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## **EXPERIMENTAL INVESTIGATION OF NOISE ANNOYANCE CAUSED BY HIGH-SPEED TRAINS**

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### **Abstract**

The observed difference in perceived annoyance caused by train and highway noise at the same averaged noise level, has led to the introduction of the 'railway bonus'. This bonus has found its way to the noise legislation in many countries, leading to more relaxed restrictions on time averaged noise levels,  $L_{Aeq}$ . With the introduction of high-speed trains and train-like transportation systems based on magnetic levitation, the question has risen whether the railway bonus can still be applied. The design of the present experiment was different from previous efforts in many ways. Most importantly, it was conducted in a realistic setting, a holiday cottage, and participants were asked to engage in light daily activities during the tests. Traffic noise was reproduced in an ecologically valid way, using outdoor loudspeakers. A stepwise selection procedure was based on a screening questionnaire that was administered at the doorstep of 1500 people living around the test site, to be representative for the Dutch population. Finally, 100 representative participants were selected.

The results from the annoyance experiment differed significantly from the results obtained using a much shorter listening test conducted afterwards. The  $L_{Aeq}$ -annoyance relationship obtained for the conventional high-speed train and for the magnetic levitation high-speed train did not differ significantly. The distance between the listening (recording) position and the track turned out to be the most important explanatory variable for the differences in exposure-response relationship observed, more so than vehicle speed or rise time.

## INTRODUCTION

Although noise annoyance caused by high-speed trains, both conventional and magnetic levitation (Maglev), has already been investigated [1-3], the results obtained were not conclusive. Previous work has neglected a few factors, potentially of importance. When short fragments of sound are used to study annoyance differences between trains, the temporal effect partly gets obscured. Longer exposures, containing several train passages and the typical quiet periods in between, seem necessary to study. Secondly, the representativity of most previous work has been questioned, as mostly only a very small group of test persons is used. Also, it is well known from environmental noise questionnaire surveys that personal factors such as noise sensitivity influence reported noise annoyance. If the participants all belong to a particular subgroup of the population, the result may get colored and become less representative.

Because the magnetic levitation system has not yet been implemented in Europe on a scale larger than a test facility, annoyance surveys are not possible. Therefore a field experiment was conducted, which tried to solve the above mentioned issues by its design. The experiment differs significantly from the earlier research in this area [1-3] on several topics. A realistic home-like setting was created, in which the test persons were exposed to longer fragments of sound, together with quiet periods. Traffic noise was reproduced in an ecologically valid way, using multiple outdoor loudspeakers to simulate pass-by sound. The experiment was performed with a set of panellists, which was representative for the Dutch population, at least in factors that are generally believed to be important modifiers for perception of noise annoyance. Finally, a master scaling transformation was applied to the annoyance data, this way calibrating the perceived noise annoyance of different participants to a common master scale.

## THE EXPERIMENT

### **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.

### **Ecologically valid sound reproduction and sample recording**

Much attention was paid at 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 experiment 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 experiment house. This setup 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 was therefore placed among the panellists, 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 trains was given during the experiment, since it seemed unnatural that one would see the train passage from indoor, especially in an environment with plenty of trees.

Two channel recordings using two 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. Test sounds for three types of train systems were collected: conventional IC trains, high-speed TGV trains and magnetic levitation trains. For master scaling and as a reference, also the sound of a highway was recorded. 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 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 panellists to sufficient duration of noise, they would have to be exposed to at least 10 minutes of each given experimental sound (henceforth called a menu). It was decided that, to create a realistic situation, within one 10-minute menu only stimuli of the same train type, at the same distance and speed should be heard. Menus with 2 and 4 passages were used because 4 passages in 10 minutes is already a time-schedule maximum.

For master scaling, seven traffic-noise-like reference sound fragments of 45 seconds duration were used. These sounds were artificially produced by changing amplitude and spectrum of the highway noise recorded at 50 m from the highway.

### **Selection of a representative panel**

In contrast to previous experimental work on noise annoyance caused by high speed trains, the selection of panellists was done in a different way to guarantee a more representative sample of panellists. For this reason, a questionnaire was administered at the doorstep of approximately 1500 persons living within a distance of 15 km from

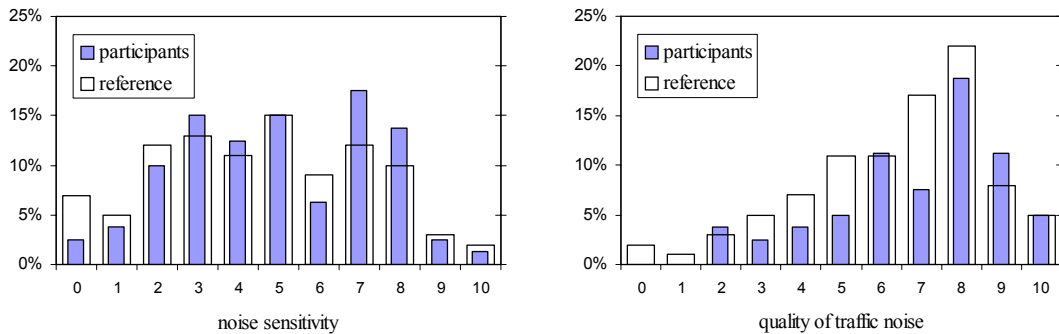


Figure 1 – Distribution of participants in the listening experiment over noise sensitivity and quality of traffic noise in the living environment, compared to the distribution of the Dutch population (reference).

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 representative structure of the Dutch population was inferred from a recent RIVM environmental noise survey [4] and partly from a Eurobarometer questionnaire. The procedure to draw panellists from the 255 replies received involved three stages. Stage 1 removed potential panellists 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 panellists on the basis of fuzzy resemblance to the typical Dutch person on the most important criteria, such as 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 1 shows a comparison of the participants with the reference population for the categories noise sensitivity and quality of traffic noise in the living environment.

### Outline of the listening test and master scaling

To illustrate how the listening test was performed, Figure 2 shows the sound pressure level in dB(A), rerecorded in front of the façade, to which a group of panellists was exposed (4 passages in a menu). About 5 panellists jointly participated in a session.

The overall structure and time schedule of the listening experiment was the same for all panellists. First a 14-minute training session was held, for which the test persons were asked to rate each of the 7 reference sounds two times (in random order). Subsequently 7 menus of 10 minutes were played, of which the first menu was 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 rate all 45-second transport noise stimuli used in the experiment.

In all, two times 6 train menus were presented to each panellist. It was decided that, within one set of 6 train menus, conventional trains (IC or high-speed) should

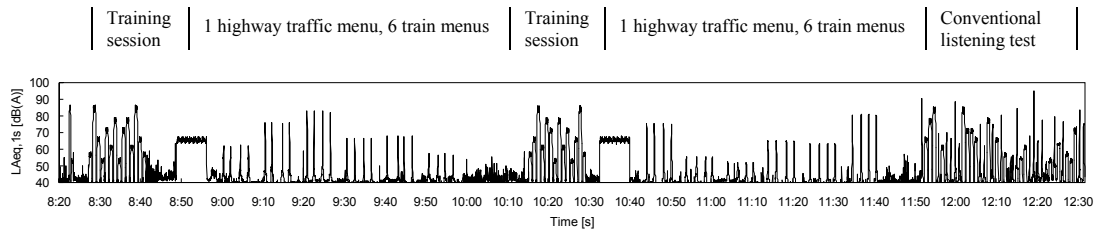


Figure 2 – Sound pressure level rerecorded in front of the façade during a session.

not be mixed with magnetic levitation trains; a retrospective evaluation over the past hour would then make sense as well. Because it was known from previous experience that the order of presenting the menus to the panellists could influence results, half of the panellists were presented the maglev train sounds first, while the other half heard the conventional trains first. Menus with the same number of passages were assembled in a single session, to avoid that panellists would start counting events. Finally, the distance to the track was not changed too much within one session, since this would help to create an unnatural setting.

During the experiment sessions, perceived noise annoyance of the transport noises was rated with the method of free-number magnitude estimation [5]. The panellists 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?”. In these questions we explicitly did not want to refer to train noise, since we wanted to allow panellists to decide themselves whether the sound they heard sounded like a train or not.

The 7 road-traffic-noise-like reference sounds, used in all experimental sessions, helped the panellists to define their scaling context. The ratings for these reference sounds made it possible to control for the individual panellists choice-of-number behavior in scaling the target train sounds. For this, the individual panellist annoyance scales were calibrated to a common master scale [6]. The hypothesis is that true interindividual variability in annoyance would remain, whereas interindividual variability due to the choice-of-number behavior would disappear.

The 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 panellist; the consistency between these 6 reference scale values can be used to assess the performance of each panellist. A second measure of data quality tests the consistent trend in the rating of the reference sounds. The deviation from the proposed master function was used to assess the data quality for each panellist and to trace errors and inaccuracies.

## RESULTS

Because noise legislation in most countries is based on time averaged façade exposure ( $L_{Aeq}$ ), it was decided to present the results mainly as a function of this parameter. Figure 3 gives an overview of the results for the annoyance of the 10-minute menus. The dashed line, which indicates the master function, can be regarded as the response for the reference road-traffic-like sounds. Figure 4 shows the same data, but now categorised in 5 dB(A) classes of façade level, ignoring differences in distance and vehicle speed.

From these figures, it can be concluded that magnetic levitation based transport systems are on the average not significantly more annoying than conventional rail based systems. Up to levels of 65 dB(A), there is no difference with conventional trains, above 60 dB(A) there is no difference with high speed TGV's. Also, railway noise is not systematically less annoying than highway traffic noise, but in the  $L_{Aeq}$  range between 55 and 65 dB(A), annoyance is lower for particular combinations of distance, vehicle speed and train type.

In the second part of the experiment, the experimental sounds were presented in a more conventional way, as a sequence of short 45-second fragments. Previous research indicates that in this type of experiment, participants often tend to assess loudness rather than annoyance, as defined in questionnaire surveys. Figure 5 shows that from this experiment we can conclude that a train passage in general is assessed to be at least as annoying (loud) as a 45-second excerpt of highway noise. Magnetic levitation and high speed TGV's are assessed as slightly more annoying (loud) than conventional trains and TGV's at low speed (the 4 lower TGV dots) once the  $L_{Aeq}$  is above 60 dB(A). This difference is in general statistically significant. The conclusion that noise annoyance caused by high speed TGV's and magnetic levitation trains is about the same for levels above 65 dB(A) is confirmed.

The short rise time of the noise of arriving high speed trains has been mentioned as a possible reason why this means of transportation could create more noise annoyance than a conventional train. In Figure 6(left) the size of the circles is proportional to the rise speed in dB(A)/s. The upward bending of the annoyance versus  $L_{Aeq}$  relationship at higher sound levels may be explained by rise time, which is not inconsistent with previous research on the effect of rise time. In Figure 6(right) the size of the circles is proportional to the distance to the track. For  $L_{Aeq}$  between 50 and 65 dB(A), annoyance is clearly less for trains passing by at larger distance.

## DISCUSSION

Previous laboratory research on noise annoyance caused by conventional IC and high-speed trains, and magnetic levitation trains [1,2] has found a significant difference between the effect of these types of sounds. In particular, they concluded that high-speed trains were more annoying for the same  $L_{Aeq}$ . Compared to road traffic noise, these studies claimed to find a lower annoyance level for conventional trains. Because both studies and ours use different annoyance scales, it is difficult to

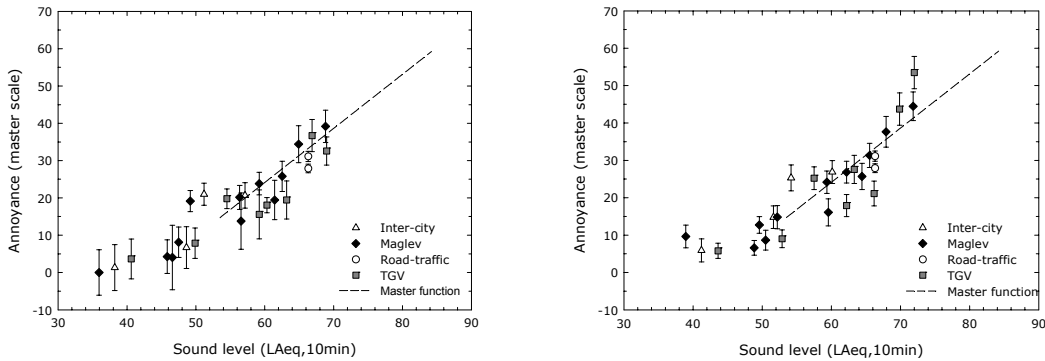


Figure 3 – Average master scaled annoyance versus  $L_{Aeq,10minutes}$  for 2 events per 10 minutes (left) and for 4 events per 10 minutes (right); standard error on means is indicated.

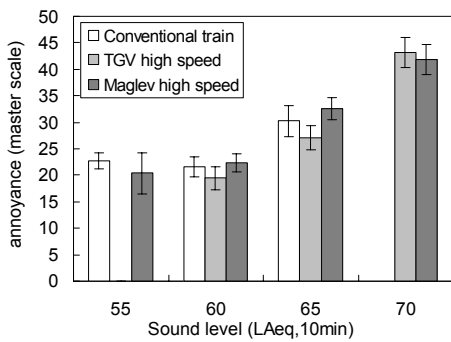


Figure 4 – Average master scaled annoyance vs.  $L_{Aeq,10minutes}$  on a categorical scale.

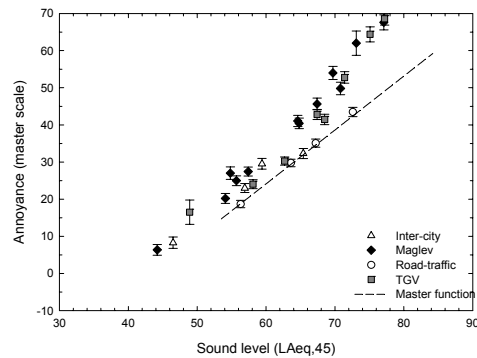


Figure 5 – Average master scaled annoyance vs.  $L_{Aeq,45sec}$  for the conventional listening test.

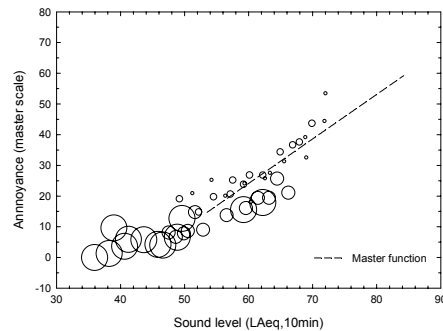
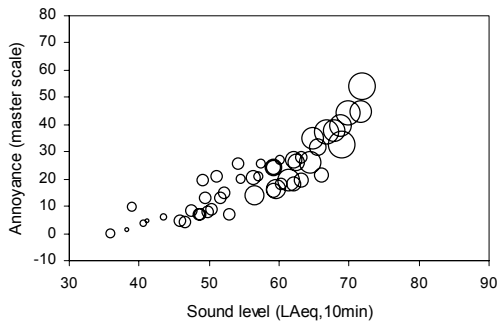


Figure 6 – Average master scaled annoyance versus  $L_{Aeq,10minutes}$ , showing the noise event rise speed (left) and the distance to the track (right) as the size of the circles.

compare results in a quantitative way. A linear scaling of noise annoyance to match the annoyance caused by Maglev trains in the three experiments can give approximately comparable data. The significantly lower noise annoyance found for conventional trains in [1] is confirmed also after this scaling. However, the noise annoyance found for conventional trains in [2] lies completely within the interval due to the different distances to the track and the different vehicle speeds considered in our study. Laboratory research which included longer experimental sound fragments [3] has not found the above mentioned annoyance difference between different train types consistently with our results.

## CONCLUSION

This study has shown that in an ‘at home’ like context, noise annoyance caused by different types of trains at the same average outdoor exposure level  $L_{Aeq,façade}$  is not significantly different. In particular, magnetic levitation systems are not more annoying than conventional high speed trains at façade  $L_{Aeq}$  over 60 dB(A), which is in agreement with earlier research. Noise annoyance caused by conventional trains was not found to be significantly lower than annoyance caused by TGV or maglev at the same average façade exposure, up to 65 dB(A).

Field surveys have shown that for the same average sound level, railway noise causes less annoyance than highway traffic noise, at least for a certain interval of noise levels. Although our study included several factors that may contribute to this effect, we could not observe it, except when the results were limited to sounds recorded at a distance of over 100 m. This is consistent with the observation made in field surveys that short distance increases noise annoyance above the expected level.

## ACKNOWLEDGMENTS

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