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THE TRAM BONUS

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The annoyance of three different sound sources was evaluated in a psychoacoustic experiment. An objective analysis of the stimuli used in the experiment has shown that calculated loudness was responsible for equally annoying pairs of different sound sources. Based on the loudness calculations and annoyance ratings, a "tram bonus" of 3 dB was found in comparison to the bus sound source. In addition, it was found that loudness explains the annoyance results when the $L_{\mathrm{pA\,max}}$ is larger than 74.5 dB(A). With sound levels smaller than 74.5 dB(A) sharpness and roughness contribute to annoyance judgments.

Key words: annoyance, tram bonus, ICBEN scale.

1. Introduction

Referring to the results obtained by SCHULTZ [1] and FIDELL *et al.* [2], MIEDEMA and VOS [3] have shown that different transportation sound sources cannot be treated equally with respect to the amount of noise annoyance tolerated in terms of day-night equivalent sound level (DNL). They found that different DNL values correspond to an equal percentage of people who are highly annoyed (%HA) by the noise. DNL values for aircraft noise are lower than for road noise and DNL values for road noise are lower than for railway noise. Due to these discrepancies concerning subjective (%HA) and physical (DNL) evaluation of noise annoyance, several countries have accordingly established a rail bonus which is in Germany for instance 5 dB(A) [4]. This bonus was derived from social surveys where numerous residents were interviewed and asked to evaluate the acoustic load (mainly from transportation traffic) to which they are exposed daily. A similar bonus is expected if various types of traffic noise are presented in the laboratory where the participants have to evaluate annoyance caused by the single noise immediately after presentation. This was at least found by FASTL *et al.* [4] who evaluated loudness of rail noise versus road noise. The present study was performed in the laboratory and was done to find out if a tram bonus exists when annoyance of tram noise was evaluated versus annoyance due to bus noise. This issue is important in regard to the means of transport and traffic management in European cities.

2. Method

2.1. Stimuli and equipment

The stimuli used in the psychoacoustical experiment were mono recordings of a tram, a bus and a heavy truck. One representative recording was chosen from the database developed in the Integrated Project of EU with the acronym "SILENCE" for each vehicle category. The vehicles chosen were: a Polish tram type 105N, a bus type NEOPLAN N4020 and a typical heavy truck with semi-trailer. The noises generated by these three different sound sources were recorded 15 meters from the midpoint of the lane or rail-track. Each stimulus was of 6 seconds duration and was equalized in respect to the maximum A-weighted sound pressure level, $L_{\mathrm{pA\,max}}$. After calibration, the maximum A-weighted level of each recording was 74.5 dB(A). This sound level was then used as a reference level (0 dB). An objective analysis of the stimuli used in the psychoacoustic experiment was performed with the help of Artemis software. Four different characteristics are presented in Fig. 1. These are: the A-weighted sound level versus time, 1/3 octave spectrum, and loudness and sharpness versus time.

The loudness of the tram (20.9 sone) is the lowest and is comparable to the loudness of the heavy truck (21.3 sone) with a loudness ratio of 1.05. The loudness of the bus (26.0) is much larger than the loudness of the tram and truck (the loudness ratio of the bus and tram is equal to 1.25). Similar relationships occur for the sharpness of the stimuli. The sharpness of the tram (1.77 acum) is significantly lower than the sharpness of the bus (2.18 acum) and the sharpness of the heavy truck (2.08 acum). In addition, the sound exposure level L_{AE} and roughness were calculated and presented in Table 1.

Table 1. Calculated values of $L_{\mathrm{pA\,max}}$, L_{AE}, loudness, roughness and sharpness for the reference stimuli used in psychoacoustic experiment.

Sound source	$L_{\mathrm{pA\,max}}$ [dBA]	L_{AE} [dBA]	Loudness [sone]	Roughness [asper]	Sharpness [acum]
Tram	74.2	70.5	20.90	2.30	1.77
Bus	74.2	71.0	26.02	2.70	2.18
Truck	74.2	70.4	21.31	2.47	2.08

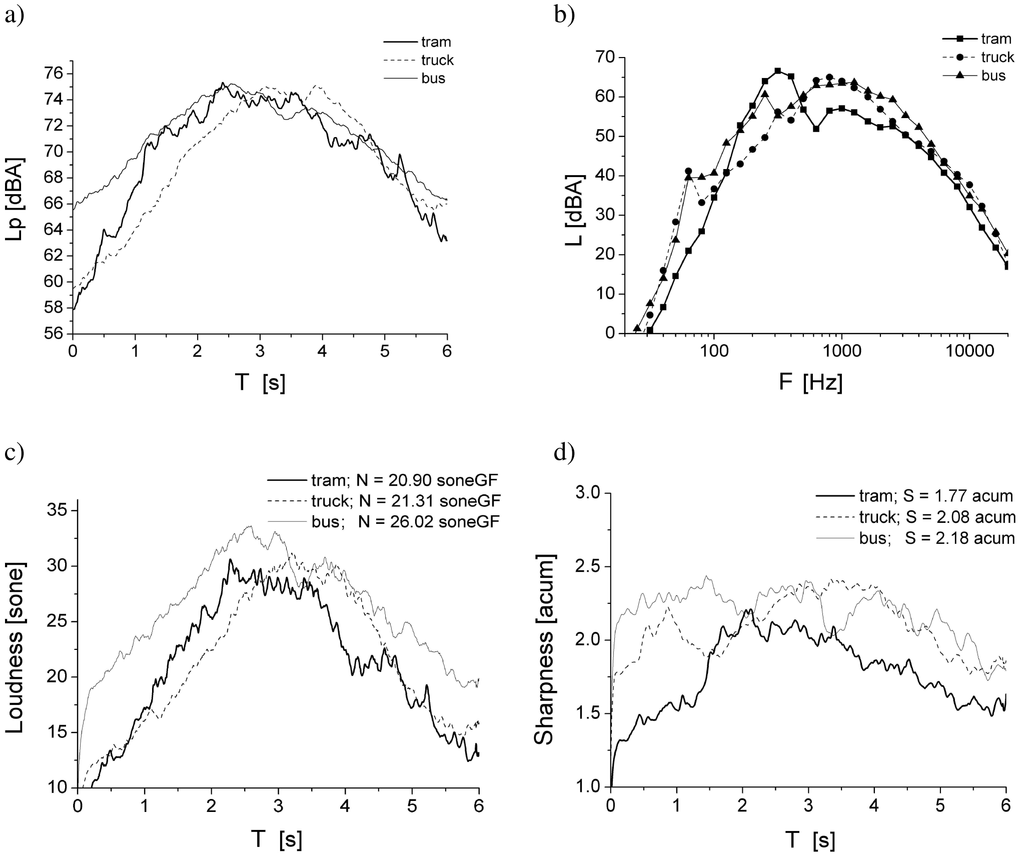

Fig. 1. Results of the objective analyses of three reference stimuli: the A-weighted sound level versus time (a), 1/3 octave spectrum (b), the loudness versus time (c) and the sharpness versus time (d).

2.2. Subjects

Twenty one listeners participated in the experiment. The listeners were between 19–22 years old. All listeners qualified as having normal hearing (normal hearing was defined as the audiometric threshold of 20 dB HL, or better, for the frequency range from 250 to 8000 Hz, according to ANSI standard [5]) and were paid for their participation.

2.3. Procedure

All stimuli were presented at 7 different sound levels (-9 dB, -6 dB, -3 dB, 0 dB, $+3$ dB, $+6$ dB and $+9$ dB), where 0 dB means the reference level ($L_{\mathrm{pA\,max}} = 74.5$ dB) described in previous section. Each of the 21 resulting different stimuli was presented 30 times. The stimuli were presented in random order. The whole experiment was carried out in 3–30 minutes long sessions – one session per day. Listeners judged the annoyance of each stimulus using a 11 point scale (0–10). The scale used in this study is recommended for noise surveys by ICBEN [6, 7]. The subjects were given the following instruction: *what number from zero to ten best shows how much you are bothered, disturbed, or annoyed by noise? If you are not at all annoyed choose zero, if you are extremely annoyed choose ten, if you are somewhere in between choose a number between zero and ten.*

3. Results and discussion

3.1. Results of the objective analysis

Since the loudness of the reference stimuli was not the same for the three sound sources at the same $L_{\mathrm{pA\,max}}$, a similar difference in loudness was expected with the other values of sound level. The values of calculated loudness for all three sound sources at each sound level are presented in Table 2. From the data presented in Table 2 and Fig. 2, one can notice a tram bonus of 3 dB when compared to the bus. It means the calculated loudness is equal for the tram and bus, when the sound level of the tram is 3 dB higher than that of the bus. However, based on the loudness calculation there should not be any difference between truck and tram judgments.

Table 2. The calculated total loudness values for three sound sources at all sound levels.

Loudness [sone]							
Source	Level [dB]						
	−9	−6	−3	0	3	6	9
Tram	11.45	14.04	17.15	20.96	25.4	30.78	37.19
Bus	14.53	17.71	21.49	26.02	31.44	37.94	45.71
Truck	11.75	14.38	17.54	21.31	25.8	31.15	37.56

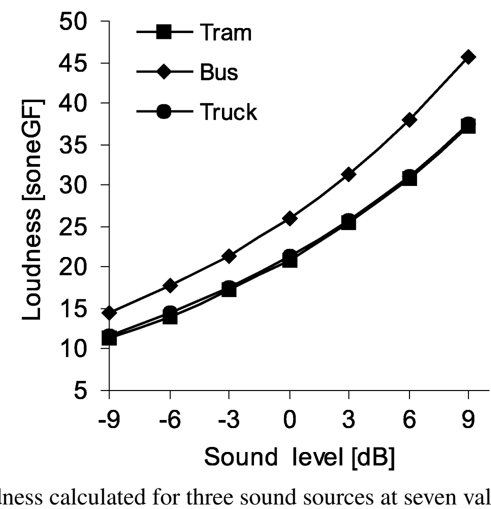

Fig. 2. Total loudness calculated for three sound sources at seven values of sound levels.

Similar calculations were performed for sharpness and roughness and are presented in Tables 3, 4 and Figs. 3, 4, respectively. When it comes to sharpness and roughness, there are differences between their values for different sound sources, but it is not clear if these differences are large enough to be perceived by the subjects. This can be checked indirectly. If they are perceived by the subjects, then loudness cannot explain all the annoyance results. If no, the loudness calculations and annoyance ratings should lead to the same results.

Table 3. The calculated sharpness values for three sound sources at all sound levels.

Sharpness [acum]							
Source	Level [dB]						
	−9	−6	−3	0	3	6	9
Tram	1.47	1.56	1.66	1.77	1.89	2.02	2.17
Bus	1.83	1.94	2.05	2.18	2.33	2.5	2.7
Truck	1.76	1.86	1.96	2.08	2.21	2.36	2.54

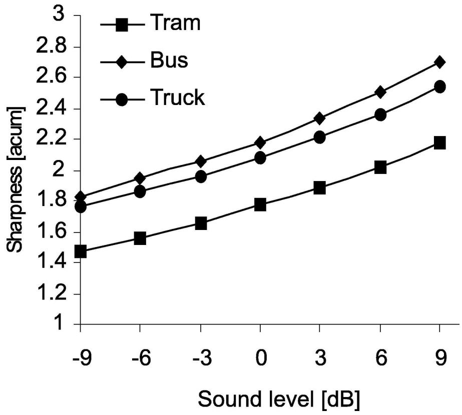

Fig. 3. Sharpness calculated for three sound sources at seven values of sound levels.

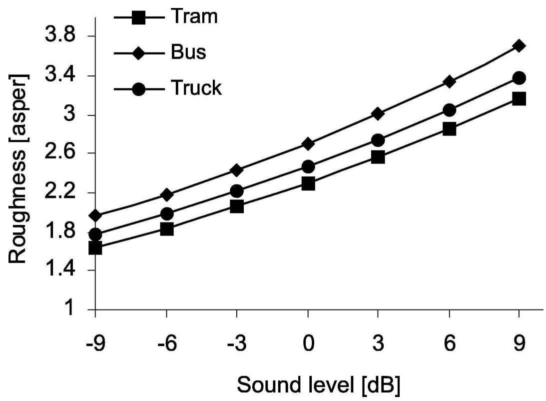

Fig. 4. Roughness calculated for three sound sources at seven values of sound levels.

Table 4. The calculated roughness values for three sound sources at all sound levels.

Roughness [asper]							
Source	Level [dB]						
	−9	−6	−3	0	3	6	9
Tram	1.63	1.84	2.06	2.3	2.56	2.85	3.17
Bus	1.96	2.18	2.43	2.7	3.01	3.34	3.71
Truck	1.78	1.99	2.22	2.47	2.75	3.05	3.39

3.2. Results of the psychoacoustic experiment

Pearson's coefficient of correlation calculated over all 21 stimuli for 21 subjects reveals significant concordance among subjects and, therefore, group data is used in the analysis. The annoyance ratings averaged over 21 subjects for the three sound sources versus sound level are plotted in Fig. 5. According to the ANOVA test there are significant differences $[F(12, 13209) = 4.91;\ p < 0.05]$ between sound sources presented at different sound levels. However, the post hoc analysis (Sheffe test) shows the pairs of stimuli that do not differ in their annoyance ratings. These pairs are presented in Tables 5–7.

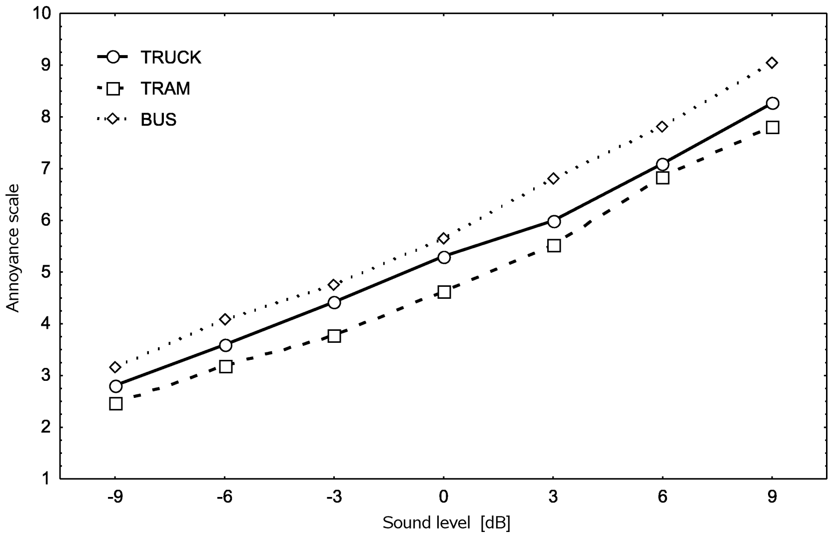

Fig. 5. Perceived annoyance scale for three different sound sources presented at seven sound levels.

Table 5. Pairs of stimuli from tram and bus sources that were judged as equally annoying by the subjects, marked by X. The letter L means loudness.

	BUS -9	BUS -6	BUS -3	BUS 0	BUS 3	BUS 6
TRAM -6	X L					
TRAM -3		X L				
TRAM 0			X L			
TRAM 3				X L		
TRAM 6					X L	
TRAM 9						X L

From the data in Table 5 we can say that the tram bonus was found in this study and it is 3 dB(A). It means that tram noise with 3 dB higher sound level than that of a bus is judged as equally annoying.

Table 6. Pairs of stimuli from tram and truck sources that were judged as equally annoying by the subjects, marked by X. The letter R means roughness and L loudness.

	TRUCK −9	TRUCK −6	TRUCK −3	TRUCK 0	TRUCK 3	TRUCK 6	TRUCK 9
TRAM −9	X L						
TRAM −6	X R	X L					
TRAM −3		X R					
TRAM 0			X R				
TRAM 3				X R	X L		
TRAM 6						X L	
TRAM 9							X L

From the data presented in Table 6 we can conclude that a similar tram bonus exists for the truck but only for the soft sound levels −9, −6, −3 and 0 dB. In addition, at the same sound level (except for −3 and 0 dB) the truck was perceived as equally annoying as the tram.

Table 7. Pairs of stimuli from bus and truck sources that were judged as equally annoying by the subjects, marked by X. The letter S means sharpness and L loudness.

	TRUCK −9	TRUCK −6	TRUCK −3	TRUCK 0	TRUCK 3	TRUCK 6	TRUCK 9
BUS −9	X S	X L					
BUS −6			X L				
BUS −3			X S				
BUS 0				X S	X L		
BUS 3						X L	
BUS 6							X L
BUS 9							

From the data presented in Table 7, the bus was perceived the equally annoying as the truck only for soft sound levels −9, −3, 0. For the sound levels −6, −3, 3, 6, 9, the truck bonus exists. The truck of 3 dB higher sound level than the bus was perceived as equally annoying.

3.3. Discussion

In the Tables 5, 6, 7, the letters L, R, or S mean that the calculated values of loudness, or roughness or sharpness was responsible for the equal annoyance rating for that pair of sounds sources. If we compare the results of the psychoacoustic experiment, it is clear that equal loudness was responsible for the equally annoying pairs of sound sources at the sound levels 3, 6 and 9 dB. For the sound levels −9, −6, −3 and 0 roughness and loudness were responsible for the equally annoying judgments for the tram and truck, while sharpness and loudness were responsible for the equally annoying sound sources of the truck and bus. One conclusion of our study is that loudness is totally responsible for the stimuli that have the $L_{\mathrm{pA\,max}}$ larger than 74 dB(A). While for the noises of the smaller values of $L_{\mathrm{pA\,max}}$ sharpness and roughness also influence annoyance judgments.

Based on the objective analysis of calculated total loudness for all stimuli, one could predict the existence of a tram bonus in annoyance judgments in a psychoacoustic experiment. The same value of 3 dB can be seen in both cases – compare Figs. 2 and 5. However, the value of the tram bonus (3 dB) is smaller than the rail bonus (5 dB) obtained by FASTL *et al.* [4]. The reason for the “rail bonus” was discussed in several papers and is well known. The question which is not yet answered is why the tram bonus obtained in this study is smaller than the rail bonus. One of the possible explanations comes from the environmental factors that seem to play a significant role in sound source perception [8]. In everyday listening we are used to listen to the train from greater distances than to the tram. This fact may influence subjects’ noise annoyance perception when they recognize a tram instead of a train.

The difference to the results reported by FASTL *et al.* [4] might also be explained by the fact, that the tram noise differs from the rail noise, first, due to the lower speed, second due to the shorter length and thereby another acoustic structure as well as by the fact, that the ground below is different. Additionally the present results are only valid for the three selected noises and for the range of maximum levels applied here.

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