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Guidelines for noise reduction by traffic management.

This task aims at the evaluation of noise scenarios. The evaluation was performed with **psychoacoustic listening tests** and **validation tests** as described below. These tests concern the evaluation of

- differently structured traffic flow (even, uneven/clustered, Study 1),
- traffic composition concerning the amount of light and heavy vehicles (Study 1),
- traffic composition concerning vehicles for public transport (busses, trams, Study 3),
- variability of maximum levels (Study 2).

This means that the same problems were studied while using different approaches. the differently structured traffic flow (even, uneven/clustered),

o the traffic composition concerning the amount of light and heavy vehicles,
o the traffic composition concerning vehicles for public transport (busses, trams) and
o the variability of maximum levels

were first evaluated in psychoacoustic listening tests (10 minutes noise scenarios in study 1 and 2 and single sound sources in study 3) and then in validation tests (2 hours noise scenarios). In the psychoacoustic listening tests a direct method and in the validation tests a rather indirect measure of noise annoyance assessment was applied. While the psychoacoustic listening tests focused on the 'psychoacoustic part of annoyance', the validation tests respected the real-life situation, where annoyance results from interference with actual activities, here with the solution of more or less strenuous cognitive tasks.

In both approaches, however, the subjects assessed noise annoyance by answering standardized questions. In the psychoacoustic listening tests it was the Polish version of the standardized numerical 10-point scale about annoyance while in the validation tests it was the German version of the modified standardized verbal five-point scale (not at all, slightly, moderately, very, extremely).

1 The significance of traffic flow and traffic composition for annoyance and performance (Study 1)

1.1 Introduction

The most frequently ascertained extra-aural effect of noise is annoyance, defined as any feeling of displeasure, discomfort and irritation when noise intrudes into someone's thoughts and moods or interferes with actual activities. Annoyance increases with the equivalent sound pressure level of complex noise scenarios and with the maximum level of single events. As shown by Miedema and co-workers [1, 2] the sources of sounds are decisive where annoyance increases most steeply with aircraft and the least with railway noises. Among the physical parameters of noise the frequency spectra and temporal structures are thought to influence the degree of noise annoyance significantly. Concerning the temporal structures it is important to distinguish between two sources:

- The microstructure is related to the pass-bys of single vehicles. The temporal microstructure contains the specific information of a vehicle and comes into the fore particularly with long vehicles (e.g. freight trains or trucks with trailers).
- The macrostructure is determined by traffic flow, the timetables of railway traffic and of air traffic or concerning road traffic by traffic lights as well as by the mixture of light and heavy vehicles.

This study focused on road traffic noise which was presented experimentally in a rather evenly and in a lumped version. Moreover, the composition of light and heavy vehicles was varied with an amount of heavy vehicles of 0 %, 20 % and 40 %. Apart from the physical parameters of noise the degree of annoyance is, as repeatedly shown in numerous social surveys and experimental studies, greatly influenced by noise sensitivity [e.g. 2-6].

Noise sensitivity is as a rule ascertained by self-report, most frequently in field studies by a single question, in experimental studies and less extended social surveys, however, by multi-item questionnaires. Most of these questionnaires [5-7] determine noise sensitivity globally. But as already supposed by Zimmer and Ellermeier [6] it is conceivable to assume that noise sensitivity varies in different situations. Therefore the present study used the noise sensitivity questionnaire (NoiSeQ) that allows the differentiated determination of noise sensitivity separately for different everyday activities, namely sleep, habitation, work, communication and leisure [8].

The degree of annoyance depends as well on the actual activity. Therefore the participants in this study performed differently strenuous mental tasks which were applied with two levels of difficulty each. In addition heart rates were recorded continuously throughout the entire sessions. Thus annoyance, performance and physiological reactions were recorded simultaneously. This analysis presents, however, only the effects of noise on annoyance and performance.

This study includes both, the results from the psychoacoustic listening tests and the validation tests.

1.2 Materials and Methods

1.2.1 Psychoacoustic listening tests

<u>Participants</u>. Twenty one persons (14 men, 7 women, 20-28 yrs) took part in the experiments. All participants qualified as having normal hearing (defined as the audiometric threshold of 20 dB HL or better for the frequency range from 250 to 8000 Hz, according to ANSI standard [34]).They were paid for their participation.

<u>Design and procedure</u>. Each of five scenarios was assessed by 21 participants three times. The whole experiment was carried out in five sessions that lasted 40 minutes each. In each experimental session the participants judged three different scenarios of 10 minutes duration with 5 minutes pause between them. During one day they participated at most in two such sessions – one in the morning and the second in the afternoon.

The experiments took place in a laboratory that was equipped with eight workplaces. The participants listened to the sounds via headphones. After each 10 minutes scenario the participants assessed annoyance of the noise they heard. They were also instructed to judge the annoyance of the noise continuously (during 10 minutes of noise exposition) by turning a knob that has a scale from 0 to 10. It was done only in order to keep the participants' attention on the noise. The results of these responses are not yet presented here.

<u>Noise load</u>. Five road noise scenarios with a duration of 10 minutes each and a traffic density of 12 vehicles per minute were presented at L_{Aeq} = 55 dB with a rather even traffic flow (three scenarios with 0%, 20% and 40% of heavy vehicles) and a clearly lumped traffic flow (two scenarios where the amount of heavy vehicles was set to 20 and 40 %).

The level was calibrated by using a PEQ IV.1 programmable equalizer from Head Acoustics. The PEQ IV.1 also served as a headphone amplifier. The stimuli were presented via Sennheiser HD600 headphones, which were individually calibrated by HEAD acoustics company.

The noise scenarios were constructed in the same way as described below for the validation test. The only difference is duration, in psychoacoustic listening test 10 minutes noise scenarios were applied while 2 hours noise scenarios were used in a validation test.

Annoyance rating. In the psychoacoustic listening tests the internationally standardized [15] numerical 10-point annoyance scale was used. Noise annoyance was assessed immediately after the termination of each 10 minutes noise scenario. This numerical annoyance scale is equivalent to the Polish version of the standardized verbal five – point and by definition with a German version of annoyance scale. This makes possible to compare the results of both experiments. In psychoacoustic listening tests the participants were given the following instruction: 'What number from zero to ten best shows how much you are bothered, disturbed, or annoyed by the 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'.

Evaluation and Statistics. Noise annoyance was assessed by mean annoyance rating averaged for all 21 participants and the amount of errors for each noise scenario.

A within-design was chosen to study annoyance with repeated measurements on the factor noise condition (5 noise conditions).

1.2.2 Validation tests

Participants. One-hundred and twenty healthy and normal hearing young persons (60 men, 60 women, 18-31 yrs) participated and gave their written consent to the study which was approved by the Local Ethics Committee.

Design and procedure. According to the aim of the study 10 men and 10 women each were assigned to four groups defined by the amount of heavy vehicles (20 or 40 %) and traffic flow (even or lumped, see Table 2 in Section 3: Results). Again 10 women and 10 men were assigned to the two control groups (see Section 2.3: Noise load). Each person was exposed to only one noise condition but all participants 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 four hours and consisted of two parts. During the first two hours the participants were familiarized with the experimental environment and the mental tasks that were applied in the second part. After detailed instructions and – if required additional personal explanations – the participants practiced each task while exposed to the background noise (see Section 1.3.3: Noise load). The second part followed after a break of 15 minutes and consisted of two hours that were subdivided into six 20-minute sections. The participants performed, according to Table 1.1, three different tasks each of which was applied with two levels of difficulty. To rule out potential sequence effects the six tasks were systematically permuted. The tasks were completed during the first 14 minutes of each section. Then the participants rated their annoyance and mood and worked, after a short break, on the next task.

Noise load. A background noise was constructed as a steady flow of passenger cars made from recordings of noise from single pass-bys. The sound exposure level of each pass-by was adjusted randomly within limits of ± 3 dBA and the interval between each vehicle was set to 5 ± 2 seconds. Several of such sequences were superimposed to generate a noise where single pass-bys could no longer be identified. The resulting noise was applied during the control condition C with L_{AeqT} = 43.6 dB and L_{Amax} = 48.7 dB. Realistic road traffic scenarios (of 2 hours duration) with 1440 pass-bys were applied during the other conditions. There were 3 conditions with a rather even traffic flow, where one vehicle occurs on average every 5 seconds with time intervals between the maximum level of each event varying between 2 and 8 seconds. The 3 conditions differ with respect to the mixture of heavy and light vehicles. The percentage of heavy vehicles amounts 0 %, 20 % and 40 %. The respective conditions are labelled as E0, E20, and E40. The level (L_{Amax}) of each event is adjusted within a range of ± 3 dB, and the average difference between the level of a light and a heavy vehicle is 8 dB. Condition E0 is taken as a second control condition. Two other conditions correspond to the conditions E20 and E40, where the traffic flow is, however, lumped with clusters consisting of 12 vehicles each and occurring every minute. These conditions are labelled as L20 and L40. The corresponding situations E20/L20 and E40/L40 consist of identical vehicle fleets, where only the time pattern varies. Each of these conditions was superimposed to the background noise as described above. The sound sequences are based on outdoor recordings. They have been filtered so that the sound appears as if heard indoors.

The noises were amplified using a Behringer 4-Channel Headphones Distribution Amplifier Type HA4700 and presented via open headphones (AKG 501). The noise level at the ears of the participants was adjusted using the sound-level meter Brüel & Kjær 2238.

Cognitive tasks. To address different cognitive resources three standardized types of tasks were assigned each with two levels of difficulty. The difficulties of the grammatical reasoning task (GRT) and the mathematical processing task (MPT) tasks have been well evaluated by Schlegel and Gilliland [9]. 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 [10].

A grammatical reasoning task (GRT) developed by Baddeley [11] was applied in a version provided by Shingledecker [12]. This task 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 mathematical processing task (MPT)is a standardized loading task designed to place variable demands upon information processing resources associated with the manipulation and comparison of numerical stimuli [12]. 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 [13]. Task difficulty is manipulated by using one-operator problems (low demand) or three-operator problems (high demand).

The figural logic task (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.

Table 1.1: Principal course of the experiments
(abbreviations of tasks see text, e: rather easy, d: difficult).

	3 performance tests with 2 levels of difficulty each, permuted sequence					
14 minutes Tests	**Test 1 (MPTe)**	**Test 2 (GRTd)**	**Test 3 (FLTd)**	**Test 4 (MPTd)**	**Test 5 (GRTe)**	**Test 6 (FLTe)**
6 minutes Ratings	annoyance mood	annoyance mood	annoyance mood	annoyance mood	annoyance mood	annoyance mood

Noise sensitivity. Noise sensitivity was ascertained as a well-known moderator of annoyance. It was assessed using the Noise Sensitivity Questionnaire (NoiSeQ) [8] that enables the estimation of noise sensitivity globally and separately for 5 everyday situations (sleep, habitation, work, communication, leisure [14]). As annoyance was determined during different cognitive tasks, the subscale 'Work' was regarded as suitable for the present study.

Annoyance rating. Noise annoyance was assessed by means of category subdivision scaling immediately after the termination of each single task. The German version of the standardized verbal five-point scale (not at all, slightly, moderately, very, extremely) [15] 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: 'Concerning the task you performed, how much has the presented noise disturbed or annoyed you?'

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

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

1.3 Results

1.3.1 Psychoacoustic listening tests

Objective analysis. Table 1.2 gives the results of objective analysis of all noise scenarios. Besides the equivalent A-weighted sound pressure levels and the respective A-weighted maximum levels in each of the 5 noise conditions averaged as well as percentile loudness and fluctuation strength were calculated.

Table 1.2: Acoustic characteristics of 5 noise conditions

Condition	L_{Aeq} [dB]	L_{Amax} [dB]	N	N5	F	F5
Even flow E0	55,2	64,6	9,03	15,00	0,0037	0,0073
Even flow E20	54,8	67,0	8,49	14,98	0,0040	0,0087
Even flow E40	55,6	66,1	9,11	15,49	0,0041	0,0089
Lumped flow L20	55,3	71,9	5,81	16,31	0,0025	0,0056
Lumped flow L40	55,2	70,2	6,13	17,48	0,0027	0,0059

Annoyance ratings. The averaged over 21 subjects annoyance ratings and standard errors for each noise condition is presented in Figure 1.1

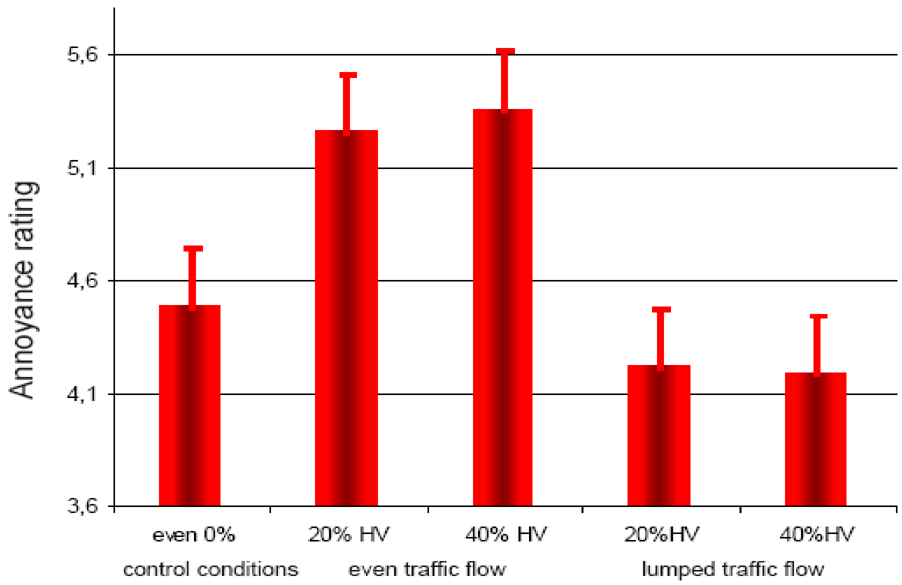

Figure 1.1: Means and standard errors of annoyance in 5 different noise conditions averaged over 21 participants

The analysis of variance with repeated measurement provided significant main effects for the factor noise condition. Post hoc-tests (Tukey's HSD) on the factor noise condition showed that there are significant differences between even 20% and even 40% comparing to even 0% and lumped 20% and lumped 40%.

1.3.2 Validation tests

Participant and noise load. Table 1.3 gives an overview over the acoustic stress, i.e. the equivalent A-weighted sound pressure levels and the respective A-weighted maximum levels in each of the six conditions and as person-related factors the means and standard deviations of the ages and the noise sensitivity of the participants in each group. Apart from the control condition (C) the equivalent sound pressure levels were about 53 dBA and the maximum levels varied between 64 and 71 dBA. The difference between the equivalent noise levels and the maximum levels (the emergences) were 5 dBA in the control condition C, 10 dB in the condition without heavy vehicles and about 12-13 dBA and 17-18 dBA in the even and in the lumped condition, respectively. Concerning age and noise sensitivity the six groups were comparable.

Table 1.3: Acoustic conditions and personal data of the participants of each of the 6 groups

Condition	L_{Aeq} [dB]	L_{Amax} [dB]	Δ	N	Age mean (SD)	Noise sensitivity mean (SD)
Control C	43.6	48.7	5.1	20	23.7 (3.07)	1.68 (0.53)
Even flow E0	53.3	63.6	10.3	20	23.5 (2.78)	1.37 (0.47)
Even flow E20	53.2	66.1	12.9	20	23.7 (2.94)	1.59 (0.33)
Even flow E40	53.1	64.6	11.5	20	24.4 (3.05)	1.80 (0.41)
Lumped flow L20	53.6	71.0	17.4	20	23.6 (3.76)	1.79 (0.42)
Lumped flow L40	52.6	70.7	18.1	20	23.9 (2.54)	1.75 (0.49)

Performance. The performance of the participants was indicated by the mean time needed for the processing of the trials (mean reaction time) and the amount of errors for each task separately. The analysis of variance revealed, however, no statistical differences between the participants exposed to different noisy conditions.

Annoyance ratings. Figure 1.2 depicts mean annoyance ratings and standard errors in the six groups which were exposed to different acoustic conditions. The control group was exposed to the background noise with an L_{Aeq} = 43 dB and thereby to a 10 dBA lower level than the other groups and these participants showed the least annoyance. Concerning the even traffic flow the Figure indicates a slight increase of annoyance with increasing amounts of heavy vehicles, but the differences between the background condition and the three noisier conditions were not significant. A similar observation concerns the lumped traffic flow, both situations caused a higher degree of annoyance where again the amount of heavy vehicles was associated with a further increase (40 vs 20 %), but as compared to the background situation the differences were again not significant.

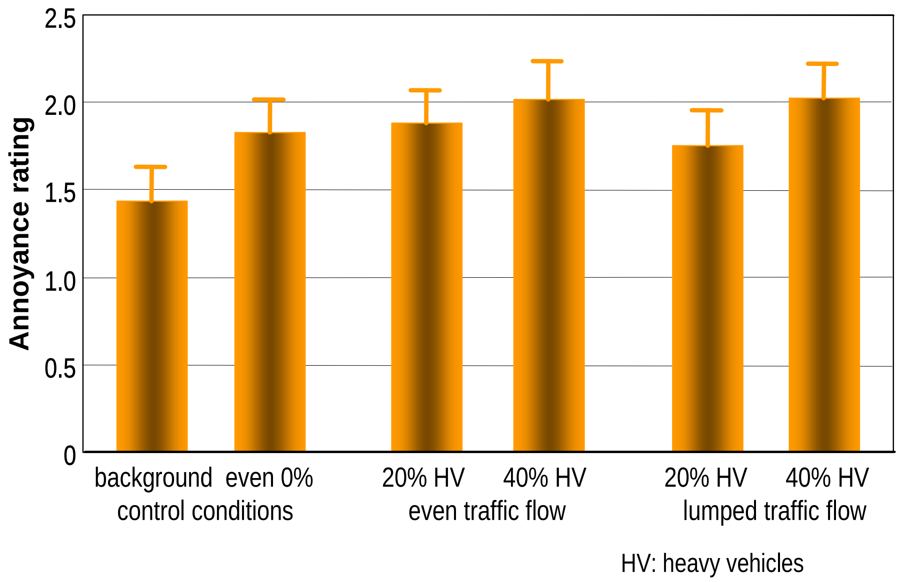

Figure 1.2: Means and standard errors of annoyance in 6 different acoustic situations with 20 participants each (10, women, 10 men, 18-31 yrs).

Figure 1.3 presents means and standard errors of annoyance ratings related to the different tasks and the two levels of difficulty. Thereafter annoyance due to noise is highest when the participants carry out the grammatical reasoning task and lowest when they perform the figural logic task. In any case annoyance is rated higher during the difficult than during the rather easy tasks, a difference that is significant for the mathematical processing task and for the figural logic task.

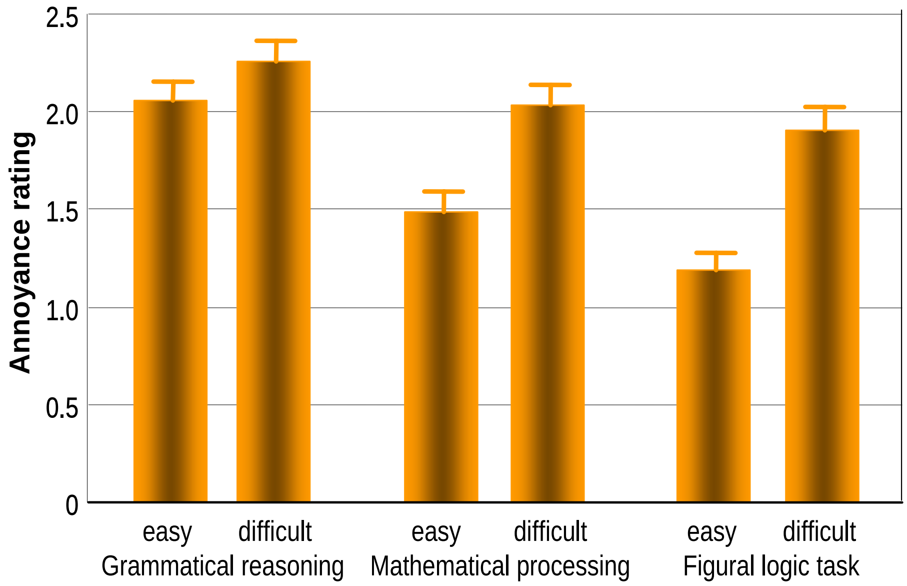

Figure 1.3: Means and standard errors of annoyance related to the type and the level of difficulty of the mental tasks (60 women, 60 men, 18-31 yrs).

Noise sensitivity. Figure 1.4 shows the effect of noise sensitivity on the annoyance rating. Thereafter more sensitive persons are, as expected, more annoyed than persons with lower sensitivity.

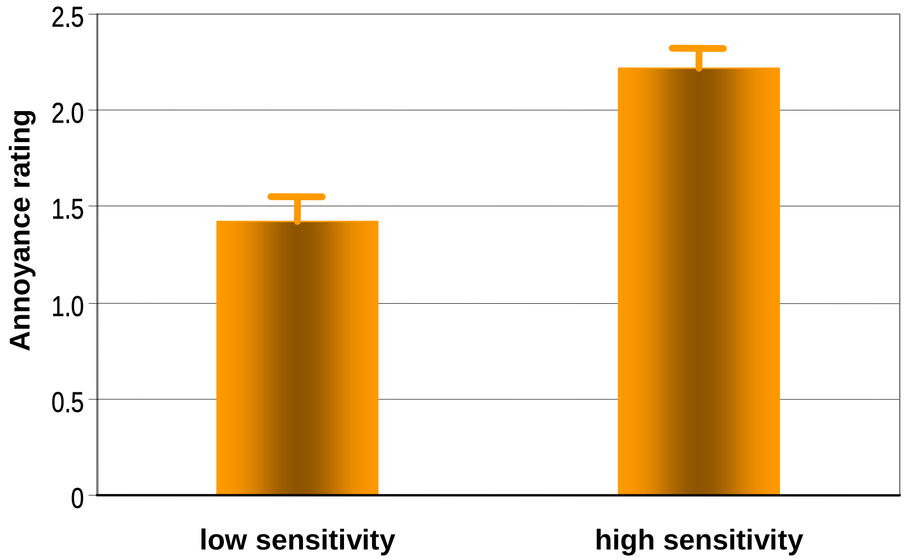

Figure 1.4: Means and standard errors of annoyance related to noise sensitivity (60 women, 60 men, 18-31 yrs).

Table 1.4 presents the results of the analysis of variance. The various noisy conditions did not significantly affect the rating of annoyance. The influence of the between-factor 'noise sensitivity' and of the within-factor 'task' was highly significant ($p < 0.001$). There were, however, neither interactions between conditions and noise sensitivity nor between the tasks and the conditions and noise sensitivity.

Table 1.4: Results of the analysis of variance (MSQS: mean square sum).

Source	MSQS	Df	F	P
Noise condition, C	532.85	5	1.22	0.31
Noise sensitivity (NS)	**10266.94**	**1**	**23.43**	**< 0.01**
C * NS	258.60	5	0.59	0.71
Error	438.20	108		
Task	**1933.48**	**4.51**	**35.64**	**< 0.01**
Task * C	61.06	22.57	1.13	0.31
Task * NS	66.33	4.51	1.22	0.30
Task * C * NS	41.07	22.57	0.76	0.78
error (task)	54.25	487.56		

1.4 Discussion

1.4.1 Psychoacoustic listening tests

In the psychoacoustic listening tests the 'psychoacoustic part of annoyance' was studied. The participants were exposed to the noise for relatively short time, namely 10 minutes. During that time they were able to follow the changes in acoustic characteristics of the noises they were exposed to. Definitely they have noticed the shorter and longer 'gaps' in a lumped traffic flow than in an even traffic flow noise condition. The participants' attention was focused on noise because they were asked to judge annoyance continuously by using a knob with a scale from 0 to 10. (the results of these measurements were not presented here).

Noise conditions and annoyance. Both the averaged calculated loudness and averaged fluctuation strength explain the part of the results of short time annoyance ratings obtained in this study. The relatively large ratio of loudness as well as fluctuation strength for even/lumped noise conditions could be responsible for significant differences between these two structures of traffic flow. On the other hand the difference in the loudness and fluctuation strength ratio for even40%/even20% as well as for lumped40%/lumped20% noise conditions was probably too small to be identified as a different amount of annoyance. However, the averaged calculated loudness as well as fluctuation strength for even 0% noise condition is almost the same as for the even 20% and even 40% noise conditions while participants' annoyance ratings for even 0% noise condition were lower than for even 20% and even 40% noise conditions. The only reason why the participants judged the noise condition even 0% as less annoying than even 20% and even 40% is the fact that they recognize the different sound sources in both cases. In the even 0% noise condition there were only the passengers cars while in the others even traffic flow (20% and 40% noise conditions) it was a mixture of passenger cars and heavy vehicles. This means that sound source recognition is important factor in noise annoyance assessment as it was already pointed out in a literature [35].

1.4.2 Validation tests

In this study annoyance was understood as the result from the interaction of noise with actually carried out activities [16, 17]. It was therefore advisable to force the participants in the experimental sessions to carry out controlled performance tasks 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. [18, 19] or Ma and Yano [20].

Noise load and performance. Irrelevant sounds are noises that are not related to currently performed activities. These noises were found to disturb several cognitive processes such as perception, attention and working memory [21-24]. The degree of disturbances depends on acoustic features, in particular on the temporal microstructure of noise [25, 26]. Intermittent noises in particular distract and interfere with the processes of the working memory. This consequently disturbs the perception, the storage and the processing of intruding acoustic as well as visual information. Therefore tests were chosen with high demands on working memory and concentration [27] and the difficulty of these tasks was varied by two levels each.

Despite the high demand of the tasks and the intermittent character of the road traffic scenarios at least in the conditions with lumped traffic flow the intruding noise did not cause performance decrements. This might be due to the well known ability of human beings to suppress the intruding noises deliberately at least to a certain degree. This, however, causes a higher mental load and thereby premature fatigue [28]. This might apply for the present study.

A possibly greater need of mental capacity might be reflected in higher degrees of annoyance during the execution of more difficult tasks. This would support the findings of Kjellberg et al. [29] who reported lower annoyance ratings in persons working on less demanding tasks as compared to persons working on more difficult tasks. This turned out to be true. Annoyance varied with the type of the task and was greater during the difficult as compared to the less demanding tasks.

Noise conditions and annoyance. Concerning the impact of noise on the degree of annoyance it was hypothesized that annoyance increases with the percentage of heavy vehicles and would be greater during conditions with lumped as compared to conditions with rather even traffic flow.

The equivalent noise level was in the control condition C with 43 dBA by about 10 dBA lower than in all the other conditions and the emergence was with 5 dBA about 11-12 dBA or 17-18 dBA lower than in the conditions with even and lumped traffic flow, respectively. Visual inspection of Figure 1.2 indicates the lowest degree of annoyance during the control condition C and a moderate increase with an increasing rate of heavy vehicles from 0, over 20 to 40 % and from an even to a lumped distribution of pass-bys. The lack of significant differences might be related to the relative low number of participants in each group or indicate that the various conditions are equivalent with respect to annoyance.

Noise sensitivity and annoyance. Several studies have shown that persons rating themselves as sensitive to noise are usually more annoyed by noise than less sensitive persons [4, 6, 30-32]. It was therefore expected that sensitive persons would be more annoyed and that their performance would be more degraded as compared to rather tolerant persons. However, only the first assumption i.e. greater annoyance in sensitive persons proved to be true. Significant performance decrements occurred, however, neither in the sensitive nor in the rather tolerant persons. These observations are supported by Ljungberg & Neely [33] who also did not report any effects on performance but who found higher annoyance ratings in sensitive as compared to tolerant persons. Another study executed by Belojevic et al. [18] points into the same direction. The result of this study supports the explanation of Miedema and Vos [31] who suppose that annoyance in noise sensitive persons is more related to the evaluation of these disturbances than to the interference of noise with this actual activity.

Heart rates. The heart rates did not vary with the noise conditions. They were essentially similar to those recorded in Study 2 where an example is given in Figure 2.3.

1.5 Conclusion

As the effects in this study on the extent of annoyance were not related to the various acoustic conditions the present results support strongly the idea of the energy equivalence. This conclusion applies, however only to the rather limited spectrum of noisy situations used here. Moreover, to determine the effect of the amount of heavy vehicles the equivalent noise levels were kept constant. In the real life situation an increase of the amount of heavy vehicles invariably elevates the equivalent noise level. But if both these alterations would have been realized here, it would be questionable whether alterations of annoyance could be related to the increase of heavy vehicles or to the increase of the equivalent noise level. Therefore the present results indicate the necessity to continue with this study while increasing both the percentage of heavy vehicles and the equivalent noise level.

There are two possible explanations why the results obtained in the psychoacoustic listening tests and validation tests were different concerning traffic flow. The first factor is attention and the second is duration. In the psychoacoustic listening tests participants' attention was focused on the acoustic characteristics of noise, they were forced to listen to the noise. On the contrary in the validation tests their attention was focused on the cognitive tasks. During the 2 hours cognitive works the participants were not able at the same time to perform their tasks and to follow the changes in the time structure of the traffic flow. The common result obtained in both parts of Study 1 is that no difference in annoyance judgement was observed for different amount, 20% or 40%, of heavy vehicles presented in noise scenarios.

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2 The significance of emergence for annoyance and performance (Study 2)

Study 2 was, concerning the basic design and the procedure very similar to Study 1 and could therefore be kept very short.

2. 1 Introduction

The hypothesis tested in Study 2 concerns the assumption that annoyance increases and that performance decreases gradually with emergence i.e. the difference between maximum and equivalent noise levels, i.e. the variance of maximum noise levels.

2.2 Materials and Methods

2.2.1 Psychoacoustic listening tests

Participants. The twenty one persons (14 men, 7 women, 20-28 yrs) took part in this experiment. They were the same persons as in Study 1.

Design and procedure. The design and procedure of the experimental conditions was identical to that of Study 1 that was described in detail in Section 1.2.1.

Noise load. The noise presented as a control condition was the same as in Study 1 (even 0%) i.e. a background noise constructed as a steady flow of passenger cars made from recordings of noise from single pass-bys. The three noisy conditions consisted of road traffic noise scenarios of 10 minutes each with a traffic density of 12 vehicles per minute and an amount of 20 % heavy vehicles were presented at L_{Aeq} = 55 dB with a rather even traffic flow. The actual noise loads concerning the equivalent noise levels and the maximum levels are listed in Table 2.1 in Section 2.3 (Results). The emergences, i.e. the difference between the equivalent noise level and the maximum levels were in the three conditions 8, 10, and 13 dB, respectively.

The level was calibrated by using a PEQ IV.1 programmable equalizer from Head Acoustics. The PEQ IV.1 also served as a headphone amplifier. The stimuli were presented via Sennheiser HD600 headphones, which were individually calibrated by HEAD acoustics company.

Annoyance rating. In the psychoacoustic listening tests the internationally standardized [15] numerical 10-point annoyance scale was used. Noise annoyance was assessed immediately after the termination of each 10 minutes noise scenario. This numerical annoyance scale is equivalent to the Polish version of the standardized verbal five – point and by definition with a German version of annoyance scale. This makes possible to compare the results of both experiments. In psychoacoustic listening tests the participants were given the following instruction: ‘What number from zero to ten best shows how much you are bothered, disturbed, or annoyed by the 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’.

Evaluation and Statistics. Noise annoyance was assessed by mean annoyance rating averaged for all 21 participants and the amount of errors for each noise scenario.

A within-design was chosen to study annoyance with repeated measurements on the factor noise condition (4 noise conditions).

2.2.2 Validation tests

Participants**.** Eighty young, healthy and normal hearing young persons (40 men, 40 women, at an average age of 23.6 years participated in the experiments. They gave their written consent to the study which was approved by the Local Ethics Committee.

Design and procedure . According to the aim of the study 10 men and 10 women each were assigned to three groups defined by the variance of maximum levels (see Table 2.1, Section 2.3: Results). Further 10 women and 10 men were assigned to the control group which was identical to the control group in Study 1. The participants were tested in groups of four in a laboratory where the 4 work places were separated by sound-insulating mobile partitions. Each participant was exposed to only one condition but all participants experienced the same procedure.

The procedure of the experimental conditions was identical to that of Study 1 that was described in detail in Section 1.2.2.

Noise load. The background noise was the same as described in Section 1.3.3 with L_{AeqT} = 43.6 dB and L_{Amax} = 48.7 dB. The three noisy conditions consisted of road traffic noise scenarios of 2 hours each, with a traffic density of 720 vehicles per hour and an amount of 20 % heavy vehicles. The actual noise loads concerning the equivalent noise levels and the maximum levels are listed in Table 2.1 in Section 2.3 (Results). The emergences, i.e. the difference between the equivalent noise level and the maximum levels were in the three conditions 8, 10, and 13 dB, respectively.

The noises were amplified using a Behringer 4-Channel Headphones Distribution Amplifier Type HA4700 and presented via open headphones (AKG 501). The noise level at the ears of the participants was adjusted using the sound-level meter Brüel & Kjær 2238.

Cognitive tasks. Each session consisted of 6 blocks of 20 minutes each, again subdivided into 14 minutes for performance tests and 6 minutes for the determination of annoyance using the ICBEN-scale and mood. Three performance tests, Mathematical Processing (MPT), Grammatical Reasoning (GRT), and a Figural Logic Task (FLT) were applied with two difficulties and in a systematically permuted order (see Table 1.1, Section 1.2.2). Heart rate was recorded throughout. For details please refer to Section 1.2.2.

Noise sensitivity. Noise sensitivity was ascertained as a well-known moderator of annoyance using the Noise Sensitivity Questionnaire (NoiSeQ)]. As annoyance was determined during different cognitive tasks, the subscale 'Work' was regarded as suitable for the present study.

Annoyance. To ascertain noise annoyance the internationally standardized ICBEN-scale was modified by means of category subdivision scaling (see Section 1.2.2). Ratings were performed immediately after the termination of each single task (after 14 minutes).

Evaluation and Statistics. Performance was assessed by mean reaction time measured from the beginning of each single trial until pressing a response key and the amount of errors for each task.

According to the experimental design, 3-factorial analyses of variance with repeated measurements on the factor 'task' were conducted (4 (noise condition) * 2 (noise sensitivity, low, high) * 6 (task)).

2.3 Results

2.3.1 Psychoacoustic listening tests

Objective analysis. Table 2.1 gives the results of objective analysis of all noise scenarios. Besides the equivalent A-weighted sound pressure levels and the respective A-weighted maximum levels in each of the 4 noise conditions averaged as well as percentile loudness and fluctuation strength were calculated.

Table 2.1: Acoustic characteristics of 5 noise conditions

Condition	L_{Aeq} [dB]	L_{Amax} [dB]	ΔL	N	N5	F	F5
Control	55.2	64.6	9.4	9.03	15.00	0.0037	0.0073
Δ 8 dBA	54.9	63.7	**8.8**	9.35	13.31	0.0038	0.0060
Δ 10 dBA	55.5	66.1	**10.6**	8.79	16.24	0.0038	0.0072
Δ 13 dBA	55.0	68.3	**13.3**	9.48	14.58	0.0032	0.0053

Annoyance ratings. The averaged over 21 subjects annoyance ratings and standard errors for each noise condition is presented in Figure 2.1

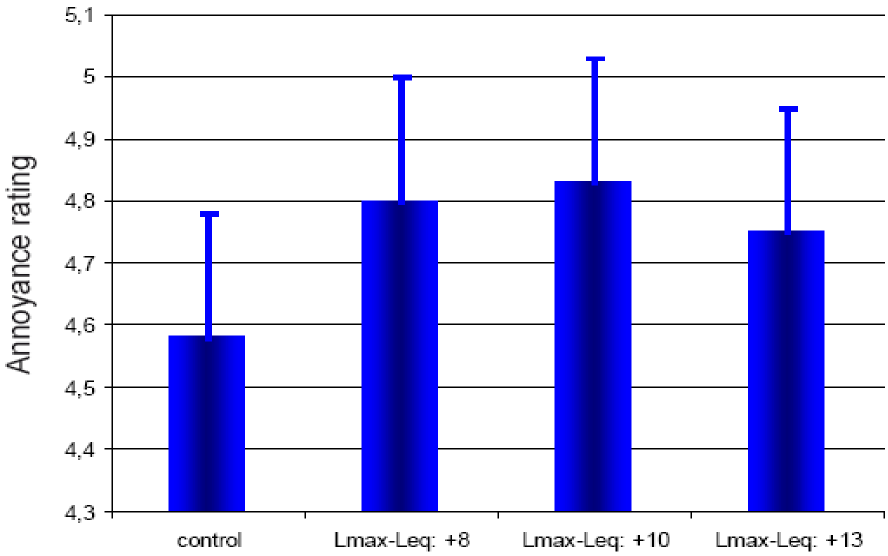

Figure 2.1: Means and standard errors of annoyance in 5 different noise conditions averaged over 21 participants

The analysis of variance with repeated measurement did not provide significant main effect for the factor noise condition. Post hoc-tests (Tukey's HSD) on the factor noise condition showed that there are not significant differences between all noise conditions.

2.3.2 Validation tests

Table 2. 2 informs about the acoustic stress, i.e. the equivalent A-weighted sound pressure levels and the respective A-weighted maximum levels in each of the four conditions and as person-related factors the means and standard deviations of the ages and the noise sensitivity of the participants in each group.

Apart from the control condition (C) the equivalent sound pressure levels were about 53 dBA and the average maximum levels varied between 63.6 and 67.3 dBA. The difference between the equivalent noise levels and the maximum levels (the emergences) were 5 dBA in the control condition C, and 8, 10 and 13 dBA in the three noise conditions, respectively. Concerning age and noise sensitivity the six groups were comparable.

Table 2.2: Acoustic conditions and personal data of the participants of each of the 6 groups

Condition	L_{Aeq} [dB]	L_{Amax} [dB]	Δ	N	Age mean (SD)	Noise sensitivity mean (SD)
Control C	43.6	48.7	5.1	19	23.9 (3.0)	1.61 (0.57)
Δ 8 dBA	54.8	64.3	10.3	19	23.4 (3.2)	1.56 (0.60)
Δ 10 dBA	53.5	64.2	10.7	20	23.2 (3.8)	1.56 (0.39)
Δ 13 dBA	54.0	67.3	13.3	20	23.9 (3.6)	1.64 (0.48)

Performance. Concerning performance the analysis of variance revealed for each of the three tasks a significant effect of the difficulty where as expected the number of errors was greater for the difficult as compared to the rather easy tasks. There was no main effect, neither for the noise condition nor for noise sensitivity.

Annoyance As annoyance due to noise is related to the actual mental demand and as this varies with the type of the task, annoyance ratings were analyzed separately for the three tasks. The results presented in Tables 2.3 to 2.5 for the Grammatical Reasoning (GRT), the Mathematical Processing (MPT) and the Figural Logic Task (FLT), respectively.

Irrespective of the difficulty as well as the noise condition had a main effect on the annoyance ratings. A greater difficulty was associated with a higher annoyance and annoyance increased with the emergence, where post-hoc tests revealed a significant difference between the control condition and the condition with the highest emergence. As it was true for Study 1 noise sensitivity had again no statistically significant effect on annoyance.

Table 2.3: Results of the analysis of variance for annoyance rating after the Grammatical Reasoning tasks

Source of variance	**df**	**MQS**	**F-value**	**P**
Difficulty (D)	1	234.88	5.91	0.02
D * C	3	55.43	1.39	0.25
D * L	1	4.80	0.12	0.72
D * C * L	3	26.82	0.68	0.57
Error (D)	72	39.74		
Condition (C)	3	1038.41	5.94	< 0.001
Noise sensitivity (L)	1	576.276	3.29	0.07
C * L	3	361.83	2.07	0.12
Error	72	174.84		

Table 2.4: Results of the analysis of variance for annoyance rating after the Mathematical Processing Tasks

Source of variance	**df**	**MQS**	**F-value**	**P**
Difficulty (D)	1	24.43	33.01	> 0.001
D * C	3	1.16	1.56	0.21
D * L	1	0.25	0.34	0.56
D * C * L	3	0.10	0.14	0.94
Error (D)	73	0.74		
Condition (C)	3	17.82	4.88	< 0.01
Noise sensitivity (L)	1	14.60	4.00	0.05
C * L	3	4.98	1.37	0.34
Error	72	3.65		

Table 2.5: Results of the analysis of variance for annoyance rating after the Figural Logic Tasks

Source of variance	**df**	**MQS**	**F-value**	**P**
Difficulty (D)	1	42.01	65.46	> 0.001
D * C	3	1.04	1.61	0.19
D * L	1	1.32	2.06	0.16
D * C * L	3	0.85	1.32	0.27
Error (D)	72	0.64		
Condition (C)	3	10.06	3.76	0.01
Noise sensitivity (L)	1	7.16	2.68	0.11
C * L	3	4.70	1.76	0.16
Error	73	2.68		

Concerning the four noise conditions there was a more or less steady increase of annoyance. As this was similar for each of the 3 tasks the data are visualized in Figure 2.2 only for the Grammatical Reasoning Test.

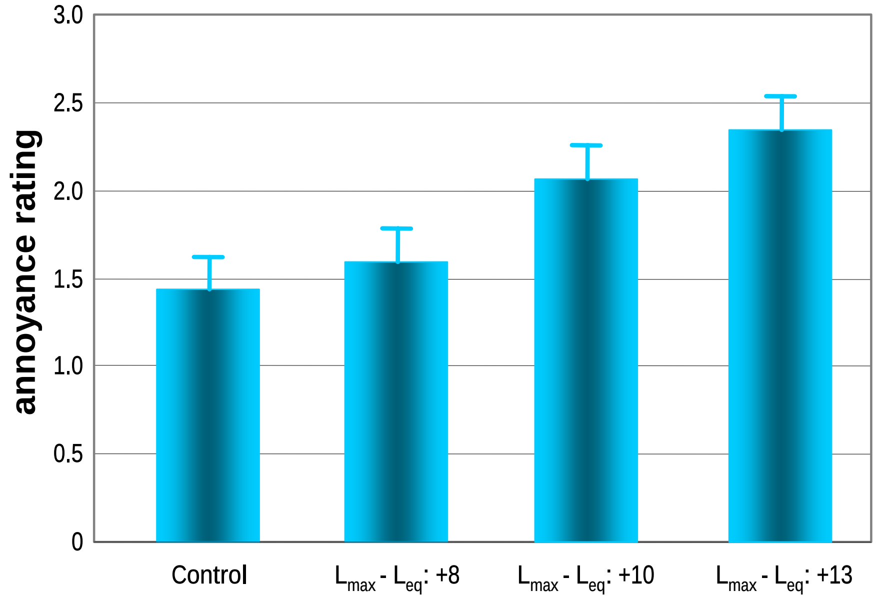

Figure 2.2: Means and standard errors of annoyance related to the three noise conditions (40 women, 40 men, 18-31 yrs).

Noise sensitivity. The effect of noise sensitivity on the annoyance rating was almost identical with the findings in Study 1 (see Figure 1.4). Thereafter more sensitive persons are. more annoyed than persons with lower sensitivity.

Heart rate .In all the studies, heart rate was continuously recorded throughout. The distances between consecutive R-peaks were used to calculate the heart rate in beats per minute. These data were then averaged over the 14 consecutive minutes during each of the tests and the acoustic conditions. As this course is almost the same the alterations of heart rates are shown in Figure 2.3 only for the easy and the difficult Grammatical Reasoning Task.

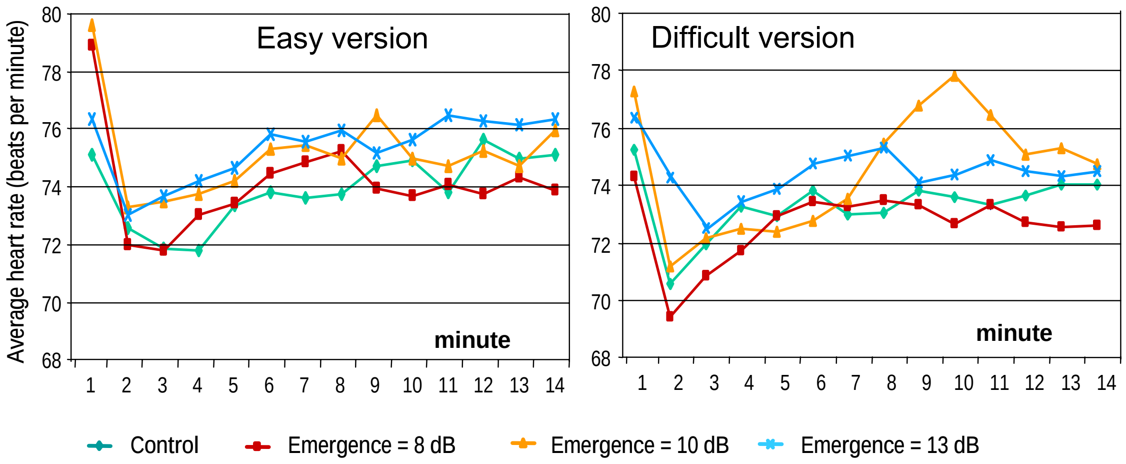

Figure 2.3: Alterations of heart rates during the Grammatical Reasoning Task

The analysis of variance was then completed for each of the 3 tasks and each level of difficulty separately. As shown in Tables 2.6 to 2.8 there was again irrespective of the tasks a significant effect only of the time. Heat rates were at the beginning of each task some beats per minute higher, fell thereafter in the second minute and increased slowly toward the end of each test. There was no effect of the noise condition nor of noise sensitivity.

Table 2.6: Results of the analysis of variance for heart rates during the Grammatical Reasoning Tasks

	Easy version				Difficult version			
Source	**df**	**MQS**	**F**	**p**	**df**	**MQS**	**F**	**p**
Time (T)	5,334	288,256	12,049	,000	3,14	435,50	5,96	0,00
T * NS	5,334	12,133	,507	,782	3,14	36,23	0,50	0,69
T * C	16,003	31,048	1,298	,195	9,43	72,33	0,99	0,45
T*NS*C	16,003	37,067	1,549	,080	9,43	56,10	0,77	0,65
Error (time)	384,084	23,924			226,25	73,08		
Noise sensitivity (NS)	1	1504,133	1,396	,241	1,00	1165,14	1,20	0,28
Condition ©	3	152,460	,142	,935	3,00	244,34	0,25	0,86
NS * C	3	1476,133	1,370	,259	3,00	871,81	0,90	0,45
Error	72	1077,301			72,00	970,18		

Table 2.7: Results of the analysis of variance for heart rates during the Mathematical Processing tasks

	Easy version				Difficult version			
Source	**df**	**MQS**	**F**	**p**	**df**	**MQS**	**F**	**p**
Time (T)	2,8	885,33	8,61	0,000	4,09	410,46	5,25	0,00
T * NS	2,8	130,703	1,27	0,29	4,09	59,38	0,76	0,56
T * C	8,5	119,30	1,16	0,32	12,27	60,78	0,78	0,68
T*NS*C	8,5	115,05	1,12	0,35	12,27	52,53	0,67	0,78
Error (time)	203,5	102,85			294,58	78,23		
Noise sensitivity (NS)	1	717,05	0,70	0,41	1,00	2290,30	2,48	0,12
Condition ©	3	28,12	0,03	0,99	3,00	495,28	0,54	0,66
NS * C	3	1124,81	1,09	0,36	3,00	519,46	0,56	0,64
Error	72	1031,36			72,00	924,76		

Table 2.8: Results of the analysis of variance for heart rates during the Figural Logic Tasks

	Easy version				Difficult version			
Source	**df**	**MQS**	**F**	**p**	**df**	**MQS**	**F**	**p**
Time (T)	7,38	241,58	19,79	0,00	5,29	172,80	6,01	0,00
T * NS	7,38	8,96	0,73	0,65	5,29	24,38	0,85	0,52
T * C	22,13	16,05	1,31	0,15	15,87	17,88	0,62	0,87
T*NS*C	22,13	8,43	0,69	0,85	15,87	29,32	1,02	0,43
Error (time)	531,11	12,21			380,96	28,76		
Noise sensitivity (NS)	1,00	974,64	0,86	0,36	1,00	1754,99	1,74	0,19
Condition ©	3,00	463,65	0,41	0,75	3,00	184,12	0,18	0,91
NS * C	3,00	1654,95	1,46	0,23	3,00	1263,95	1,25	0,30
Error	72,00	1137,01			72,00	1007,94		

2.4 Conclusion

The hypothesis that annoyance increases with increasing emergence was verified here. The results suggest to reduce emergence e.g. by avoiding heavy vehicles at least during times where people are particularly vulnerable against the impact of noise, particularly during the evening.

In the psychoacoustic listening tests no statistically significant differences were observed. The calculated averaged loudness and fluctuation strength can explain these results. This explanation can be supported by the fact that in all noise scenarios the same types of sound sources were presented. When people are familiar with sound sources usually they do not pay attention to the exact values of physical characteristics of noise. In these cases there is a clear difference in LAmax value among the noise scenarios. However, these differences do not create the different annoyance ratings. Generally, it is more difficult to scale absolute than the relative annoyance rating of noises that are generated by the sound sources that are familiar to the participants.

3 Experimental studies on annoyance caused by noises from trams and buses (Study 3)

The evaluation of single noises was performed in Poznan (Poland, IA UAM), Scenarios were created in Trondheim (Norway, SINTEF) and the evaluation of the scenarios in Dortmund (Fed. Rep. Germany, IfADo). The interpretation was done in co-operation of all partners.

Summary

Acute annoyance due to noise from trams and buses was ascertained and compared in two experimental studies. First, 21 healthy young persons (19-22 yrs) using a standardized 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-hour realistic road traffic scenario in the second study. This study was conducted with sixty healthy young persons (18-31 yrs). Twenty participants were each exposed either to the scenario with the tram or the bus (LAeqT = 55 dB(A)) or to a control condition (L_{AeqT} = 43.6 dB(A)) 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.

3.1 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 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 and co-workers [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 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. Firstly, trams are usually less distant from residents' homes than railway tracks; secondly, their frequency spectra and temporal acoustic microstructures are different; thirdly, as a rule trams pass more frequently; and lastly, and probably most importantly, noises from trams are usually combined with realistic road traffic noise.

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.

This was done in two steps. Psychoacoustic listening tests were performed first at the Institute of Acoustics at Adam Mickiewicz University Poznan, Poland, where annoyance was related to the single pass-bys of a tram, a bus and a truck. 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 SINTEF (Stiftelsen for industriell og teknisk forskning ved Norges tekniske høyskole) in Trondheim, Norway.

In this second study annoyance was understood as the result from the interaction of noise with actually carried out activities [4-6]. 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. [7, 8] or Ma and Yano [9].

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 [10-13], or at least cause premature fatigue due to coping strategies[14]. The degree of disturbance depends on acoustic features, in particular the temporal microstructure [15, 16]. 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. 17, 18]. 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 [19, 20, 7, 21, 22, 23, 24]. Therefore this personality trait and moderator for the evaluation of annoyance was ascertained as well..

3.2 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.

Experiment 1: Comparison of noises emitted from a tram, a bus, and a truck

Participants. Twenty-one healthy listeners with normal hearing (3 women, 18 men, 19-22 years) participated in the experiment (normal hearing was defined as hearing thresholds ≤ 20 dB HL between 250 to 8000 Hz).

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 meters 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 normalize the differences between the individual subjects.

Each stimulus was of 6 seconds duration and was equalized with respect to the maximum A-weighted sound pressure level (L_{pAmax}) to 74.5 dB, which was then used as a reference level (0 dB). The level was calibrated by using a PEQ IV.1 programmable equalizer 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.

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

Each stimulus was presented at 7 levels with –9 dB, –6 dB, –3 dB, 0 dB, +3 dB, +6 dB 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-minutes sessions – one session per day. Annoyance was judged after each stimulus, using the ISO standardized scale (ISO/TS 15666:2003)[25] 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? 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

Experiment 2: Comparison of noises of the tram and the bus within complex noise scenarios

Participants. Sixty healthy people with normal hearing (30 men, 30 women, 18-31 yrs) participated in the study where 10 men and 10 women each were randomly assigned to one of three groups ('tram', 'bus', 'control').

Design and procedure. A mixed 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 four hours and was divided into two parts. The first part served to familiarize 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 AGARD (Advisory Group for Aerospace Research & Development) [26] while exposed to the background noise (see Section 'noise load'). The second part followed after a break of 15 minutes. The participants performed, as schematically outlined in Table 3.1, three different tasks each of which was assigned with two levels of difficulty. Each task was completed during the first 14 minutes of a 20-minute 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.

Table 3.1: Schematic course of the experimental session (MPT: mathematical processing task, GRT: grammatical reasoning task, FLT: figural logic task, e: easy, d: difficult)

	Six 20 min periods (3 performance tasks, 2 levels of difficulty) permuted sequence					
Tasks (14 min)	**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

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 seconds. 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_{AeqT} = 43.6 dB and L_{Amax} = 48.7 dB. Realistic road traffic scenarios (of 2 hours 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 seconds was superimposed onto this scenario. The L_{Amax} of each tram and bus was 10 dB higher than average L_{Amax} of a 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 level at the ears of the participants was adjusted using the sound-level meter Brüel & Kjær 2238.

Cognitive tasks. To address different cognitive resources three standardized types of tasks were assigned, each with two levels of difficulty. The difficulties of the GRT and the MPT tasks have been well evaluated by Schlegel and Gilliland [27]. The single tasks of the FLT were divided into easy or difficult tasks by means of the reaction time recorded in a previous study [28].

A grammatical reasoning task (GRT) developed by Baddeley [29] was applied in a version provided by Shingledecker [30]. 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 mathematical processing task (MPT) is a standardized 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 figural logic task (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.

Noise sensitivity. Noise sensitivity was ascertained as a well-known moderator of annoyance. It was assessed using the Noise Sensitivity Questionnaire (NoiSeQ) [31] that enables the estimation of noise sensitivity globally and separately for 5 everyday situations (sleep, work, communication, habitation, leisure) [32]. As annoyance was determined during different cognitive tasks, the subscale ‘work’ was regarded as suitable for the present study.

Annoyance. Noise annoyance was assessed by means of category subdivision scaling immediately after the termination of each single task. The German version of the standardized verbal five-point scale (not at all, slightly, moderately, very, extremely) [25, 32] 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?'

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, 3-factorial analyses of variance with repeated measurements on the factor ‘task’ were conducted (3 (noise condition) * 2 (noise sensitivity) * 6 (task)). Noise sensitivity was categorized by a median split into high and low sensitivity.

3.3 Results

Experiment 1: Psychoacoustic tests - Comparison of the noises of a tram and a bus

Results of the objective analysis: Table 2 presents the 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 dB(A) for the tram as compared to the bus.

Results of the psychoacoustic experiment.

Pearson’s coefficient of correlation calculated over all 21 stimuli for all 21 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 judgements obtained for the heavy truck were used as reference stimuli to normalize the results obtained for the bus and tram stimuli.

Table 3.2: The loudness, sharpness, and roughness values calculated for the two sound sources at all the seven sound levels.

	Sound level relative to the reference L_{pAmax} = 74.5 dB						
Source	-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

For each subject, based on the annoyance judgements 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 normalize 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. Normalized annoyance ratings averaged over the 21 participants for the two sound sources are plotted versus sound level in Figure 1.

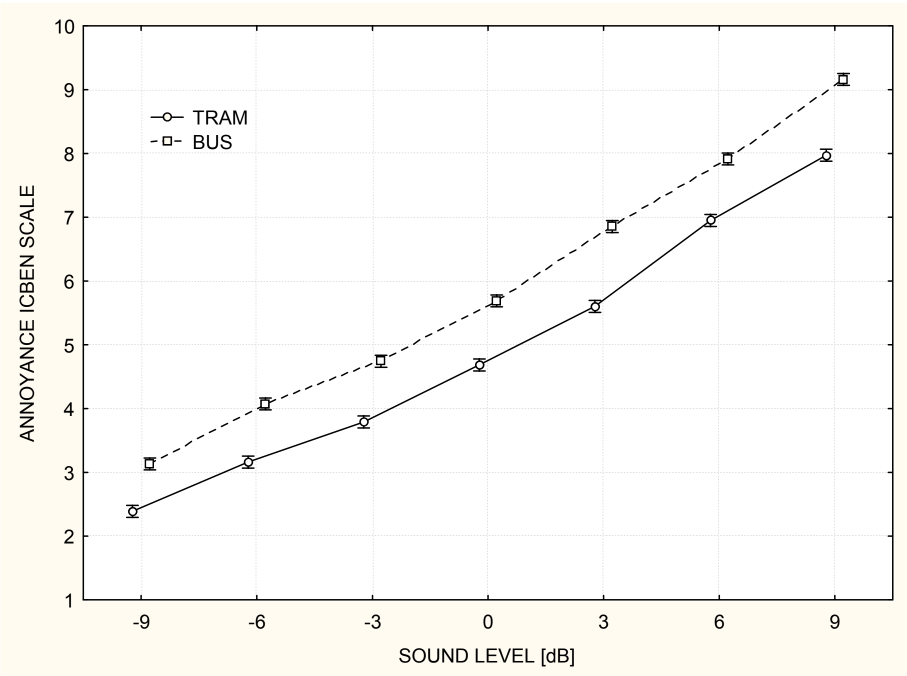

Fig. 1. Perceived annoyance scale for two different sound sources presented at seven sound levels: means and standard errors are marked in the figure.

The analysis of variance with repeated measurement provided significant main effects for the factors ‘source’ ($F (1, 406) = 943,2$ $p < 0.01$) and ‘noise level’ ($F (6, 406) = 2287,2$ $p < 0.01$).

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.

Experiment 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 3.3, differences between the three groups determined by ‘noise condition’ are negligible as far as age and noise sensitivity are concerned.

Table 3.3: 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)

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 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 3.4, 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.

Table 3.4: 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

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.

3.4 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.

The two studies performed here may contribute to the solution of this problem. Experiment 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 difficulty in Experiment 2. The scenario with the tram was significantly less annoying than the scenario with the bus, though the maximum levels were by 1.4 dB(A) higher than in the scenario with the bus. This certainly supports 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 to 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. [34] 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 [35, 36]. The newly revised standard ISO1996, part 1, [37] 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 traveling 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 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. [38] who found lower annoyance ratings in persons working in less demanding tasks compared to 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 [9] 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 & Neely [39] who could not find effects on the performance level in a grammatical reasoning task, but revealed higher annoyance ratings in noise sensitive persons, and to the findings of Belojevic et al. [7], 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 [23], 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.

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 two hours 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 busses, despite the higher maximum level (1.4 dB(A)), 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 [40, 41, 42].

Possibly the most important 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 might be possible, but with the application of a more economical procedure. It might be sufficient to complete the whole procedure performed here only in the case of relatively small differences between 2 noises concerning calculated loudness and psychoacoustic tests, whereas in the case of large differences more lavish experiments might be omitted.

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