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Experimental studies on annoyance caused by noises from trams and buses

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Abstract

Acute annoyance due to noise from trams and buses was ascertained and compared in two experimental studies. First, 22 healthy young persons (19–22 years) using a standardised scale, rated their annoyance caused by noise from trams, buses and trucks, which were each presented at seven sound levels. The noise of a tram was judged to be equally annoying as the noise of a bus with a 3 dB lower level, which corresponds to the calculated loudness difference. The noises of a tram and of a bus were superimposed onto a 2-h realistic road traffic scenario in the second study. This study was conducted with 60 healthy young persons (18–31 years). Twenty participants were each exposed either to the scenario with the tram or the bus ($L_{\mathrm{AeqT}} = 55\,\mathrm{dBA}$) or to a control condition ($L_{\mathrm{AeqT}} = 43.6\,\mathrm{dBA}$) while working on different mental tasks. Performance data did not differentiate between the noise conditions, but the participants were again less annoyed by the scenario with the tram, suggesting a possible bonus for the tram. This assumption has to be verified in future studies. The fact that calculated loudness could predict annoyance in the psychoacoustic tests and this annoyance due to the same noises presented in complex scenarios might indicate the possibility of a more economical approach, at least to noises between which loudness differs greatly.

1. Introduction

Though noise emission of individual road vehicles has been significantly reduced within the last decades, the overall noise load in terms of equivalent noise levels, day–evening–night levels, etc. became nevertheless higher due to the considerable increase of the traffic volume. As traffic volume is expected to further increase and as the actual noise load in many areas is already above critical limits, noise abatement is a major challenge. The effects of noise are relevant for health, and essential for general well-being.

Apart from the reduction of noise emission from single vehicles there is also an increasing effort to reduce individual transportation in favour of mass public transit systems. With regard to inner city traffic there are

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mainly two alternatives, namely trams and buses. A decisive criterion for the preference of either of these means of transportation should be the annoyance caused by the noise emitted by these vehicles.

Studies focused on the comparison between rail and road noise with respect to annoyance have found that, for equal noise levels, railway noise annoys less than road traffic noise. This has been particularly well demonstrated by a meta-analysis performed by Miedema et al. [1,2]. This probably also applies to performance, as shown by Hygge [3], who studied the effects of aircraft noise, rail noise and road traffic noise on performance in school children. These findings support the bonus–malus regulations that are established in several European countries allowing higher equivalent noise levels for rail noise than for road traffic noise.

It is, however, uncertain whether this bonus applies to trams as well. Possibly, one of the main differences between trains and trams at least for the urban region is the speed. Trams are slower and in consequence the spectrum of the tram noise at least in the range of high frequencies is different comparing with spectrum of the train noise. However, the comparison of the noises of trains and trams is not matter of the present study. As suitable comparative studies are not available, one goal of Sub-Project A of the EU-funded Integrated Project 'SILENCE' was to compare the annoyance caused by trams and buses, particularly to answer the question, whether in a traffic situation annoyance will increase or decrease in dependence of the appearance of buses or of trams.

This was done in two steps. Psychoacoustic listening tests were performed first at the Institute of Acoustics at Adam Mickiewicz University Poznan, Poland, where noise annoyance of the single pass-bys of a tram, a bus and a truck, with the same LAE index, was assessed in a laboratory setting. In the first study, annoyance was understood as psychoacoustic annoyance or unbiased annoyance [4], where this annoyance is assumed to be independent of the relationship of the listener and the sources of the noises. Moreover, the term psychoacoustic annoyance is used as a psychoacoustic concept of annoying sounds that can be described by a combination of hearing sensation such as loudness, sharpness, fluctuation strength and roughness [4]. According to this definition, psychoacoustic annoyance can quantitatively describe annoyance ratings obtained in psychoacoustic experiments. There are few evidences that perceived annoyance may be exchanged for perceived loudness for rather loud sounds but for other, usually softer sounds, perceived annoyance deviates greatly from perceived loudness [4–6]. The main goal of study 1 was to find out which of two sound sources, namely bus or tram, is perceived as more annoying when equal measures of noise load have been generated. The responses obtained for a third sound source-truck were used as reference stimuli to normalise the results of tram and bus obtained by the same subjects [7].

Thereafter, annoyance was ascertained in a more realistic approach at the Institute for Occupational Physiology at Dortmund University, Germany. For this purpose, the pass-bys of the bus or the tram were superimposed on a realistic road traffic scenario arranged at Stiftelsen for industriell og teknisk forskning ved Norges tekniske høyskole in Trondheim, Norway. In this second study, annoyance was understood as an unpleasant mental state resulting from the interaction and distraction of noise with actually carried out activities [8–10]. Since in field studies, the term noise annoyance is associated with longer term exposure to noise potentially associated with feelings of helplessness or perceived control [11], it should be denoted, that noise annoyance in the present study is understood as short term annoyance. It was therefore advisable to force the participants in the experimental sessions to carry out a controlled performance test where it is not necessarily assumed that both performance and annoyance are associated, as indicated by the studies reported, e.g. by Belojevic et al. [12,13] or Ma and Yano [14].

Irrelevant sounds, i.e. noises that are not related to actual activities, were found to disturb several cognitive processes such as perception, attention and working memory [15–17], or at least cause premature fatigue due to coping strategies [18]. The degree of disturbance depends on acoustic features, in particular the temporal microstructure [4,19]. Intermittent noise distracts and interferes with the processes of the working memory, with consequences for perception and the storage and the processing of acoustic and visual information. It was therefore advisable to choose tests which place high demands on working memory and concentration (e.g. Refs. [20,21]). Thus, the difficulty in this study was varied by the application of 3 different tasks, each with 2 levels of difficulty.

Several studies have shown that persons rating themselves as sensitive to noise are usually more annoyed by noise than less sensitive persons [12,22–27]. Therefore, this personality trait and moderator for the evaluation of annoyance was ascertained as well.

From these delineations, it can be concluded, that two different approaches of investigating noise annoyance were used, on the one hand a psychoacoustic and thus more technical approach, on the other hand a more socio-psychological approach.

2. Materials and methods

The experiments reported here were approved by the Ethics Committee. The participants gave their written consent and were paid for their contribution.

2.1. Study 1: comparison of noises emitted from a tram, a bus and a truck

2.1.1. Participants

Twenty-two healthy listeners with normal hearing (4 women, 18 men, 19–22 years) participated in the experiment (normal hearing was defined as hearing thresholds $\leqslant$20 dB HL between 250 and 8000 Hz). Before the experiment a training session was conducted, where all possible sounds were presented in order to get familiar with the rating scale. The results of this session were not included in the analysis. None of the participants had taken part in an experiment like that.

2.1.2. Stimuli and equipment

Representative mono recordings from a large database established within the EU-funded Integrated Project SILENCE were chosen for the experiment. These were a Polish tram type 105N and a bus type NEOPLAN N4020, each of which were recorded 15 m from the midpoint of the lane or rail–track. A third noise from a typical heavy truck with a semi-trailer was added only in order to get reference annoyance judgments that were used to normalise the differences between the individual subjects. In Fig. 1, the original and equalised spectra of the three recordings are presented.

The L_{pAmax} was 90.2, 84.7 and 80.8 dB for truck, bus and tram, respectively, with the value for bus as an average. Having in mind the comfortable level of listening the stimuli for the subjects in laboratory settings, we chose the value of 10 dB lower from the average measured sound level.

The stimuli presented to the subjects were equalised in duration and with respect to the maximum A-weighted sound pressure level (L_{pAmax}) to 74.5 dB. For each stimulus, the averaged value of calculated loudness (in some) is marked. Originally, the truck was the loudest sound source while for equalised sound levels the sound of the bus was louder than the truck, i.e. the value of calculated loudness of a truck as a reference stimulus lay between the loudness of the tram and the bus. Each stimulus was of 6 s duration and was then used as a reference level (0 dB). The level was calibrated by using a PEQ IV.1 programmable equaliser from Head Acoustics. The experiments were controlled by computer. Stimuli were sent from a PC equipped with an RME DIGI 96/8 PAD sound card to the PEQ IV.1 through an AES/EBU digital output. D/A conversion was made by the PEQ IV.1 with 16 bits resolution and a 44100 Hz sampling frequency. The PEQ IV.1 also served as a headphone amplifier. The experiment took place in a laboratory that was equipped with eight workplaces. The stimuli were presented via Sennheiser HD600 headphones, which were individually calibrated by HEAD acoustics Company. By applying Artemis software (HEAD acoustics), loudness, sharpness and roughness were calculated for all stimuli.

2.1.3. Procedure

All participants were exposed to all stimuli and experienced the same procedure.

Each stimulus was presented at 7 levels with -9, -6, -3, 0, $+3$, $+6$ and $+9$ dB relative to the reference level ($L_{pAmax} = 74.5$ dB). The resulting 21 stimuli were randomly presented 30 times each. The experiment was run in three 30-min sessions—one session per day. Annoyance was judged after each stimulus, using the ISO standardised scale (ISO/TS 15666:2003) [28] and the following instruction was given: ‘What number from zero to ten best shows how much you are bothered, disturbed, or annoyed by the noise you have just heard? 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’. A within-design was chosen to study annoyance with repeated measurements on the factors source and noise level.

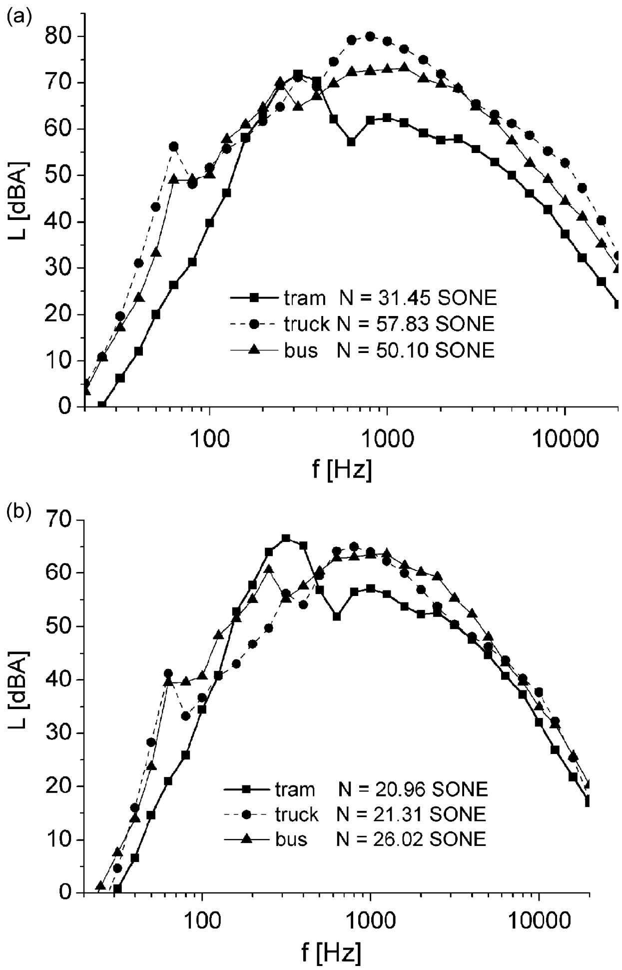

Fig. 1. The 1/3 octave spectra of three original (a) and three reference (b) stimuli. The averaged calculated loudness is marked in the figure.

2.2. Study 2: comparison of noises of the tram and the bus within complex noise scenarios

2.2.1. Participants

Sixty healthy people with normal hearing (30 men, 30 women, 18–31 years) participated in the study where 10 men and 10 women each were randomly assigned to one of three groups ('tram', 'bus' and 'control'). Normal hearing was defined as hearing thresholds $\leqslant$20 dB HL between 250 and 8000 Hz. None of the participants had taken part in an experiment like that.

2.2.2. Design and procedure

A mixed control-group design was chosen for the study, with experimental noise conditions and noise sensitivity as between-factors and task difficulty as within-subject factor, meaning that each person was exposed to only one noise condition but experienced the same procedure. The experiments took place in a laboratory that was equipped with four workplaces separated by sound-insulating mobile partitions.

Each experimental session lasted about 4 h and was divided into two parts. The first part served to familiarise the participants with the experimental environment and the tasks. After detailed instructions and—if required—additional personal explanations, the participants practiced each task according to the recommendations of the Advisory Group for Aerospace Research & Development [29] while exposed to the background noise (see Section 2.3). The second part followed after a break of 15 min. The participants performed, as schematically outlined in Table 1, three different tasks each of which was assigned with two

Table 1
Schematic course of the experimental session

Tasks (14 min)	Six 20 min periods (3 performance tasks, 2 levels of difficulty) permuted sequence					
	Task 1 (MPTe)	Task 2 (GRTe)	Task 3 (FLTe)	Task 4 (MPTd)	Task 5 (GRTd)	Task 6 (FLTd)
Rating (6 min)	Annoyance mood	Annoyance mood	Annoyance mood	Annoyance mood	Annoyance mood	Annoyance mood

MPT: mathematical processing task; GRT: grammatical reasoning task; FLT: figural logic task; e: easy; d: difficult.

levels of difficulty. Each task was completed during the first 14 min of a 20-min period. Then the participants rated their annoyance and moods and started to work on the next task after a short break. To rule out potential sequence effects the six tasks were systematically permuted.

2.3. Noise load

A background noise was constructed as a steady flow of passenger cars made from recordings of noise from single pass-bys. The SEL value for each pass-by was adjusted randomly within ± 3 dB and the interval between each vehicle was 5 ± 2 s. A number of such sequences were superimposed to generate a noise where single pass-bys could no longer be identified. This noise was applied during the control condition with $L_{\text{AeqT}} = 43.6$ dB and $L_{\text{Amax}} = 48.7$ dB. Realistic road traffic scenarios (of 2 h duration) with 1440 rather evenly distributed pass-bys of passenger cars were applied during both the other conditions. The pass-by sound of either a tram (Polish tram type 105N) or of a bus (NEOPLAN N4020) that occurred on average every 60 s was superimposed onto this scenario. The L_{Amax} of each tram and bus was 10 dB higher than average L_{Amax} of passenger cars. The L_{AeqT} of resulting scenarios was 55 dB in both conditions, L_{Amax} was 68.6 dB in the condition ‘tram’ and 67.2 dB in the condition ‘bus’.

The noises were amplified using a Behringer 4-Channel Headphones Distribution Amplifier Type HA4700 and presented via open headphones (AKG 501). The noise levels were adjusted with a calibration signal according to the level of the scenarios at the ear side of the headphones using the sound-level metre Brüel & Kjær 2238.

2.3.1. Cognitive tasks

To address different cognitive resources three standardised types of tasks were assigned, each with two levels of difficulty. The difficulties of the GRT and the mathematical processing task (MPT) have been well evaluated by Schlegel and Gilliland [30]. The single tasks of the figural logic task (FLT) were divided into easy or difficult tasks by means of the reaction time recorded in a previous study [31].

A grammatical reasoning task (GRT) developed by Baddeley [32] was applied in a version provided by Shingledecker [33]. This test mainly requires working memory and tests the ability of logical processing. The participants are requested to assess the agreement of a sequence of symbols (e.g. # & *) with (a) previously presented statement(s) (e.g. ‘& after #’, ‘& before *’). If the sequence of symbols agrees with the previous statement(s), the response is ‘equal’, if not the response is ‘different’. The level of difficulty was varied by the application of one (low demand) or two statements (high demand).

The MPT is a standardised loading task designed to place variable demands upon information-processing resources associated with the manipulation and comparison of numerical stimuli [30]. The participants have to perform one or more simple operations (addition, subtraction) on visually, individually presented single digit numbers to determine whether the result is lower or higher than a prespecified value (5). Task difficulty is manipulated by using one-operator problems (low demand) or three-operator problems (high demand).

The FLT identifies the recognition and application of rules, respectively, with statements on a figural level. The stimuli consist of three rows; the first two of which consist in sequences of three graphic images. The third row contains two images and the participants have to decide whether one of eight alternatives is the solution to complete the sequence.

2.3.2. Noise sensitivity

Noise sensitivity was ascertained as a well-known moderator of annoyance. It was assessed using the Noise Sensitivity Questionnaire [34] that enables the estimation of noise sensitivity globally and separately for 5 everyday situations (sleep, work, communication, habitation and leisure) [35]. As annoyance was determined during different cognitive tasks, the subscale 'work' was regarded as suitable for the present study.

2.3.3. Annoyance

Noise annoyance was assessed by means of category subdivision scaling immediately after the termination of each single task. The German version of the standardised verbal 5-point scale (not at all, slightly, moderately, very and extremely) [28,36] was presented vertically on the computer screen and each of the five categories was subdivided into ten graduations resulting in a 50-point scale. The participants were given the following instruction: 'With regard to the task you performed, how much has the presented noise disturbed or annoyed you?'

2.3.4. Evaluation and statistics

Performance was assessed by mean reaction time for each task. Reaction time was measured from the beginning of each single trial until the pressing of a response key. Recordings were made using a DT340-timer (Data Translation Inc.).

According to the experimental design, three-factorial analyses of variance with repeated measurements on the factor 'task' were conducted (3 (noise condition) $\times$ 2 (noise sensitivity) $\times$ 6 (task)). Noise sensitivity was categorised by a median split into high and low sensitivity.

3. Results

3.1. Study 1: psychoacoustic tests—comparison of the noises of a tram and a bus

3.1.1. Results of the objective analysis

Table 2 presents the averaged values calculated separately for loudness, sharpness and roughness for the two sound sources and the seven sound levels. At each test level, these psychoacoustic parameters were lower for the tram than for the bus and the difference was the greatest for loudness. The data in Table 2 suggest a bonus of about 3 dBA for the tram as compared with the bus.

In Fig. 2, the loudness patterns calculated for original and equalised stimuli i.e. for truck, bus and tram are presented.

Similar analyses were performed in relation to the railway bonus [37]. However, there is a main difference between train and tram that is related to the loudness pattern of compared stimuli. The typical speed of a tram is much lower than that of a train. The higher speed of trains creates more high-frequency components in a

Table 2
The loudness, sharpness and roughness values calculated for the two sound sources at all the seven sound levels

Source	Sound level relative to the reference $L_{pAmax} = 74.5$ dB						
	−9	−6	−3	0	3	6	9
Loudness (sone)							
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
Sharpness (acum)							
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
Roughness (asper)							
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

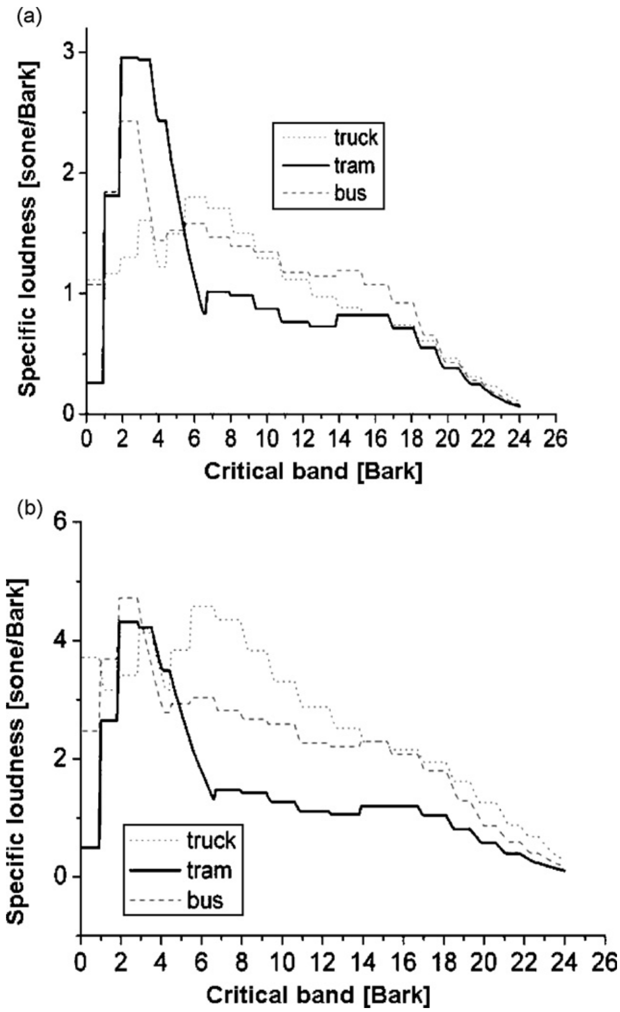

Fig. 2. Loudness patterns of three original (a) and three reference (b) stimuli.

train than in a tram spectrum. This fact also explains the lower calculated sharpness for the tram stimulus than for the bus and truck stimuli.

3.2. Results of the psychoacoustic experiment

Pearson's coefficient of correlation calculated over all 21 stimuli for all 22 subjects revealed significant concordance among the participants (on average $r = 0.73$). However, because the main objective of this study was to compare annoyance of noise generated by a tram and a bus, the annoyance judgments obtained for the heavy truck were used as reference stimuli to normalise the results obtained for the bus and tram stimuli.

For each subject, based on the annoyance judgments of a heavy truck, a weighting coefficient was calculated as a ratio of the mean of the annoyance ratings for a given subject and the grand mean of the annoyance ratings of all subjects. To normalise the annoyance data for tram and bus noises, the original individual annoyance ratings were multiplied by these coefficients (different for each subject) and then averaged to represent group data. Normalised annoyance ratings averaged over the 22 participants for the two sound sources are plotted versus sound level in Fig. 3.

The data of the 30 measurements were averaged for each subject and analysed with a two-factorial analysis of variance. In a first step, data were checked for normality by means of the ratio of skewness and kurtosis to

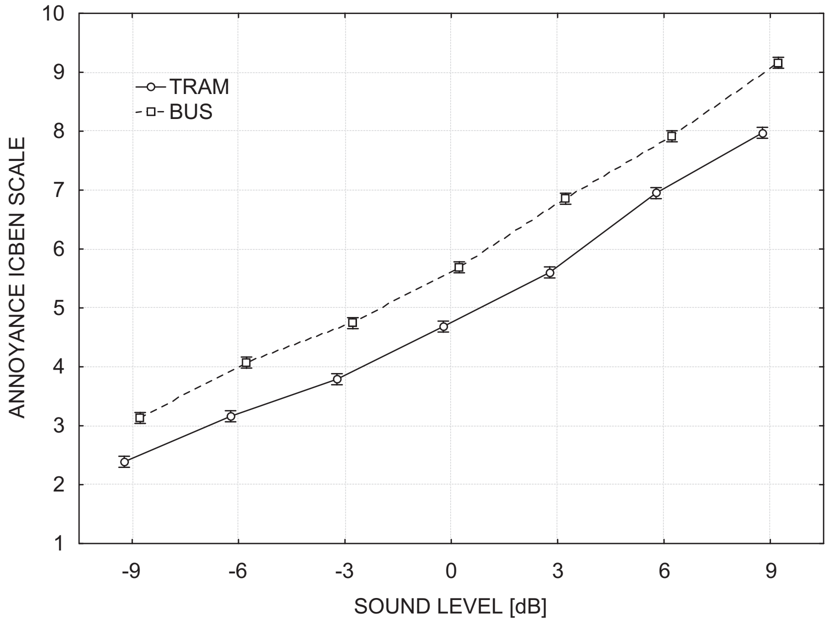

Fig. 3. Perceived annoyance scale for two different sound sources presented at seven sound levels: means and standard errors are marked in the figure.

the corresponding standard errors [38]. Data indicated that there were no substantial deviations from normality. Since the Mauchly-Test was found to be significant for the factor 'noise level' and the interaction 'source × noise level', the F-values were corrected according to Greenhouse–Geisser.

The ANOVA provided significant main effects for the factors 'source' ($F(1, 21) = 102.24$ $p<0.01$) and 'noise level' ($F(6, 126) = 141.23$ $p<0.01$) and a significant interaction 'source by noise level' ($F(6, 126) = 3.51$, $p = 0.01$). The latter indicates that the distance of the annoyance ratings were not the same at each level.

Post-hoc tests (Tukey's HSD) on the factor 'source' showed, that there are significant differences between sound sources at all sound levels. The bus was perceived as more annoying than the tram. However, no difference concerning annoyance were found when tram noises were compared with busses of a 3 dBA lower level, thus suggesting a tram bonus of 3 dBA.

One reason for the tram bonus is due to different spectral patterns of bus and truck noise versus tram noise. The data displayed in Fig. 1 could also indicate that the sharpness of the tram is lower than the sharpness of the bus or the truck. First, the spectrum of the tram stimulus is narrower than the spectra of bus and truck and second, there are more high-frequency components in their spectra comparing to the tram spectrum.

3.3. *Study 2: comparison of noises of the tram and the bus within complex noise scenarios*

To rule out any bias due to noise sensitivity and age, two one-factorial analyses of variance with 'noise condition' as grouping factor were conducted first. Confidence intervals were adjusted to 80%. Significant group effects were neither found for age ($F(2, 57) = 1.285$, $p = 0.29$) nor for noise sensitivity ($F(2, 57) = 0.046$, $p = 0.96$). As shown in Table 3, differences between the three groups determined by 'noise condition' are negligible as far as age and noise sensitivity are concerned.

3.3.1. *Annoyance*

The three-factorial analysis of variance with repeated measurement on the factor task provided significant main effects for the between-factors 'condition' ($F(2, 54) = 6.181$, $p<0.01$) and 'noise sensitivity' ($F(1, 54) = 7.266$, $p<0.01$) and for the within-subject factor 'task' ($F(5, 270) = 15.547$, $p<0.001$). A significant interaction was observed for the factors 'noise sensitivity' and 'task' ($F(5, 270) = 2.612$, $p = 0.025$), meaning

Table 3
Descriptive statistics of age and noise sensitivity

Noise source/condition	Tram	Bus	Control
Sample size	20	20	20
Age (mean/SD)	23.5 (2.46)	22.3 (3.18)	23.7 (3.07)
Noise sensitivity (mean/SD)	1.64 (0.49)	1.64 (0.40)	1.68 (0.53)

Table 4
Mean annoyance ratings (and standard deviations) immediately after completion of the different tasks

	Main effects	GRT	MPT	FLT
Condition				
Tram	15.7 (11.22)	19.8 (10.97)	13.6 (9.50)	13.8 (9.56)
Bus	23.5 (11.91)	25.6 (11.09)	24.6 (9.28)	20.4 (11.79)
Control	14.4 (12.00)	16.7 (12.60)	13.9 (11.39)	12.6 (9.38)
Noise sensitivity				
High sensitive	21.0 (12.84)	24.7 (10.72)	20.0 (11.06)	18.1 (11.35)
Low sensitive	14.8 (11.07)	16.6(10.13)	14.7 (10.63)	13.1 (9.55)
Task difficulty				
Easy	15.7 (11.69)	20.2 (11.38)	15.0 (11.75)	11.9 (11.93)
Difficult	20.0 (12.66)	21.2 (12.78)	19.7 (12.32)	19.2 (13.01)

that annoyance increased in noise sensitive participants when task demands are high. Regarding the means in Table 4, this is particularly the case for the FLT.

Post-hoc tests (Tukey's HSD) on the factor 'noise condition' showed that the condition 'bus' differed from the 'control' condition ($p = 0.005$), and from the condition 'tram' ($p = 0.02$), and the latter did not differ from the 'control' condition ($p = 0.88$). According to Table 4, the scenario with the bus was rated most annoying, followed by the scenario with the tram and the control condition. As far as the factor 'noise sensitivity' is concerned it is obvious that people who are more sensitive to noise gave higher annoyance ratings. If the factor 'task' is accounted for, it is salient that annoyance was greater in more demanding tasks.

3.3.2. Performance

According to the experimental design, data were analysed with a three-factorial analysis of variance with repeated measurements on the factor 'task'. Since the assumption of sphericity was not met, adjustment of the degrees of freedom was made according to Greenhouse–Geisser. The analysis provided a significant main effect for the within-subject factor 'task' ($F(1.07, 57.803) = 294.513$, $p < 0.001$). Neither other main effects nor interactions became statistically significant. As the difficulties of the different tasks were varied, this effect was expected.

4. Discussion

The purpose of this study was to compare the annoyance caused by the noises emitted from a tram and a bus. This is relevant for city planning when it comes to decisions concerning the establishment of a suitable means of public transportation, where noise emission is a decisive criterion. This study was performed under the assumption that only sound sources were changed, all others parameters of traffic flow were kept constant (for example, distance from the residence's homes, frequency of occurrence, etc.)

The two studies performed here may contribute to the solution of this problem. Study 1, where single pass-bys of a tram and a bus were evaluated at seven levels in psychoacoustic listening tests, has shown that the tram was equally annoying as the bus with a 3 dB lower level, suggesting a possible bonus for the tram. Taking into account the calculated psychometric values, loudness and, to some degree, sharpness were responsible for the different annoyance ratings of the sounds of the tram and the bus. Both these noises were then presented within a complex noise scenario when the participants worked on cognitive tasks of various difficulties in study 2. The scenario with the tram was significantly less annoying than the scenario with the bus, though the maximum levels were by 1.4 dBA higher than in the scenario with the bus. This may support the possibility of a tram bonus as indicated by the psychoacoustic tests.

Several studies have focussed on the possible differences between rail and road traffic noise but, to the best of our knowledge, no other comparative studies concerning trams and busses are available: previous discussions only refer to studies where road traffic noises were compared with railway noises. The possible bonus for the tram was, with 3 dBA, lower than the rail bonus of 5 dB obtained by Fastl et al. [39], which may be due to a large variety of possible reasons. These are, for example, differences concerning frequency spectra, temporal acoustic infrastructures, the distances from the residents, the lengths and the speed of the vehicles, etc. On the other hand, recently reported studies on the effects of railway noise suggest that the bonus might be less than assumed [40,41]. The newly revised standard ISO1996, part 1, [42] suggests a rail bonus of between 3 and 6. However, according to the standard, this bonus does not apply to long diesel trains and trains travelling at speeds exceeding 250 km/h. Trams and city trains are not specifically addressed in this standard.

Annoyance in the second experiment was understood as a feeling of displeasure resulting from the interaction of noise with actual activities, i.e. tasks varying in terms of how demanding they were. When the noises of the tram and the bus were presented within a complex scenario that simulates a realistic traffic situation, annoyance ratings were generally highest in the condition 'bus', regardless of the type and the difficulty of the task performed. The lack of performance decrements may be due to sufficient practice prior to the experiments, or a high motivation to meet the requirements of the tasks and work as fast and exactly as possible. But the increase of annoyance with task difficulty, which mainly concerned the MPT and the FLT, indicates interference and might be explained by a greater need for mental capacity in the more demanding tasks and therefore less capacity for coping with the noise, which then is possibly reflected in higher annoyance. These results match the findings of Kjellberg et al. [43] who found lower annoyance ratings in persons working in less demanding tasks compared with those working on tasks with high demands.

Assuming similar effects for the noises of trams and trains, the results contradict those of Ma and Yano [14] who found no differences in annoyance between situations with exposures to rail and road traffic noises when their subjects performed—as in this study—visually presented tasks.

With regard to noise sensitivity, it was expected that sensitive persons would be more annoyed and possibly more disturbed during task processing. However, only the first assumption i.e. greater annoyance in sensitive persons proved to be true, whereas no significant performance decrements were found, neither in the sensitive nor in the rather robust persons and irrespective of the tasks and the noise conditions. The results are congruent to Ljungberg and Neely [44] who could not find effects on the performance level in a GRT, but revealed higher annoyance ratings in noise sensitive persons, and to the findings of Belojevic et al. [12], who conducted an experiment with different cognitive tasks and also found a higher degree of annoyance in noise sensitive persons. In total, this finding is in line with Miedema and Vos [26], who argue that noise sensitivity is less associated with the actual interference of noises, but more with the evaluation of these disturbances, where the interaction effect of task and noise sensitivity supports the assumption that sensitive participants were more annoyed when processing tasks with high demands.

4.1. Limitations

The study is limited by several aspects. Firstly, the comparison of the noises of only one tram and only one bus is certainly insufficient for generalisation, though representative recordings from a large database established within the EU-funded integrated project 'SILENCE' were chosen for the experiments. Secondly, the frequency of busses and trams of about every minute was very high, but due to the limited exposure of only 2 h this frequency seems to be justified. Thirdly, trams operate less often than busses due to a usually greater capacity (in terms of number of passengers). But as trams were already less annoying than buses, despite the higher maximum level (1.4 dBA), it is expected that annoyance would decrease even more when the trams pass less often than busses. Another argument concerning the transferability to the field where habituation or sensitisation might take place in the long run is certainly less important, as in comparative studies the absolute values are less decisive than the relation between two (or more) conditions [45–47].

A possible outcome of both of the studies performed here is that the calculated loudness of single pass-bys of a tram and a bus was suitable for predicting annoyance in the psychoacoustic listening tests and that the difference in annoyance was again verified when the same noises were presented within a complex scenario and when the participants performed various demanding tasks of different levels of difficulty. This suggests that further, indisputably necessary studies should be carried out, whereby different types of trams and trucks should be analysed, to give base for broader generalisations.

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