describing this relationship is useful both for consumers and manufacturers since better methods for quantification of the risk for noise annoyance will justify the cost of improving sound quality.
Assessment of annoyance by physical measurement is a topic of current interest. Standardized measurement procedures based on A-weighted sound pressure level are not always appropriate for describing product sound quality. Averaging in frequency, time and/or spatial domains often hides important information in the measurement. Research in the field of Psychoacoustics [3] has shown that several hearing sensations need to be measured to obtain an accurate picture. Those most commonly used are: *Loudness*, *Sharpness*, *Roughness*, *Fluctuation strength* and *Tonality*. Combinations of these descriptors are necessary when describing for example, psychoacoustic annoyance [2] and sensory pleasantness [3,4].
The purpose of this study is to describe noise annoyance here represented by household sounds using psychoacoustic descriptors. The present study uses 9 sound stimuli based on a combination of the worst, medium and least annoying sounds from three groups of sound previously investigated [5]. Group one is made up of sounds from large household appliances (white wares). Group two uses sounds from small household electrical appliances. Group three is made up of sounds from diesel buses heard inside the house. The objective is to show in what context different psychoacoustic descriptors are useful for quantifying noise annoyance in a real environment. A total of 22 subjects participated in the listening test. Assessments of annoyance were made on a seven-point scale, using the method of successive intervals [6]. Modeling of the relationships between annoyance judgement, and psychoacoustic descriptors were based on Partial Least Squares regression [7].

2 - THEORETICAL BACKGROUND

There are numerous measures available, both physical and subjective, to quantify psychoacoustic annoyance and product sound quality. Within the group of physical measures another subdivision between psychoacoustic and standardized physical descriptors can be made. Standardized physical measures are e.g., Sound pressure level (A, B, C or D weighted), L_{eq}, Third-octave-band spectrum and different statistical treatments of these signals. Psychoacoustic descriptors also rely on the measurement of sound pressure variations. The difference is that theses signals are processed using aurally adequate spectral analysis considering masking properties, and time and frequency resolution of human hearing [8]. This study focuses on the descriptors defined in Table 1.

Descriptor	(unit)	Abbreviation	Comment
A-weighted sound pressure level.	(dB)	dBA	Both right (r) and left (l) ears signal was measured. The highest value of left and right ear is indicated by max. Exponential functions of psychoacoustic descriptors are indicated by exp. Squared terms of the descriptors are indicated by ^2.
C- weighted	(dB)	dBC	
Articulation index	(%)	AI	
Loudness [3]	(sone)	N	
Sharpness [9]	(acum)	S	
Roughness [10]	(asper)	R	
Fluctuation strength [3]	(vacil)	F	
Tonality [4]		K	

Table 1: Psychoacoustic and physical descriptors considered for rating the annoyance.

Sensory pleasantness is one example where loudness, sharpness, roughness and tonality are used in combination. Annoyance is not, however, inversely proportional to sensory pleasantness since tonal components in noise are regarded as annoying. In aspect of sound quality the relationship to psychoacoustic descriptors often needs to be defined for a specific case. One useful relationship is the model of psychoacoustic annoyance [2] based on a function of loudness (5^{th} percentile), sharpness, roughness, and fluctuation strength.

3 - METHODS AND PROCEDURE

Subjects. The listening test was administered to 22 people; 12 persons had previous experience with the test procedure. There were an equal number of male and female subjects. The average age was 35.1 years (standard deviation = 11.0 years). All subjects had normal hearing.

Experimental design. A listening test was performed in order to refine the results of a previous study [5] and to allow a comparison of annoyance judgements from three groups of sound stimuli. The sound stimuli were recorded with an artificial head (Head Acoustics HMS III). The first and second groups of sounds (16 in each) were recorded inside a modern house (built 1998) with a low exterior background level (<30dBA). The third group comprised 15 sounds from idling busses recorded inside a room 20 m from a bus stop. The third group of sound stimuli was, however, re-designed by removing sounds louder than commonly found in a home environment.

The first group of sounds was generated by large household appliances like: 1) Ventilation system, **Ve**, 2) Heating system, **Co**, 3) Refrigerator, **Rf**, 4) Freezer, **Fr**, 5) Dishwasher, **Dw** and, 6) Washing machine **Wa**. The second group comprised sounds from small electrical household appliances: 1) Kitchen fan **Kf**, 2) Microwave oven, **Mw**, 3) Electric whisk **Ew**, 4) Vacuum cleaner **Vc**, 5) Shaver **Sh**, 6) Hair dryer **Hd** and 7) Personal computer, **Pc**. The third group of sounds was as described in the previous paragraph. The position of the dummy head as well as the vehicle's position at the bus stop varied for each sound stimuli. Sometimes a window was slightly open. Detailed descriptions of all sound stimuli are found in [5].

Listening test. The listening test comprised 9 sound stimuli (Table 2). Sounds selected from each group were those judged to be the worst, medium and least annoying. The listening test was carried out in an anechoic room. Sounds were presented through carefully calibrated and diffuse field equalized electrostatic headphones (Head Acoustics HA II). Prior to each test oral and written instruction was given. The test subject chose stimuli (Table 2) by mouse clicking one of 9 boxes displayed on a computer screen. To minimize possible bias the subject followed a predefined randomized order in the first trial. Each sound was a 7 s long recording continuously repeated as long as the subject did not choose another sound. Each sound was judged using a 7-point scale with linearly spaced markings ranging from 1 to 7. The two extremes were "Not at all annoying" and "Very much annoying". The middle interval was "moderately annoying". Each subject also made judgements on perceived loudness, sharpness, roughness, fluctuation strength and tonality. When judgements of all sounds were done, subjects were allowed to compare stimuli and modify their judgements.

Test no	Group	Index	description
1	1 min	W1	Ve on, remaining sources off.
2	1 median	W6	Fr, Ve and Co on, remaining sources off.
3	1 max	W12	Dw during dish washing, Ve, Co, Rf and Fr on.
4	2 min	H15	Pc, Ve, Co, Rf and Fr on.
5	2 median	H12	Sh, Ve, Co, Rf and Fr on.
6	2 max	H10	Vc high, Ve and Co on.
7	3 min	D12	Conf. room. Corner. 2 idling buses. Window closed
8	3 median	D11	Conf. room. Back pos. 1 idling bus. Window opened.
9	3 max	D13	Conf. room. Window pos. 1 idling bus. Window opened

Table 2: Sound stimuli assessed in the present study.

Analysis. A non-linear transformation of the results from the new experiment facilitated comparison of annoyance judgements from the previous study. The transformation was based on a second order polynominon. Annoyance judgements were scaled using the method of successive intervals [8]. Psychoacoustic and physical descriptors were calculated on the basis of diffuse field equalized signals from the left and right ears of the dummy head. All psychoacoustic and physical descriptors were calculated using the software ArtemiS/v.1.08 (Head Acoustics). All psychoacoustic descriptors and standardized acoustic measures were defined using an extended matrix. The 43 sound stimuli were represented by rows. Scaled annoyance values, and different psychoacoustic/physical measures as columns. To investigate the interrelationships between annoyance judgements and descriptors, data was evaluated by Partial least squares regression (PLS) [7], [11].

4 - RESULTS AND DISCUSSION

The assessed sound stimuli covered a dynamic range from 31 to 71 dB(A). The sounds represented three different product categories. The aim was to merge the annoyance judgements of these groups. The results of annoyance judgements are presented as median, quartile and scaled values in Figure 1. It shows that the median of annoyance assessments varies from 1.44 (W1) to 6.86 (H10). The inter quartile range varies from 0.63 to 2.3. The greatest variations in subjective assessment were found in W6 and H15.

Scaled annoyance judgements varied from 0.16 to 4.68, where values below 0.72 correspond to "not at all annoying", and values greater than 4.78 correspond to "very much annoying". The midpoint is equal to 2.43. The results were used to transform all judgements from the previous study. Figure 2 shows the transformed annoyance judgements compared to the original values. The greatest differences can be seen in groups 1 and 2.

Within group 1, the dishwasher (W9−W12) generates the most annoying sound, especially when combined with the background noise. Ventilation (W1) is the least annoying sound. An interesting phenomenon is that annoyance reduces when the freezer sound (W7, tonal) is masked by the refrigerator, ventilation and compressor (W8). Within Group 2 the vacuum cleaner (H9 & H10) and the electric whisk (H7 & H8) generated the most annoying sounds. The least annoying sound is from the computer combined with background noise (H15). The bus sounds (group 3, D) were rated as less than moderately

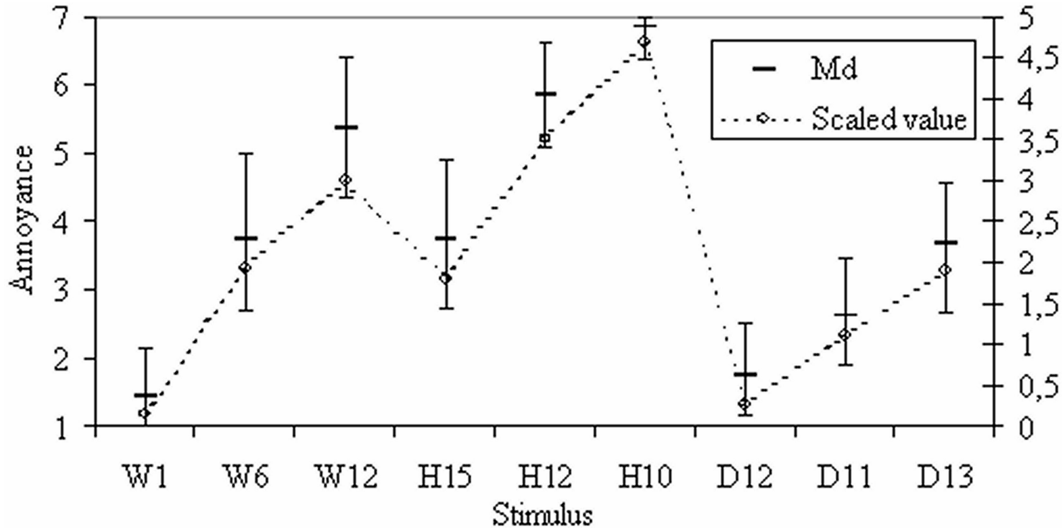


Figure 1: Medians (Md), quartile ranges, and scaled values of annoyance (right y-axis).

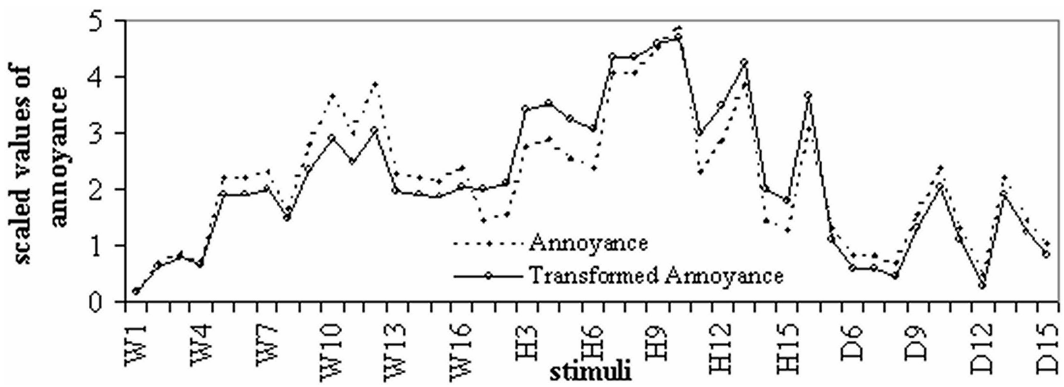


Figure 2: Transformed values of annoyance in comparison to the previous result [5].

annoying; especially when the window was closed. When the window was open annoyance increased (D10 and D13).

Partial least squares regression (PLS) was carried out on the data matrix X and annoyance vector y. X consists of 43 rows (sound stimuli) and 32 columns (descriptors and different combinations of descriptors). Vector y is comprised of 43 scaled annoyance values. Prior to analysis each variable was scaled to unit variance and zero mean value. After modeling all variables it was found that the differences between max, average and exponential functions of the psychoacoustic descriptors were small. Squared terms of the psychoacoustic descriptors only increased explained variability in case of tonality (K).

The initial model was reduced to include 9 variables. The new PLS regression resulted in 2 statistically significant principal components, which explained 94% of the variance in annoyance. Figure 3 shows the score and loading values for component 1 (88.5%) and component 2 (5.5%). The high loading values of loudness and roughness closely coincide with the first component axis (x-axis). This indicates that annoyance results from loud and rough sound characteristics. Score values (Figure 3b) shows that the first component is mainly caused by loud electrical household appliances e.g., vacuum cleaner (H9, H10). The first component also indicates a relationship between loudness and A-weighted sound pressure level (L_A). L_A, however, is the single descriptor that gives the best overall description of annoyance since it also has a relatively high loading value in the second dimension.

The second component (y-axis in figures 3a and 3b) describes the differences between sounds in terms of tonality and fluctuation strength. Sound stimuli having high positive score values on the second component axis (Figure 3b) have a tonal and sharp character e.g., W7 and W5, since sharpness and tonality have positive loading values. The sounds from idling buses (D6 and D15) are examples of sounds with dull character.

The PLS-model was refined and ultimately two different regression models were established. The first

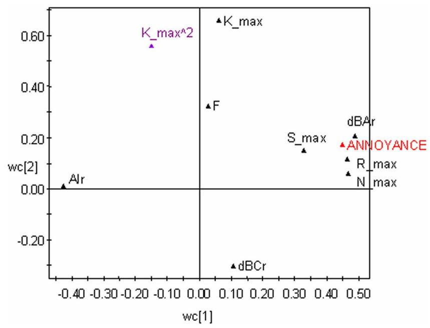


Figure 3(a): Loading values (wc) of component 1 & 2.

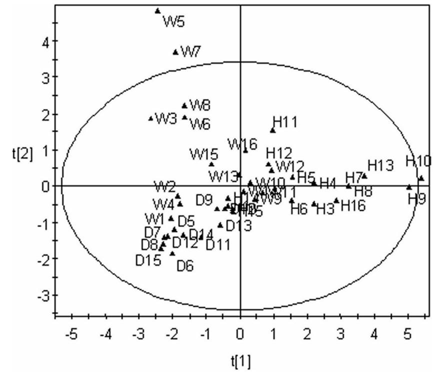
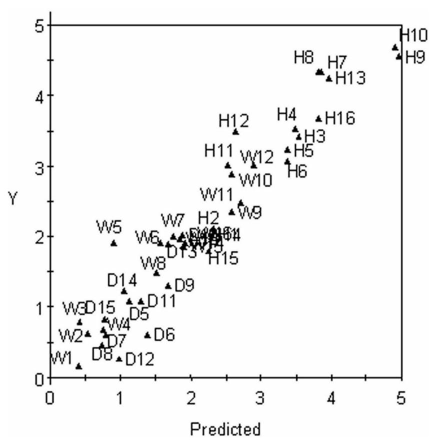


Figure 3(b): Score values (t) of component 1 & 2.

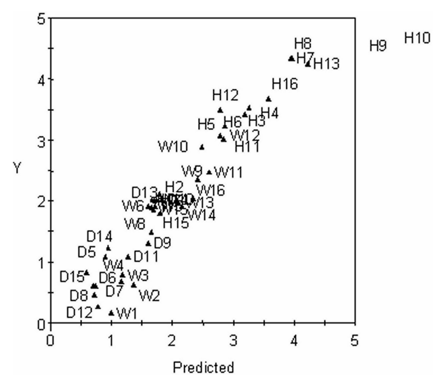
model is simple and predicts scaled annoyance as a linear function of A-weighted sound pressure level (Figure 4a). This model fails, however, in describing annoyance differences between sounds similar in level. The second model is more complex and is based on a linear combination of loudness, sharpness, tonality and fluctuation strength, see Equation 1. This model gives better predictions of annoyance in case of small level variations (Figure 4b), but does not predict the extreme values of annoyance as accurately as the first model.

$$\text{Annoyance} = 1.73 + 0.84N_{\text{max}} + 0.18S_{\text{max}} + 0.14K_{\text{max}} + 0.05F \quad (1)$$

where the coefficients show the relative importance of the psychoacoustic descriptors (mean centered and scaled to unit variance).



(a): A-weighted SPL.



(b): Loudness (N), sharpness (S), tonality (K) and fluctuation strength (F).

Figure 4: Predicted vs observed scale values of annoyance.

5 - CONCLUSIONS

The results show good agreement in the judgements of psychoacoustic annoyance of 43 sound stimuli recorded in a home environment. These results also suggest that it is possible to quantify psychoacoustic annoyance using psychoacoustic descriptors. The A-weighted sound pressure level was, however, the best single descriptor of psychoacoustic annoyance. Subject judgement seemed to be influenced by the large variations in loudness between sounds used. A linear regression model based on loudness, sharpness, tonality, and fluctuation strength, however, better describes annoyance for sounds having small differences between levels.

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