Observation on the Influence of Non-aoustical Factors on Perceived Noise Annoyance in a Field Experiment

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Abstract  The influence of non-aoustical factors on noise annoyance was studied in a unique field experiment. An innovative system was implemented for selecting representative participants from the Dutch population, as regards age, gender, level of education, noise sensitivity, reported anxiety, pre-exposure to train and road traffic noise, general quality of the living environment, and general health. It was grounded in 1500 participants’ responses to a specifically constructed questionnaire, which contained items from a nation-wide Dutch and Eurobarometer surveys. Finally, 100 representative participants were selected. During the experiment, which took place in a realistic setting (living room of holiday cottage), groups of 5-7 participants were asked to be seated, relax, reading a magazine or newspaper and were served refreshments. During their stay, traffic noise was reproduced in an ecologically valid way via outdoor loudspeakers. Every ten minutes, the participants were asked to assess traffic noise annoyance. At the beginning and after at least 1 hour of the experiment, participants were also asked to scale the annoyance of a set of 7 reference sounds utilized for master scaling. In this field experiment, residual effect on noise annoyance was found from non-aoustical factors like noise sensitivity, environmental worry, and health status. Even after master scaling, it seems that inter-individual variation in traffic-noise annoyance remains which is dependent on certain important non-aoustical factors.

1. INTRODUCTION

As it is well known from literature [1]-[4] that noise annoyance is only partly explained by acoustical factors such as noise level. Average noise level thus only allows to predict noise annoyance at the community level with a reasonable degree of precision. Many non-aoustical factors – social as well as personal – that influence inter-individual differences in perceived noise annoyance at the same exposure level have been identified. Transportation
noise annoyance experiments typically do not take non-acoustical factors into account, because one is only interested in average response of a large population. One often ignores the requirement that, even with this goal in mind, the panelists have to be a representative subgroup of the population under study. Particular care is needed for factors that are generally believed to be important modifiers for perception of noise annoyance, such as noise sensitivity and environmental worry. Previous work concerning the annoyance of high-speed trains and train-like transportation systems based on magnetic levitation [5]-[7] for example has been questioned on this topic, because only a small, non-representative group of panelists was used.

The present study that had noise annoyance caused by magnetic levitation trains as its primary focus, tried to solve this issue by its design. Using an innovative system, participants representative for the Dutch population were selected. Age, gender, level of education, noise sensitivity, reported anxiety, pre-exposure to train and road traffic noise, general quality of the living environment, and general health were the most important target descriptors. A master scaling transformation was applied to the annoyance data for calibrating out some of the inter-individual differences in perceived noise annoyance between panelists.

The present field experiment was also unique in the way the sound samples were presented to the panelists. A realistic home-like setting was created, in which the participants were exposed to longer fragments of sound, together with typical quiet periods in between. Traffic noise was reproduced in an ecologically valid way, using multiple outdoor loudspeakers to simulate the pass-by effect. In a previous paper [8], general annoyance results of this field experiment were already presented as a function of $L_{Aeq}$. In this paper we will focus on the observed effects of non-acoustical factors on psychophysical function and the residual effects on master-scaled noise annoyance.

**2. THE FIELD EXPERIMENT**

**2.1 Realistic Setting**

As a natural setting, a holiday cottage in Westkapelle (Zeeland, The Netherlands) was selected because of its quiet environment and accessibility. During the experiment, subgroups of participants were seated in the living room, reading a magazine, engaging in light conversation or having something to drink. Figure 1(a) shows the house and its environment.

Figure 1 – Snapshots of the house where the experiment was performed. (a) Entrance through garden to house at the left; (b) Playback equipment; (c) Artificial head placed among the panelists.
2.2 Ecologically Valid Sound Reproduction

Much attention was paid to creating a realistic reproduction of the three-dimensional indoor sound field, produced by a moving source outside the house. Because of the difficulties related to the signal processing required for producing the effect of a house via headphone playback or via indoor loudspeakers, and because these systems would diminish the natural feeling of the experimental room, it was decided to reproduce the sound field from outside the house. It was assumed that two channel recording would be accurate enough to get a good three-dimensional representation indoors. This hypothesis was checked for low speed trains at short distance. For this, the indoor sound field in a house close to an existing railway produced by a real train was compared to that reproduced artificially using two loudspeakers. The evaluation was done in situ as well as offline using the binaurally recorded sound field. For most trains the artificial sound could not be distinguished from the real sound.

The loudspeaker setup was placed in front of a slightly opened window of the experimental house, as shown in Figure 1(b), and consisted of 4 Bose loudspeakers mounted on 2 tripods, a 2000 W subwoofer, an amplifier and a 31-channel equalizer. This system allowed to reproduce the sound spectrum to within 2 dB in each octave band between 30 Hz and 16 kHz. The sound reproduction system was invisible for panelists entering the house. The sound level at the façade was recorded for further reference. The attenuation of the façade and the reverberation in the living room both modify the spectrum and temporal characteristics of the sound. An artificial head, shown in Figure 1(c), was therefore placed among the panelists, to monitor the indoor sound field. The difference between the sound pressure level at the façade and at the ear of this artificial head was approximately 21 dB. No visual presentation of the passing vehicles or trains was given during the experiment, since it seemed unnatural that one would see the passages from indoor, especially in an environment with plenty of trees.

2.3 Sample Collection and Preparation

Test sounds for highway noise, as well as for three types of train systems – conventional IC trains, high-speed TGV trains and magnetic levitation trains – were collected. For this, 2-channel recordings using 2 microphones at a distance of 20 m from each other along the track, placed 1.5 m above ground level were performed at various locations in Belgium, The Netherlands and Germany. To assess the influence of distance to the track and vehicle speed on annoyance, recordings were made at 4 distances (25 m, 50 m, 100 m and 200 m) and for different vehicle speeds.

From the set of recordings made at each site, the highest quality passage-sound was selected and 45-second fragments were cut, except for the highway traffic, for which a 10-minute recording was used. Since from the start it was deemed important to expose the panelists to sufficient duration of sound, 10 minutes of sound exposure was compiled for each given experimental sound (henceforth called a menu). To create a realistic situation in case of the train menus, within one 10-minute menu only stimuli of the same train type, at the same distance and speed should be included. Menus with 2 and 4 passages were used because 4 passages in 10 minutes is the time-schedule maximum. For master scaling, seven road traffic-noise-like reference sounds of 45 seconds duration at various levels were used. These sounds
were artificially produced by changing amplitude and spectrum of the highway noise recorded at 50 m from the highway.

2.4 Selection of a Representative Panel

A careful selection of panelists aimed at guaranteeing a representative sample of the population under study. For this reason, a questionnaire was administered at the doorstep of approximately 1500 persons living within a distance of 15 km from the experimental site. In an accompanying letter, one inhabitant of the house was invited to participate in the study and to send the questionnaire back using the enclosed stamped envelope. A compensation of € 100 was offered for participation.

The reference structure of the Dutch population was inferred from a recent RIVM environmental noise survey [9] and partly from a Eurobarometer questionnaire. The procedure to draw panelists from the 255 replies received involved three stages. Stage 1 removed potential panelists on the basis of their age and hearing ability. Stage 2 further removed those that were very dissimilar from the typical Dutch person on the basis of binary coding of a large number of criteria. Stage 3 finally selected panelists on the basis of fuzzy resemblance to the typical Dutch person on the most important criteria: age, gender, education, noise sensitivity, feeling afraid or frightened, hearing train noise at home, quality of traffic noise in the living environment, quality of the living environment, general health and illness. Finally, 100 representative participants were selected. Figure 2 shows a comparison of the participants with the reference population for the categories noise sensitivity and quality of traffic noise in the living environment.

![Figure 2](image_url)

*Figure 2 – Distribution of participants in the listening experiment over noise sensitivity and quality of traffic noise in the living environment, compared to the distribution of the Dutch population (reference).*

2.5 Outline of the Listening Test

To illustrate how the listening test was performed, Figure 3 shows the sound pressure level in dB(A), rerecorded in front of the façade, to which a group of panelists was exposed. About 5 panelists jointly participated in a session. The overall structure and time schedule of the listening experiment was the same for all panelists. First a 14-minute training session was held during which the test persons were asked to evaluate each of the 7 reference sounds, used for master scaling, two times (in random order). Subsequently, 7 10-minutes menus
were played. The first menu was always a highway traffic menu. After a short break, the training session was repeated, after which again 7 other menus of 10 minutes were played. After this experiment, a more conventional listening test was conducted, for which the test persons had to scale all 45-second transport noise stimuli used in the experiment, including the reference sounds twice.

During the experimental sessions, perceived noise annoyance of the transport noises was scaled with the method of free-number magnitude estimation [10]. The panelists were asked to give their assessment of the sounds by writing numbers on different pieces of paper. After each 45-second sound (training sessions and conventional listening test), a conditional question was asked: “To what extent would you be annoyed by this traffic sound, if you heard this while relaxing?” After each 10-minute menu a very similar but retrospective question was asked: “To what extent were you annoyed by traffic sound during the previous period?”.

At the end of the experiment, the panelists were asked to complete a shortened version of the questionnaire used for panelist selection, that focused on the non-acoustical factors that are the main focus of this paper. The relevant questions for the following assessment were (translated from Dutch):

- To what extend are you sensitive to sound? / 11 point scale: not at all to very.
- Thinking about The Netherlands, how worried are you about: / list of 12 environmental issues / 4 point labeled answering scale.
- To what extend do you believe that the following could affect your future quality of life / several aspects, including noise annoyance / three-point labeled answering scale.
- How is your health in general / 5 point labeled scale.

2.6 Master Scaling

The 7 road-traffic-like reference sounds, used in all experimental sessions, helped the panelists to define their scaling context. The ratings for these reference sounds made it possible to control for the individual panelists choice-of-number behavior in scaling the target train and road traffic sounds. For this, the individual panelist annoyance scales were calibrated to a common master scale [11]. One of the research questions addressed in this paper is to what extend this master scaling eliminates inter-individual differences in response caused by non-acoustical factors.

A graphical illustration of the master scale transformation applied to the annoyance data of a single panelist is given in Figure 4. The average reported annoyance of the 7 reference road
traffic noises is plotted in lin-log coordinates against their sound levels $L_{Aeq,45s}$, measured at the façade, and the individual psychophysical function is fitted to these data, which is of the form

$$A = a + b \log S$$  \hspace{1cm} (1)

$$\log S = \frac{A - a}{b}$$  \hspace{1cm} (2)

where $A$ is the reported annoyance, and $\log S$ is the corresponding road traffic noise reference sound level in dB(A). The constants $a$ and $b$ will be different for each panelist, and will depend amongst others on their choice-of-number behavior. The following master function is then used to transform the road traffic reference sound levels to an annoyance value $R$ in master scale units:

$$R = -62.9 + 1.45 \log S$$  \hspace{1cm} (3)

The slope is defined as the average slope of all individual functions; the intercept ($a$) was set to produce an annoyance-value of zero for the most quiet train menu, because a great majority of the panelists (84%) reported its annoyance to be zero. Every target noise annoyance value was transformed this way for each panelist separately.

This master scaling also allowed to investigate the quality of the experimental data in two ways. Firstly, the reference sounds were presented 6 times in total to each panelist. The consistency between the numbers used for evaluating them, is a measure for the performance of each panelist. A second measure of data quality tests the consistent trend in the rating of the reference sounds. The deviation of a panelist’s evaluation from the proposed master function is used for assessing that panelist’s performance and to trace errors and inaccuracies. Strictly speaking, testing monotonicity of the psychophysical function would be enough.
3. RESULTS

3.1 Influence on individual psychophysical functions

In Figure 5 the intercept of the individual psychophysical functions with the $A=0$ axis (annoyance threshold): $-a/b$, is plotted against different personal factors which were extracted from the questionnaire completed on site at the end of the listening test. This parameter can be interpreted as the threshold for annoyance of the average façade sound level ($L_{Aeq}$). As one would expect, there is a negative correlation with the panelists average worry concerning environmental issues, the expected influence of the sound on their quality of life and their reported noise sensitivity. The worry concerning environmental issues was calculated as the average of 12 environmental topics; the numbers used for averaging the responses were 0 (not at all concerned), 1 (not very concerned), 2 (somewhat concerned) and 3 (very concerned). The people that report bad health are in general older, and possibly do not hear the road traffic reference sounds as well as the other panelists; this may explain the higher value of the annoyance threshold for those persons.

The cross correlation between the non-acoustical factors investigated in Figure 5 is in general low, except for the expected influence of noise on future QoL and noise sensitivity ($r = 0.46$).
3.2 Influence on perceived noise annoyance

As all subjects were exposed to exactly the same 10 minutes of road traffic at the beginning of the two listening sessions, the master scaled response to this sound could also be used for analyzing the impact of personal factors. Figure 6 shows a significant dependence on environmental worry of the master scaled reported noise annoyance. A cumulative normal distribution seems to predict the dependence. In Figure 7 one can see that the expected influence of noise on the quality of life and the reported health status modify reported annoyance in a way that is not calibrated out completely by master scaling.

4. CONCLUSIONS

A unique field experiment was set up to study annoyance by transportation noise, which was innovative in the way test persons were selected to have a representative panel, and in the way the noise stimuli were presented to the panelists. This field experiment also made it possible to study the influence of several non-acoustical factors on noise annoyance. A
significant trend was found for several reported personal characteristics investigated. This does not imply that there may not be other significant relations. This work proves that it is necessary to check for the most important personal factors when selecting a test panel for noise annoyance experiments. The master scaling procedure does not seem to eliminate the influence of all of the personal factors that may influence the perception of annoyance over a longer time period.

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