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EVALUATION OF ANNOYANCE RESPONSE TO ENGINE SOUNDS USING DIFFERENT RATING METHODS

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1. INTRODUCTION

Annoyance response to engine sound is often studied by means of personal judgements on observed stimuli. Various methods have been developed to determine the subjective judgements by means of a unidimensional rating. In the present study, three types of rating methods are considered, namely paired comparisons method [1], equal-appearing intervals method [2], and successive intervals method [3,4].

The main drawback of the paired comparisons method (PCM) is to get a reliable judgment from the subjects for a large number of stimuli [5]. A solution to this problem is to use a scaling method that requires only one judgement for each stimulus, for example, the method of equal-appearing intervals (MEAI) or the method of successive intervals (MSI) [2-4].

Various psychoacoustic (PA) descriptors relating annoyance to engine sounds have been defined in the literature [6,7]. The objectives of this study are (i) to observe the difference in annoyance judgments between the rating methods and (ii) to determine which method gives the highest correlation between annoyance response and PA descriptors.

2. EXPERIMENTAL METHODS

Subjects

Sixty subjects (30 males and 30 females), age ranging from 20 to 47 years, were participated in the listening test. An equal number of trained and untrained listeners were chosen from staffs and students of the university. A hearing test was given to each subject and found to be below 20 dB in each octave band from 125 Hz to 8 kHz.

Stimuli Preparation

Sounds were recorded in a hemi-anechoic room at different speeds and loads (Table 1). An MS stereo-microphone (Neuman 61fet) [8] was placed at a distance of 1 m from the center of the engine with a height of 1 m from the ground. The structures of the diesel and ethanol engines were identical (11 liter, 6 cylinder in-line).

For the PCM three separate subtests A, B, and C were used. Each subtest consisted of five separate sounds together with a common sound (stimulus no. 16 in Table 1). Subtest A consisted of stimuli numbers 3, 4, 11, 12, 13, and 16. Subtest B consisted of stimuli numbers 1, 2, 7, 9, 10, and 16. Subtest C consisted of stimuli numbers 5, 6, 8, 14, 15, and 16. Twenty subjects with an equal number of males and females participated in each subtest.

Procedures

The listening test was carried out in an anechoic room. All recorded sounds were presented through a pair of loudspeakers. The listening position was kept constant for all subjects. All sounds were presented at a reduced level of 17 dB from the original sound pressure level and thereby corresponding the distance of 7.5 m from the engine (ISO 362). All subjects appeared in both tests of equal-appearing intervals and of paired comparisons.

Each subtest in PCM consisted of fifteen pairs of sounds stimuli. After presenting each pair, the subject gave a rating on how much more annoying one stimulus was compared to the other or if they were equal. Each judgment was recorded on a 10 cm scale. The first two pairs were presented to familiarize with the listening test procedure.

Table 1 - Description of sound stimuli

Stimuli No.	Recording Condition	Speed (rpm)	Load (Nm)
1	Ethanol, alpha 11^0	1900	370
2	Ethanol, alpha 11^0	1900	900
3	Ethanol, alpha 11^0	1200	200
4	Ethanol, alpha 11^0	1200	900
5	Ethanol, alpha 11^0	600	20
6	Ethanol, alpha 11^0	1700	900
7	Ethanol, alpha 9^0	1500	500
8	Ethanol, alpha 13^0	1500	500
9	Diesel, alpha 24^0	1900	370
10	Diesel, alpha 24^0	1900	900
11	Diesel, alpha 24^0	1500	500
12	Diesel, alpha 24^0	1200	900
13	Diesel, alpha 24^0	1200	200
14	Diesel, alpha 24^0	1700	900
15	Diesel, alpha 24^0	600	20
16	Ethanol, alpha 11^0	1500	500

Sixteen sounds were used for MEAI. Judgment of annoyance for each sound was recorded on an eleven point rating scale from "not at all annoying" to "very much annoying". The task of the subject was to judge the degree of annoyance expressed by each sound. The first four sounds were presented to familiarize with the test procedure. Scale values for MSI were obtained from the data of MEAI [3,4]. All sounds were fed into the FFT based LMS CADA-X and B&K 2123 (real-time-third-octave band analyzer) from the listening position by a single microphone (½ inch B&K 4133) to measure the various objective descriptors of each engine sound.

3. RESULTS AND DISCUSSIONS

The consistency of annoyance judgments among the subjects in PCM was found to be high (>0.9). The internal consistency of MEAI was checked by estimating interquartile range or Q value [4] for each sound. The Q-value varied from 1 - 5, indicated disagreements among the subjects for certain sound stimuli. The disagreements were significant for stimuli numbers 7-9 and 11-13, and consequently also for MSI. Both MEAI and MSI showed a higher consistency in agreements for the extreme sounds than the moderately perceived sounds. The scale values of annoyance obtained by all three rating methods is shown in Fig. 1. All undiscriminating sound stimuli gave higher or lower scale value in both MSI and MEAI than PCM.

A multiple analysis of variance was applied on the data of PCM in order to observe the relationships between the annoyance ratings and sex. No significant difference in annoyance judgments was observed between female and male subjects. A significant difference between sound stimuli was found at a 95% significant level.

Principal component analysis was applied to determine the relationship between the scale values of three rating methods and the various PA descriptors. The model explained 98% of the total variance in the data by five significant components. Figure 2 shows the loadings plot of the first two components, indicating redundancy (enclosed within the oval) among ERR [9] and loudness (ISO 532B). Redundancy is also shown among all sound level measures (dB, dBA, dBB, and dBC) and periodicity [10] as well as between sharpness descriptors (acum and bark) [7]. Roughness [10] (smod) and impulsiveness (kurtosis) [11] show an independent behaviour as they are well separated from any of the variables. Scale values of PCM and MEAI are correlated to ERR whereas MSI is correlated to sharpness descriptors. MSI fails in describing annoyance significantly since the rating is strongly related to the second component.

Partial least squares (PLS) regression was used to observe a relationship between PCM scale values and all independent and also to one of the redundant variables. The selection of the redundant variable was based on its higher contributions to the model. Two significant components of the PLS model explained 94% of the variance in the data. The first component was described by loudness and periodicity and the second component was related to sharpness and impulsiveness. Figure 3 shows the magnitude of the descriptors in the prediction model related to the sound stimuli. Judges were found to be inconsistent in both MEAI and MSI when the sounds were perceived by periodicity and roughness.

A prediction model based on the data of MEAI was developed by using PLS regression. The model explained only 80% of variance in annoyance response by one significant component. Both MEAI and MSI showed that the untrained listeners could only judge consistently when the sounds were perceived by loudness and sharpness or by impulsiveness. An earlier investigation of successive intervals and equal-appearing intervals methods for the trained listeners yielded a significant relationship between annoyance judgment and various sound stimuli [12].

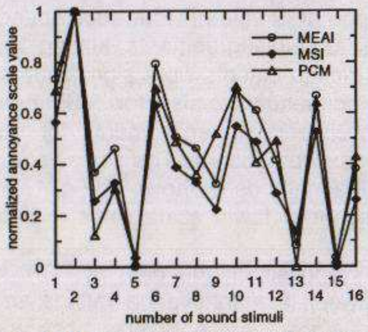

Fig. 1. Three types of rating scores for all sound stimuli.

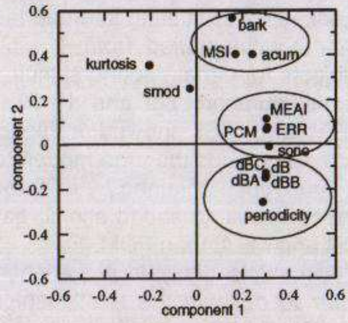

Fig. 2. Loading plot for the first two components of PCA.

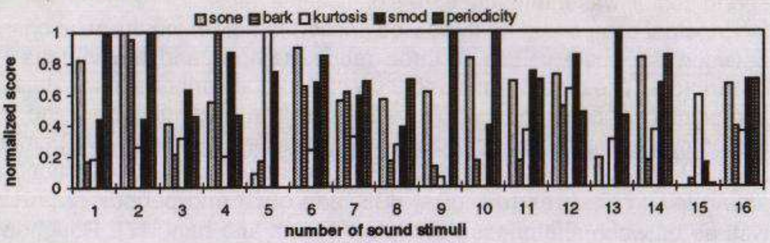

Fig. 3. Contributing descriptors in the prediction model related to sound stimuli.

4. CONCLUSIONS

A consistent judgment of annoyance response to various sound stimuli for trained and untrained listeners was observed by the paired comparisons data. Judgments of annoyance based on equal-appearing and successive intervals methods were only consistent for the trained listeners. Untrained listeners showed larger variation in annoyance rating on a unidimensional scale when the sounds were not perceived by loudness or impulsiveness.

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