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NOISE ANNOYANCE WITH RESPECT TO THE DISTANCE OF THE NOISE SOURCE

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ABSTRACT
Noise produced by source located farther from a listener is assessed as less annoying than noise produced by source of the same type that is located closer. This is explained by pointing to the fact that increase in distance of the source of noise causes decrease in loudness. However, the ground effect and air absorption phenomena change not only the sound level of the stimulus but also its spectral content. The aim of the present paper is to answer the question: what is the annoyance of noise produced by sources located at different distances but reaching listener's ear with the same loudness. The original railway noises recorded at two distances were artificially modified to make them equal in loudness. In psychoacoustic experiments subjects were asked to assess noise annoyance of original and modified sounds. The results are discussed with respect to the existing noise annoyance models.

1 - INTRODUCTION
The works on perceived auditory distance [1], [2], and [3] show that changes in sound level and/or in high-frequency spectral content can produce changes in the apparent distance to a source. The decrease of sound energy with distance causes decrease in sound level and this is usually accompanied by the perception of increased distance. Moreover selective attenuation by passage through the air leads to decrease in high-frequency content and in consequence sound source is perceived at an increased distance. When such changes (in sound level an/or spectral content) are introduced artificially they also cause a change in perceived distance [3]. There is no information in literature whether the changes in low and middle frequency spectral content caused by the ground effect [4] also influence the perceived auditory distance.

It seems natural to expect that perception of noise produced by sources located at different distances influences annoyance assessment of these auditory events. Noise produced by source located farther from a listener is assessed as less annoying than noise produced by source of the same type that is located closer. These differences in annoyance are explained by pointing to the fact that increase in distance of the source of noise causes decrease in loudness. This is a well-known fact. What has not been investigated so far is the following problem: is loudness the only factor that influences annoyance assessment of noises recorded at different distances? Are the changes in spectral content of noises recorded at different distances sufficient enough to produce a change in annoyance assessment?

The answer to this question could help to evaluate the existing models of noise annoyance. Noise annoyance models can be divided into one-component and multi-component. The one component models are based on the sound equivalent level ($L_{Aeq}T$) or sound exposure level (L_{AE}), or loudness measure (N). They assume that changes in the chosen parameter − be it $L_{Aeq}T$ or L_{AE} or N − definitely determine changes in annoyance. In multi-component models apart from loudness other attributes of sound such as: sharpness [5], fluctuation strength [6], etc., are taken into account in explanations of noise annoyance. Results of experiments reported here can be used in the discussion, which model of annoyance to choose.

In the present work the original railway noise recorded at two distances was used as a source of annoyance. The loudness equalization was done in two steps. At first the sound recorded at the farther distance was amplified in a linear way until its L_{AE} was the same as the L_{AE} of the noise recorded at the closer distance from the source. Then, based on the spectra of these noises the loudness, N, according to the

Zwicker method [7] was (ISO532B) calculated. This procedure guaranteed that the noises presented in pairs were always equal in L_{AE} but not all of them were equal in loudness. The pairs of noises equal in loudness are marked in the Table 1 with an asterisk.
The hypothesis tested in this work is the following: the difference in the distance of the noise source produces the difference in noise annoyance assessment of the equally loud noises.
This hypothesis was tested in the psychoacoustic experiment, where subjects were asked which of the two noises presented in a pair they would prefer to switch off given such a possibility.

2 - METHOD

Stimuli and apparatus. Twelve original railway noises, recorded at two distances (s1=25m and s2=450m) from the moving source (Fig. 1), were used as a test stimuli. There were noises generated by InterCity (IC), passenger (PT) and goods trains (GT), each of 25s duration. The sound exposure level at two distances, velocity and length of each train are presented in Table 1.

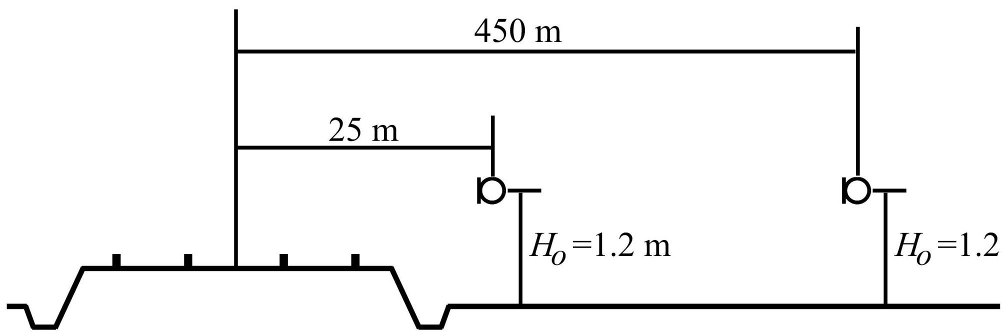

Figure 1: Positions of the microphones at two distances, 25m and 450 m, and at the height of 1.2 m used for recording the original railway noises.

Train	L_{AE} (s1) [dB]	L_{AE} (s2) [dB]	Velocity, V [km/h]	Length, l [m]
*IC1	97.3	74.1	126	264
*IC2	92.7	69.5	140	257
IC3	93.9	78.4	134	204
IC4	89.8	73.7	138	230
PT1	93.9	75.0	97	184
*PT2	90.2	68.3	95	137
*PT3	90.9	79.5	95	175
*PT4	87.3	68.0	95	91
GT1	99.2	73.7	76	463
GT2	92.1	67.9	68	166
*GT3	91.5	68.8	60	258
*GT4	94.5	70.3	76	452

Table 1: Description of the test stimuli; (* noise that is equal in loudness with its modified counterpart).

In Fig. 2 spectra of L_{AE} based on he original recordings of all railways noises, averaged over each type of a train noise are presented. The upper curves represent the railway noises recorded at the closer distance from the source and the three lower curves represent the same railway noises but recorded at the further distance from the source.
In order to create pairs of railway noises recorded at two distances but having the same loudness the noises were artificially modified (by using the Matlab Tools): the noise from the distance s2, was linearly amplified and the noise from the distance s1, was linearly attenuated. In Fig. 3 two pairs of the original and modified spectra of original railway noise recordings of passenger train, PT3 are presented.
Each pair of noises has the same sound exposure level and, in addition, the stimuli marked with asterisk in the Table 1 have their modified counterparts equal in loudness. The whole test consisted of 24 pairs of noises and was designed with a sound-editing program (Sound Designer II of the Sound Tools II system

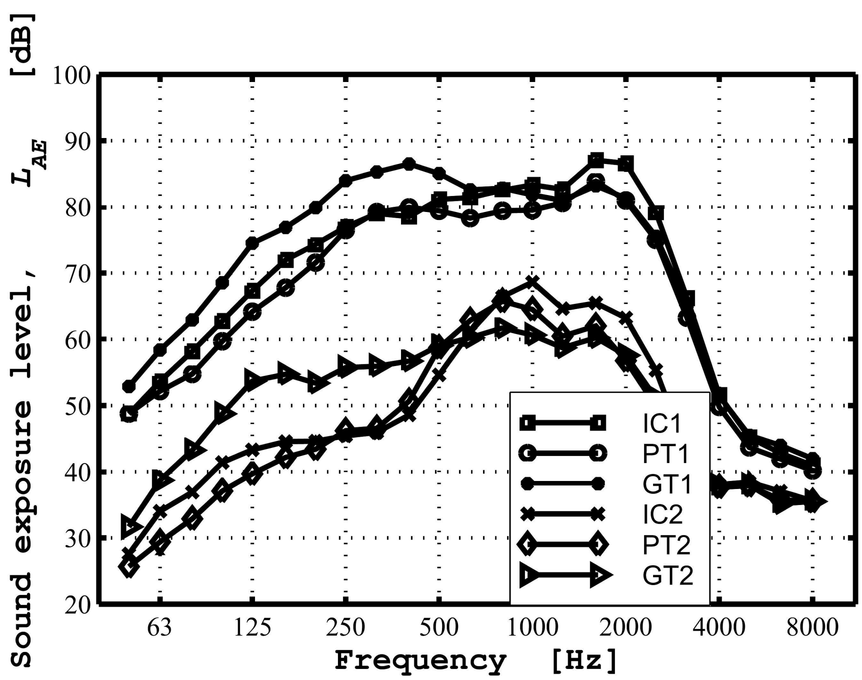

Figure 2: Averaged spectra of L_{AE}, for three types of railway noises (IC, PT and GT trains) recorded at distance 1 and 2.

and a Macintosh Quadra 700) and presented diotically through earphones (Beyer DT 48 with free-field equalizer [7]). The subjects were sitting in a sound-proof booth.
Subjects. Subjects were normal-hearing students of the A. Mickiewicz University (15 female and 16 male).
Procedure. Before performing the test, subjects were given the following instruction: "You will listen to a pair of railway noises, please mark which of the two noises presented in a pair you would prefer to switch off, if given the possibility". Each subject judged each pair of noises only once. The results are presented in terms of percentage of all comparisons in which a particular noise was chosen as non-preferred. The higher this non-preference percentage, the greater was the number of subjects who wanted to switch this particular noise off. In all, each of the 31 subjects made 24 preference judgements, one for each of 24 pairs.

3 - RESULTS

The results are presented in the Table 2 in terms of percentage of all comparisons in which a particular noise was chosen as non-preferred.

Train	**s1-org** [%]	**s2-mod** [%]	**s2-org** [%]	**s1-mod** [%]
*IC1	42	58	**61**	39
*IC2	48	52	**61**	39
IC3	58	42	**16**	84 L
IC4	58	42	**55**	45
PT1	**84**	**16**	**39**	**61**
***PT2**	**87**	**13**	**55**	**45**
***PT3**	**90**	**10**	**42**	**58**
***PT4**	**87**	**13**	**32**	**68**
GT1	23	77 L	**52**	**48**
GT2	**77**	23	**52**	**48**
*GT3	**81**	19	29	**71**
*GT4	48	52	10	90

Table 2: Percentage of all comparisons in which a particular noise was chosen as non preferred; sign L in two cases means that this noise was louder in N value.

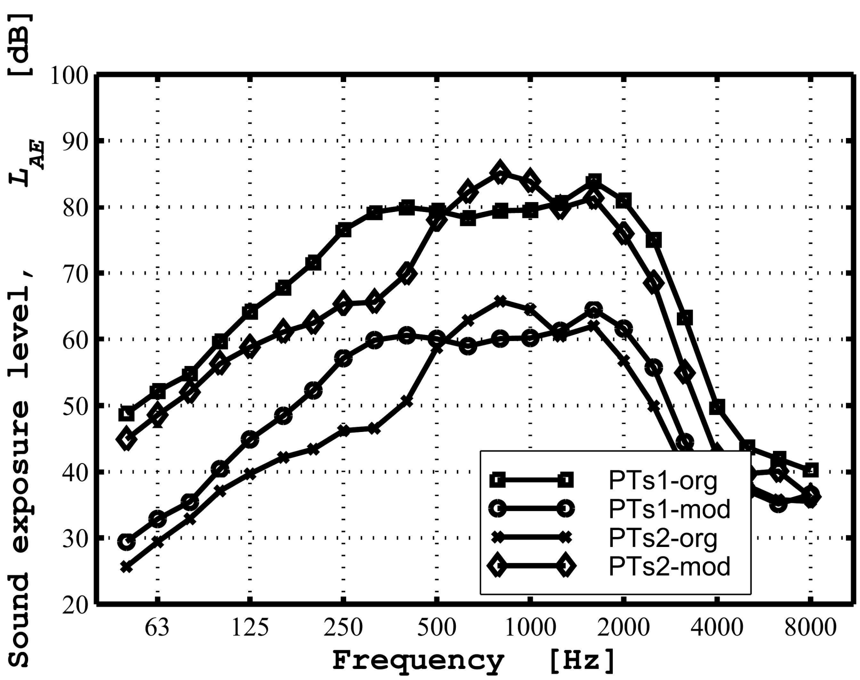

Figure 3: Original L_{AE} spectra recorded at two distances (PT3s1 org and PT3s2 org) and modified L_{AE} spectra (PT3s1 mod and PT3s2 mod); noises in pairs (PT3s1org, PT3s2mod) and (PT3s2org, PT3s1mod) are equal in sound exposure level, L_{AE} , and in loudness, N.

We assume that results above 75% indicate that subjects' choices were not casual. The results presented in the Table 2 in columns 4 and 5 show that comparisons between original noise recorded at the farther distance (s2=450m) with the modified noise recorded at the closer distance do not allow to formulate definite statements about subjects preferences. This result can be accounted for by the fact that in case of softer sounds the spectral differences are to small to evoke significant differences in noise annoyance assessments. This is shown in Fig. 1 (three lower curves in this graph) where the curves are of the similar shape. The only exception is GT4 train. In this case the train noise was recorded together with the sounds of the singing birds. It turned out that singing birds were stronger cue for noise assessment than train noise itself.
The results for the noise recorded at the closer distance from the source (columns 2 and 3) are not homogenous. The subjects were consequent in their choices for noises from all passenger trains (PT) and two good trains (GT). It means, that the change in the frequency content was significant enough to influence their noise annoyance assessments. In the other cases (all IC trains and one GT train) such influence cannot be detected.

4 - CONCLUSION

The discussed experiment suggests that noise annoyance models should consider the distance of the source of noise. Annoyance judgment of noise from sources that are farther from the subject is based only on loudness. On the contrary, loudness is not enough to assess noise annoyance of signals from sources that are closer to the subject.

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