forumacusticum 2023

EFFECTS OF NOISE ON EMPLOYEES IN A CONCENTRATION TASK: SOME RESULTS AND A CRITICAL VIEW ON THE CHOSEN PERFORMANCE TEST

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ABSTRACT

In a laboratory study on the effects of noise on cognitive performance and wellbeing, a standardised concentration-performance test (KLT-R) was applied as one of two cognitive tasks. The KLT-R consists of small arithmetic problems. Solving the problems requires concentration as well as memorization of instruction and interim results.

The study was carried out in a repeated measurement design, with an interval of around one week between T1 and T2. Each participant (N=68) worked on the test once under a silent condition and once under a condition with one of three pre-recorded experimental sounds (open-plan office, checkout at fashion retailer, construction site).

In total, results showed on average a significant increase of correctly finished items between T1 and T2, but only a small difference between the silent and the sound condition. However, the amount of this increase (T1, T2) varied with the presentation order of the acoustical conditions and slightly between the three groups with different experimental sounds.

Although a small degree of influence of noise was observed, critical issues arose whether this performance test is appropriate for studies with a repeated measurement design, especially with a very ambitious group of participants, who apparently found ways to optimise their performance between both measurement points.

Keywords: *concentration test, cognitive performance, employees, effects of noise, training effect.*

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1. INTRODUCTION

The statement that noise at work can disturb or interrupt performance in cognitive tasks is a statement that in principle many people would agree with. Previous work published in the literature also confirms that cognitive functions included in cognitive tasks, are prone to be affected by adverse acoustical conditions (for an overview see e.g. [1]). This has mainly been proven for tasks involving demands on short term memory, but there are also studies which demonstrated detrimental effects of particular acoustical conditions on other tasks or other depending variables, respectively (see e.g. [2, 3]). A closer look at the literature reveals that there are many studies reporting results from classical laboratory studies investigating effects on specific cognitive skills, but there are notably fewer studies investigating the effects of noise on performance in settings that are closer to real work environments or even in the field. Surveys often show that noise at the work place in general is a problem for many employees (e.g. [4]).

Because one of the main goals of the BAuA (Federal Institute for Occupational Safety and Health in Germany) is to protect employees from possible detrimental effects at work, our institute is interested in effects of noise on people in work environments. Although the study reported here was designed as a laboratory study, the configuration of some of the aspects was chosen in order to come closer to real occupational settings. This should be achieved as follows: the participants should be aged approximately between 30 and 60 years, the cognitive tasks should to some extent be related to tasks at real work places, the sounds should be recordings from real work environments, or they should at least be realistic for working situations.

Two experimental studies were conducted in the context of a research project with an intended duration of three years. However, the project was interrupted for nearly two years

between the first and the second study because of restrictions caused by the Covid 19 pandemic.
In the first study, a self-developed reading task was applied as the only task. In that study, which is completed, one main question was whether there is a training effect when the task is processed twice in the same acoustical condition (twice in silence, twice in noise). Results from that study regarding performance and subjective assessments were reported in [5, 6, 7]. In the second study, the main aim was to investigate whether different acoustical conditions have different effects on performance and subjective assessments, when comparing the results under a silent condition with those under conditions with a particular background sound. The training effect is still considered. In this study, a concentration-performance test was applied as a second task, in addition to the reading task. For the concentration test the "Konzentrations-Leistungstest - Revidierte Fassung - (KLT-R)" was selected [8]. The KLT-R is a standardised and normalised test procedure for children and adults.

The following sections in this contribution deal with the second study of our research project and focus on the results in the concentration test.

2. THE USE OF A CONCENTRATION TEST

Because the concentration test and a critical view on this test are in the focus of this contribution, it will be explained why this test and the paper-pencil format were chosen for this study. There are different reasons:

- In Germany, the maximum of permissible rating levels during particular activities at work places are formalised in the Technical Rule for Workplaces "Noise" (ASR A3.7 [9]; rating level: LpAeq during a particular activity plus supplements of max. 6 dB in case of impulsiveness and/or tonality and/or informational contents). There are three categories of activities with different maximum rating levels. The three categories are defined along the demand on concentration and speech intelligibility of the activities. For example, during activities at work places with a high demand on concentration or speech intelligibility, like e.g. software development, scientific work, or medical examinations, a rating level of 55 dB(A) must not be exceeded. That means, concentration is a key aspect in this regulation.
- The KLT-R exists in a paper-pencil version and also in a digital version. For this study, it was explicitly decided to use the paper-pencil version, because there should be a complement to the reading task, which had to be processed on a computer screen. Even though work in many occupations is nowadays often done using digital devices, there are still situations where written information has to be extracted from paper.
- A particular degree of concentration is needed in many cognitive tasks, in order to work on the task in a proper way. This applies, for example, for tasks involving short term memory, arithmetic, reading or listening.
- The KLT-R had already been used previously in a study by Sukowski and van de Par [10], also to investigate effects of noise on cognitive performance. In that study, a significant effect was observed with a higher number of correctly finished items in the silent condition than in the condition with background noise. Posthoc-tests revealed that the main effect derived from the sub-groups working first in the sound condition and then in the silent condition, but there was no significant training effect in the other sub-groups and the KLT-R had proven to be more sensitive to noise than another attention test with less demand on short term memory. In that study the test was carried out with a reduced number of columns, but also in a repeated measurement design.

Although it can be said that the task in the KLT-R does not really represent an everyday task at the work place and may therefore be considered to be somewhat artificial, this test was still chosen for this study based on the arguments described here.

3. METHODS

3.1 Participants

In this study, 68 persons participated in two separate test sessions. All participants were employees of the Federal Institute for Occupational Safety and Health. Some participants had to be excluded from the data analysis of the concentration test for different reasons, which were: applying a new strategy during the second session ($n = 1$), feeling unwell during the second session ($n = 2$), no glasses ($n = 1$), identified as outlier with respect to the differences between the first and the second test session in a boxplot ($n = 2$).

The age of the remaining persons (32 females, 30 males) ranged from 29 to 65 years (mean = 42.8 years; median = 38.5 years). In an initial questionnaire, in which participants were asked for their self-assessed hearing status, 57 participants assessed their hearing as normal and five reported a slight hearing loss, but without the use of any hearing device and with no noticeable problems in communication. Because it was intended to include persons in the age from 30 to 60, a slight hearing loss was explicitly mentioned as not being a criterion for exclusion during the recruitment phase. Slight differences between participants in their hearing status are not relevant for this study.

3.2 Cognitive tasks

The following tasks were applied in both test sessions:
Reading task: The reading task is a proofreading task, where participants are asked to read sentences on a computer screen and to decide whether there is a mistake in a sentence or not. All this has to be done in a predefined time. The task was developed by the author and has been continuously refined on the basis of the results from former studies. For details see [11].
Concentration task: As mentioned above, for this study the KLT-R [8] in the version for pupils (6th to 13th school grade) and adults in the paper-pencil format was applied. This test has two versions (A and B). Each version consists of 9 columns with 20 arithmetic problems each. The arithmetic problems are additions and subtractions. On the first glance they look rather simple. But the task becomes more demanding, because it is necessary for a proper solution to keep interim results in mind and also the instruction on how to proceed, depending on single results. All this has to be done under pressure of time.

3.3 Subjective assessments

After each performance test in each session all participants were asked to give their subjective assessments regarding the following four aspects: experienced effort, self-assessed concentration, self-assessed performance and experienced disturbance. All aspects were to be rated on scales ranging from 0 to 100 with respect to the previous task processing. For further details on the subjective assessments see [7 and 12] (full questions and first results from the second study [12]; first study [7]).

3.4 Sound conditions

In total three different sounds were used as background sounds, namely: (1) A recording from a work place at the checkout at a fashion retailer (short name: checkout). This sound consists of many different elements, like sounds from the checkout process, speech from employees, customers waiting at the checkout or passing this point, music, or sounds caused by the workflow of other colleagues. (2) A recording from a multi-space office with 30 work places and rooms for specific activities inside (short name: office). The sound elements in this recording include speech from different distances, like conversations inside the office, but also sounds from doors or footsteps from passing colleagues. Room acoustical measures were already in place in that office. (3) A recording from a construction site. This sound includes sounds from different machines used on the site and construction vehicles. There is no speech conversation included in this sound.

The basis for all sounds were recordings from real work places. For this study, in each case sections from the original recordings were used. The sound recordings from the multi-space office and the fashion retailer were provided by colleagues from the "Institute for Occupational Safety and Health of the German Social Accident Insurance" (IFA). For detailed information on the sounds see [13, 14]. The recordings are binaural recordings carried out with an artificial head (HEAD acoustics HSU III.2 + HEAD acoustics SQobold). To compensate for the transfer function of the reproduction chain, an equalization for realistic listening was carried out. This allowed to utilise the advantages of this high quality recording including the spatial cues in the test setting. The recording from the construction site was provided by a colleague from the "Institut National des Sciences Appliquées de Lyon" (INSA Lyon).

All sounds were presented via closed supra-aural headphones (Sennheiser HD 25). Participants wore the headphones also in the silent condition and also while answering the questions on the scales, but without any sound presentation in these situations. Table 1 shows the presentation levels for the different sounds.

Table 1. Sound pressure levels in dB(A) of the three different sounds used as background sounds.

Scene	**Leq left in dB(A)**	**Leq right in dB(A)**
Checkout at fashion retailer	62	60
Multi-space office	50	47
Construction site	65	65

3.5 Study design and procedure

Each person participated once in a silent condition and once in one of the three sound conditions. This produced three groups, hereafter called "sound groups", with "checkout" = Group 1, "office" = Group 2 and "construction site" = Group 3. The time between the first test session (T1) and the second test session (T2) should be between one week and 10 days. This could be realised in

most cases. In each session the participants worked on a different test version (A or B) of the developed reading task and the concentration test. The sequences of the test versions and the acoustical conditions were balanced. That means, regarding the acoustical conditions there were the two sequences in the KLT-R: T1 silence, T2 sound (n=31); T1 sound, T2 silence (n=31).
Each test session had several elements (see Table 2). The points 2 and 3 were only conducted during the first session. All other elements were identical in the first and the second test session and were conducted in the same order, but with different acoustical conditions.

Table 2. Sequence of the elements conducted in the test sessions. The sections dealing with the concentration test are marked in yellow.

Sequence of different sections in each test session	
1	Welcome
2	General information and informed consent
3	Short questionnaire
4	Questions on mood and tiredness
5	Reading task • Verbal and written instruction • Training without time limit • Training with time limit • Reading task itself (10-14 min.)
6	Subjective assessments regarding the task execution
7	Questions on mood and tiredness
	Break (about 10 min.)
8	Concentration task • Verbal and written instruction • Training with feedback • Concentration task itself (18 min.)
9	Subjective assessments regarding the task execution
10	Questions on mood and tiredness
11	Time for questions and feedback
12	Farewell

The study was carried out at the BAuA where the test set up was installed in a large, sound insulated laboratory (L: 8.4 m; W: 6.4 m; H: 4.2 m). Due to the Covid-19 pandemic specific protective measures were in use. Therefore, only one person participated at a time and remote control to call the computer-based elements was set up.

4. RESULTS

4.1 Performance Data

Analyses were carried out for the "number of correctly finished items". Because the test has nine columns with 20 arithmetic problems each the maximum number of correctly finished items is 180. But as for many performance tests, also this test is designed in a way that it is nearly impossible to solve all problems in the given time.

4.1.1 Range of the number of correctly finished items:

The range of the number of correctly finished items regarding both test sessions and both acoustical conditions is:

- Entire group, $N = 62$: 14 to 150 items
- Group 1 (checkout), $n = 22$: 14 to 147 items
- Group 2 (office), $n = 19$: 27 to 150 items
- Group 3 (construction site), $n = 21$: 15 to 120 items

4.1.2 Comparison of the results in the first test session (T1) and the second test session (T2)

As a first step a paired t-test (unilateral) was carried out to compare the mean values in both test sessions. The statistical analysis showed a significant effect with ([$t(61) = -11.858$, $p < 0.05$]; arithmetic mean (M) $M_{T1} = 59.94$; $M_{T2} = 74.18$). That means participants solved significantly more items correctly in the second test session than in the first test session.

4.1.3 Comparison of the results in the silent condition and the sound conditions

The statistical analysis (paired t-test, unilateral) revealed a trend when comparing the results gained in the silent condition and in the sound conditions ([$t(61) = 1.497$, $p = 0.07$]; $M_{silent} = 68.66$; $M_{sound} = 65.45$). The participants finished slightly more items in the silent condition than in the sound conditions. This result is illustrated in Figure 1.
Three further analyses were carried out separately for each sound group. The results showed a trend for Group 1 ([$t(21) = 1.540$, $p = 0.069$]; $M_{silent} = 69.95$; $M_{sound} = 64.36$), but no significant effects for Groups 2 and 3 (each $p > 0.1$).
An analysis of variance with repeated measurements, considering the between-subject factor "sound group" in addition to the within-subject factor "acoustical condition", revealed - as expected - no significant effect for the factor "acoustical condition", but a significant effect for the factor "sound group" [$F(2/59) = 4.46$, $p = 0.016$]. The posthoc-tests (Bonferroni corrected) showed a significant difference

between the results in Group 2 and Group 3 ($p = 0.012$), with a higher number of correctly finished items in Group 2 than in Group 3. No interaction between both factors was observed. All mean values are listed in Table 3.

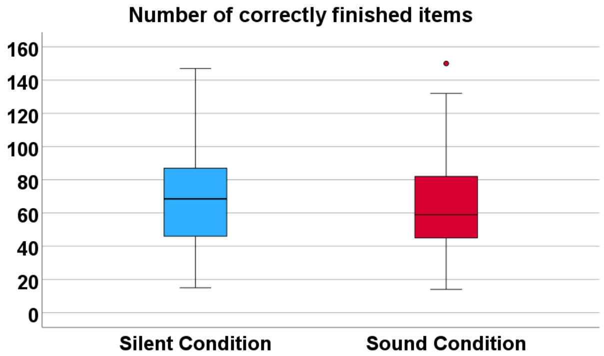

Figure 1. Boxplots showing the distribution of the number of correctly finished items in the silent condition and the sound condition ($N = 62$).

Table 3. Mean values of the number of correctly finished items in the silent and the sound conditions for the entire group and for each sound group separately.

	Mean values "number of correctly finished items"	
	Silence	Sound
Checkout	69.95	64.36
Office	81.58	80.16
Construction site	55.62	53.29
Entire group	68.66	65.45

4.1.4 Analysing the results regarding effects of different sequences of acoustical conditions

The difference between the results in the first and the second test session was calculated for all participants and both sequences of acoustical conditions: number of correctly finished items in T2 minus number of correctly finished items in T1. These differences describe the increase in performance from T1 to T2, hereafter called "training effect". A *t*-test for independent samples was applied to investigate whether there are differences between the sub-groups working with the sequence "silence-sound" and "sound-silence".
The statistical analysis showed a significant effect of the sequence ([$t(60) = -2.821$, $p < 0.01$]; $M_{silence\_sound} = 11.03$; $M_{sound\_silence} = 17.45$). The differences ranged from -3 to 38. Differences smaller than 0 were only found for six participants. Figure 2 illustrates the distribution of the differences.
This result demonstrates that the training effect is significantly higher when participants work in the sound condition first and then in the silent condition, in contrast to the reversed order.

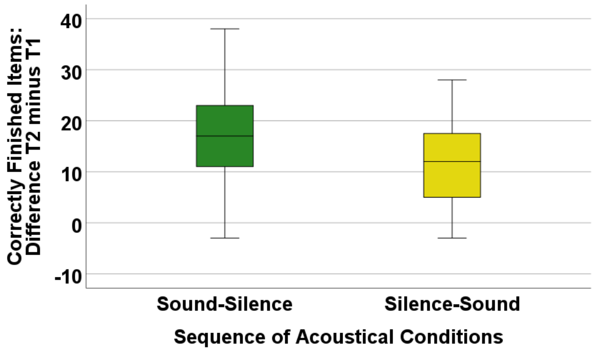

Figure 2. Boxplots showing the distribution of the differences between the number of correctly finished items in the first and the second test session separately for the two sequences of acoustical conditions (Sound-Silence; Silence-Sound). ($N = 62$).

4.2 Subjective assessments

Analyses (paired *t*-tests) were carried out to investigate whether there are differences between the assessments in the silent condition and the sound conditions. Each of the four aspects asked for was considered separately.
Regarding the entire group, the following results were found: For each aspect, the *t*-test revealed a significant difference between the assessments in the silent condition and the assessments in the condition with a background sound ($p < 0.001$). In the silent condition there were significantly lower assessments for "effort" and "disturbance" and significantly higher assessments for "self-assessed concentration" and "performance" than in the sound condition. The mean values are depicted in Table 4 (see "Entire Group").

This analysis was also carried out separately for all sound groups. In principle, the clear results observed for the entire group were confirmed. *T*-tests revealed significant differences ($p < 0.05$, unilateral) for all aspects in all sound groups. The mean values observed in each group are summarised in Table 4.

Table 4. Mean values of subjective assessments for all aspects in the silent condition and the sound condition, for the entire group and for each sound group separately.

	Mean values	
	Silence	Sound
Checkout		
Effort	65.73	76.82
Concentration	76.86	42.91
Performance	55.82	43.73
Disturbance	5.05	74.91
Office		
Effort	54.63	76.53
Concentration	77.37	41.79
Performance	52.47	42.11
Disturbance	3.95	72.58
Construction site		
Effort	75.62	84.90
Concentration	67.05	41.67
Performance	47.05	39.90
Disturbance	1.52	74.00
Entire Group		
Effort	65.68	79.47
Concentration	73.69	42.15
Performance	51.82	41.94
Disturbance	3.52	73.89

Furthermore, analyses of variance with repeated measurements were carried out involving the between-subject factor "sound group" in addition to the within-subject factor "acoustical condition". As expected from the previous results, in each analysis a significant main effect for the within-subject factor "acoustical condition" was found. With respect to "effort", a significant effect for the between-subject factor "sound group" was observed [$F(2/59) = 4.159$, $p = 0.02$). The posthoc-tests (Bonferroni corrected) showed a significant difference between Groups 2 and 3 ($p = 0.018$), with lower assessments in Group 2 than in Group 3 (mean values see Table 4). The highest assessment for the aspect "effort" was found for the sound condition in the group "construction site", with a mean value of 84.9.

Because the concentration test is in the focus of this contribution, the results for the aspect "self-assessed concentration" are demonstrated as an example in Figure 3.

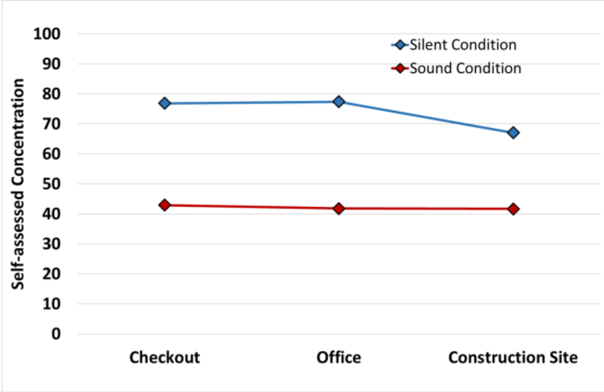

Figure 3. Interaction diagram with mean values for self-assessed concentration in the silent condition and the sound condition, separately for the three different sound groups.

5. DISCUSSION AND OUTLOOK

In this part of the study, the main findings regarding the performance data for the sounds employed here were: (1) a comparatively small effect of the acoustical condition, (2) a significant increase in performance from the first session to the second, and (3) this increase is significantly larger, when participants worked first in the sound condition and then in the silent condition than vice versa. For the subjective assessments, the effect of the acoustical condition was obvious. The ratings for the situation, when working on the task in a sound condition showed on average higher effort and disturbance as well as lower self-assessed concentration and performance.

Regarding the performance data, a striking result is the improvement from the first to the second session. In the test manual it is mentioned that participants sometimes may find strategies after a few minutes to simplify the processing of the task, but there is no hint that multiple testing will in general cause an increase in performance or that the test should not be used more than once. The test manual documents the parallelism of both test versions (A and B), but the mean values listed in the manual are from different groups and therefore do not include any information about possible training effects.

The special situation of testing colleagues might also have contributed to the observed training effect. The participants did not know the test beforehand, but after the first session they obviously did. From personal comments of the participants it can be concluded that they experienced this task as very demanding, and that they were ambitious to do a good job during the tests. Some participants even mentioned that they tried to train the calculations or applied new strategies in the second session, in order to achieve a better result. In general, all were very committed during their participation.

In a personal conversation, Prof. S. J. Schlittmeier (RWTH Aachen University) mentioned an observation she and her colleagues had made in a previous study using the KLT-R, namely that the results were better when the participants knew the investigator (unpublished results). That was the case, although all participants were reassured (like in the current study) that the analysis will be conducted on completely anonymised data. Therefore, it seems that "knowing each other", or more abstractly, the "lack of complete anonymity" might motivate participants to work more precisely or harder.

The decision to invite colleagues as participants in this study was taken due to the Covid-19 pandemic. Volunteers from out of our organisation could not be recruited, even in the time slots when no lockdowns were in place. In future studies this aspect should be taken into account. In the case that the group is mixed with respect to "knowing each other" it is recommended to record this information systematically.

Although these may be some specific explanations for the training effect in this particular study, the KLT-R should in general only be used with great care when employing a repeated measurement design in studies on noise effects. Training effects should always be reflected upon in these kinds of studies.

In a direct comparison between the results in the silent condition and the sound condition the test revealed a small effect of the acoustical condition with a higher number of correctly finished items in the silent condition than in the sound condition. This result was also observed in separate analyses in the sound group "checkout" (sound from a checkout at a fashion retailer). Two sound characteristics of this particular sound, that are also important with respect to the "rating level" (see Section 2 and [9]), should be mentioned regarding this finding: (1) In comparison to the sound from the construction site this sound included speech - namely speech from different persons, different distances and in different contexts, and also some vocal music. Speech is well known for its disturbing nature during cognitive tasks. (2) In comparison to the sound from a multi-space office, this sound was presented at a higher sound pressure level (in line with the original recording), and some particular activities in this sound were associated with certain peaks in the level (max. < 85 dB(A)). The combination of both features might therefore have led to the observation that the effect became visible.

Regarding the spontaneous comments from the participants on the sounds, the sound from the checkout was labelled most negatively, with annotations like "terrible", "horrible", or "I would go home, if I had this sound at my work place". In this study the spontaneous comments were not collected in a systematic way, but for future research a systematic acquisition should be taken into account, e.g. by an open question at the end of the test session.

In total, regarding the performance data in this study the results confirm: Sound pressure level is only one factor regarding the effects on cognitive performance. It is necessary also to consider other factors like psychoacoustic parameters or e.g. effects of the context in a specific occupational setting.

The analyses carried out for the differences between T1 and T2 showed that the size of the training effect varied with the sequence of the acoustical conditions. This can also be interpreted as a "sound effect", because working in a sound condition in the second run reduced the training effect in comparison to the reversed sequence.

After discussing the performance data, one important question is whether a possible drop in performance by adverse acoustical conditions is the only aspect we have to consider when talking about safety and health at work. The results from the subjective assessments were clear, and they showed that the personal experience when working under each of the sounds was assessed in a negative way. This even holds for the sound from the construction site, which did not include any speech. The ratings for this sound still showed higher effort, lower concentration, lower self-assessed performance and higher disturbance in comparison to the silent condition. For the aspect "effort" even the highest average in comparison to the other sounds was observed.

That means, although the time working on the task itself was comparatively short (< 20 min.), working in a condition with a background sound was a burden for the participants in any sound condition - and this is clearly expressed in the subjective assessments. Even though the effects on the performance in the cognitive tasks seem to be small, the fact that employees feel the situations with background sounds as effortful and disturbing, should be taken seriously. This enables the application of suitable measures to deliberately attenuate the noise and thereby to avoid short-term and long-term effects of adverse acoustical conditions at the work place - and this is the essential goal of occupational safety.

Regarding the study presented here, further analyses are intended: More parameters of the KLT-R will be considered, the sounds will be analysed with respect to psychoacoustic parameters, and there will be comparisons between the results in both cognitive tasks for the performance data as well as for the subjective assessments.

6. ACKNOWLEDGEMENTS

Many thanks to all colleagues from the BAuA who supported this study in several ways: “on stage” as participants, as well as “backstage” with technical support by the colleagues from the laboratory unit (Ulrich Hold, Anke Berger, Dennis Nowak and Florian Holdt) and with the assistance during scheduling the participants by the BAuA Information Center. Many thanks to Jan Selzer and Florian Schelle from the IFA for providing the realistic sound material, for installing the sounds in our laboratory and the entire helpful cooperation. Thanks a lot also to Etienne Parizet from the INSA Lyon for providing the sound from the construction site. I am very grateful that with Nina Ahrweiler an ambitious student assistant was around nearly during the entire time of the study, supporting the study by testing participants and working on data entry. Finally, many thanks to Stefan Uppenkamp and Keith Sinclair for proofreading the manuscript.

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