Effects of Chinese high-speed train compartment noise and speech on task performance

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Summary
Passengers of high-speed trains might be exposed to relatively high sound levels, compared to those inside conventional trains. In particular, sound levels inside Chinese high-speed train compartments may reach values as high as 80 dBA. Because traveling times are usually substantial in China, a wider variety of social activities occurrs inside the trains and more noise related problems for passengers can be expected. The main goal of the laboratory experiment described in this paper is to find out how the noise inside Chinese high-speed train compartments, caused by the train as well as by other passengers chatting, affects task performance. While being exposed to a combination of high-speed train noise and speech, Chinese as well as Dutch speaking participants were asked to perform a series of calculation and verbal memory tasks as quickly and as accurately as possible. Results show that (i) task duration and accuracy are independent variables for both tasks; (ii) the mother tongue of the participants has a significant moderating effect on task duration, but not on accuracy; (iii) the level and type of high-speed train noise does not have a significant influence on task performance; and (iv) the level of the interfering speech sound has a significant influence on the accuracy for the calculation task, but not for the verbal memory task.

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1. Introduction

The prominent advantages of high traveling speeds and goods carrying capabilities associated with high speed railways are an important incentive to local governments worldwide for their introduction [1, 2, 3]. For example, in 2009, the construction of the Wuhan-Guangzhou Line in China was completed, which connected more than twenty cities and 100 million people.

High speed trains come with additional aerodynamic noise [4, 5], which is potentially disturbing for residents living along the railway track, and which can also affect the travelers themselves. Substantial research work has been performed to figure out the properties and the environmental influence of the noise of the Shinkansen [5] and of European high-speed trains [4, 6, 7]. The present work will be on cabin noise inside Chinese high speed trains. In [8], the subjective quality of the sound environment in high speed trains is investigated. In [9], speech intelligibility is the main focus. Overall, however, the amount of published research on the acoustic comfort inside high speed trains is limited, and totally absent for Chinese high speed trains [10]. Nevertheless, traveling times in China are often significant due to long distances and the acoustical comfort of the traveler deserves sufficient attention. In this paper we focus on the ability to work while traveling. For this purpose, the effect of compartment sound, originating from the train as well as from other travelers chatting is investigated for performance on two different tasks (calculation and verbal memory) in a laboratory experiment.

2. Methodology

2.1. Participants

In total, 83 subjects participated in the experiment (46 male and 37 female). Both subjects with Chinese (46) and Dutch (37) as their mother tongue are selected, in order to investigate potential cultural differences, as well as the effect of meaningful vs. meaningless (disturbing) speech. The mean age is 25 years; most of the subjects are students. As a reward, each participant obtained a movie ticket.

2.2. Stimuli

Train noise was recorded binaurally, using a Brüel & Kjær head and torso simulator (HATS), inside a compartment of a Chinese high speed train travelling at speeds of 250 km/h and 330 km/h. Next to this, interfering speech noise was recorded in an anechoic cham-

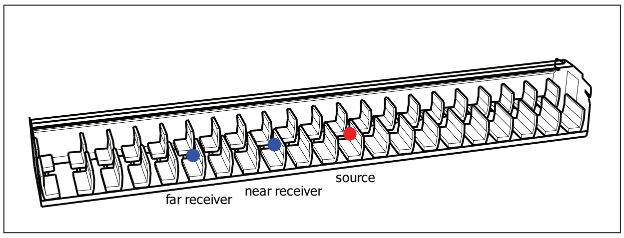

Figure 1. Positions of source and receivers in the model.

ber, with simultaneous speakers seated around a single omnidirectional microphone. The speech consisted of transcriptions of actual train conversations between four persons, translated into Chinese and Dutch. In order to simulate the real acoustic environment inside a high speed train compartment, the recorded speech sound was subsequently convolved with the BRIR (binaural room impulse response) of a modelled train compartment using the Odeon software tool [11]. The sound source (speaker) was located in the middle of the compartment, while the receiver (listener) was placed respectively three and six rows in front of the source. Figure 1 shows a screenshot of the implemented compartment model.

Different train and speech sound fragments with a 10-minute duration were subsequently selected and combined in order to create 9 stimuli. A baseline stimulus (1) contained only white noise at about 45 dBA. This quiet noise was chosen to give people the feeling that the headphones where there for a reason, in order to avoid that they would remove them. Next to this, stimuli with only train noise at 250 km/h (2) and 330 km/h (3) were created. Furthermore, train noise at both velocities was mixed with Dutch and Chinese speech with listener in the near position (4–7), and the train noise at speed 250 km/h was also mixed with Dutch and Chinese speech with listener in the far position (8–9). Stimuli 2 to 9 have A-weighted energy-equivalent sound pressure levels ranging from 70 dBA to 80 dBA.

Each participant in the experiment is exposed to a menu of four 10-minute stimuli: the baseline stimulus, a train-only stimulus at a particular speed, and two train+speech stimuli, one with Dutch and one with Chinese speech, both with the train speed corresponding to that of the train-only stimulus.

2.3. Tasks

While exposed to the acoustical stimuli, the subjects had to perform 4 calculation tasks and 4 verbal tasks, with each task corresponding to one of the 4 stimuli of the menu (i.e. each menu was played back twice). In the calculation task, 12 sets of 11 randomly generated single-digit numbers were presented, one after each other, and the subject had to make the sum (see [12] for more details). The subject could watch each number for as long as needed, and had to click to see the next number. At the end of each series of 11 numbers, the subject had to type in the sum. For the verbal task, sentences composed of "ones", "twos", "threes" and "fours", which are different degree of information, were used (see [13, 14] for more details). In a first part, the subjects were instructed to remember the sentences, and in a second part, they were presented with a series of sentences and had to recall whether they saw the given sentence before or not, and how confident they were on this (scale 0 to 10). Both the answer and the task duration (time between subsequent mouse clicks) were registered. At the very end of the test, some personal information was gathered through a small questionnaire.

2.4. Apparatus

During the experiment, subjects were seated in a well-insulated room. The auditory stimuli were played back through a Sennheiser HD280 closed circumaural headphone, and the playback system was calibrated beforehand using the B&K HATS system. The complete listening test procedure was controlled through a Matlab program with graphical user interface.

3. Results

3.1. Task accuracy

First, the experimental data was aggregated over all subjects. It was found that the average correct answer rate, as a measure of task accuracy, varies from 0.803 to 0.963 for the calculation task, and from 0.478 to 0.593 for the verbal task. As can be seen in Figures 2 and 3, no significant differences between language groups are found regarding task accuracy for the calculation as well as for the verbal task ($p > 0.1$), when the white noise (baseline) stimulus is considered. Note that the label "250n ChnSbj" for the stimulus type "Dutch+train" indicates the results for the Chinese speaking subjects, exposed to the stimulus composed of train noise with the train travelling at 250 km/h, and Dutch speech at the near position.

An ANOVA analysis suggests that the distance from the listener to the interfering speech source (and as such the sound level of the speech), and the interaction of mother tongue of the subjects and the speed of the train, influence the calculation accuracy significantly ($p < 0.005$). On the other hand, no parameters were found that influence the accuracy for the verbal task significantly. A possible explanation could be that the train noise is partially masking the speech.

3.2. Task duration

Figures 4 and 5 show the mean response times for the calculation and verbal tasks. Overall, it can be seen that response times for the calculation task do not increase when subjects are exposed to the train/speech stimuli, as compared to the baseline stimulus. This

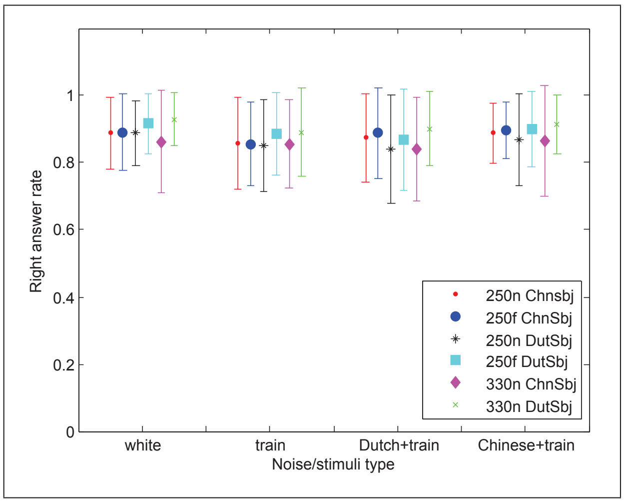

Figure 2. Mean value of the correct answer rate for the calculation task. Error bars indicate standard deviation.

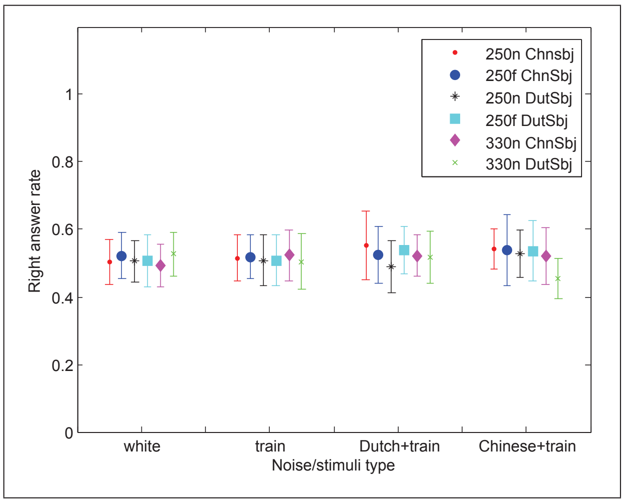

Figure 3. Mean value of the correct answer rate for the verbal task. Error bars indicate standard deviation.

implies that the variance in response time for the calculation task is mainly determined by inter-individual differences, and not by the characteristics of the interfering noise. An ANOVA analysis indeed shows that the type of noise does not have a significant influence on the mean response time for the calculation task ($p > 0.1$). However, it is found that, under most experimental conditions, the mean response time differs significantly between subjects ($p < 0.05$).

As can be derived from Figures 4 and 5, when considering the white noise (baseline) stimulus, the mean response times for the calculation task are 2.26 s and 2.49 s resp. for the Chinese and Dutch speaking subjects, and this difference is significant ($p < 0.001$). The mean recall times for the verbal task are 4.76 s and 5.17 s resp. for the Chinese and Dutch speaking subjects, and this difference is also significant ($p < 0.05$). This means that mother tongue has a significant influence on task duration for both tasks.

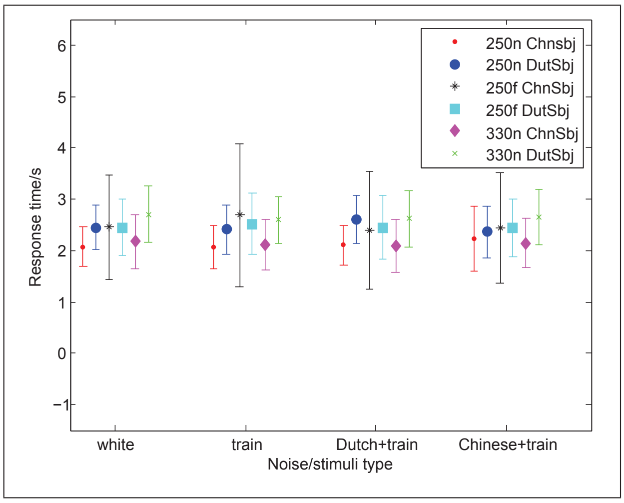

Figure 4. Mean value of the response time for the calculation task. Error bars indicate standard deviation.

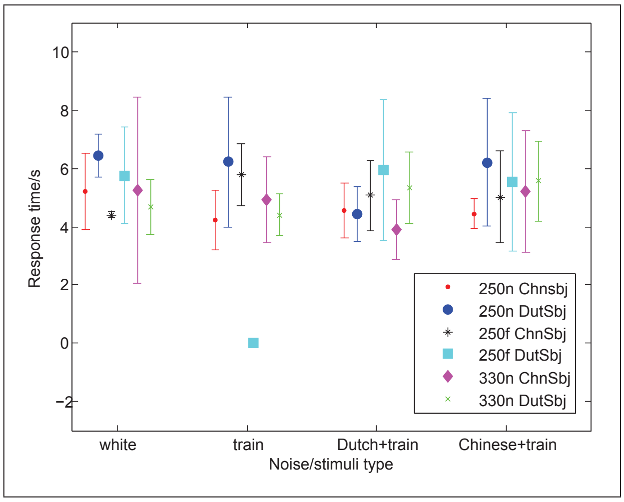

Figure 5. Mean value of the recall time for the verbal task. Error bars indicate standard deviation.

3.3. Independence of performance measures

Effects of noise characteristics on task performance could be measured by changes in task accuracy. However, even if task accuracy is not affected by the presence of disturbing noise, it is still possible that subjects require a longer time to complete a task. A series of t-tests was performed between both measures of task performance (see Table I), and it was found that task accuracy (correct answer rate) and task duration (response time) are independent ($p > 0.05$ for all combinations). This means that it was reasonable to analyze both task performance measures separately.

4. Discussion and Conclusions

In this work, a listening experiment on the effects of Chinese high-speed train compartment noise and speech on task performance was discussed. The main goal of this laboratory experiment was to find out

Table I. Correlation coefficients and p-values for a comparison between task accuracy (correct answer rate) and task duration (response time).

Task	Parameters	baseline	train noise	train+Dutch	train+Chinese
Calculation	correlation	-0.018	0.036	0.058	0.128
	p-value	0.871	0.748	0.602	0.247
Verbal	correlation	0.011	0.173	0.053	-0.039
	p-value	0.947	0.432	0.741	0.795

how the noise inside Chinese high-speed train compartments, caused by the train as well as by other passengers chatting, affects accuracy and duration on calculation and verbal tasks. Two language groups were considered (with Chinese and Dutch mother tongue), in order to be able to consider the effect of meaningful vs. meaningless speech. It was found that both task duration (response time) and accuracy (correct answer rate) are independent variables for both types of tasks considered, but that task duration is more sensitive to auditory context than task accuracy.

Firstly, results regarding task accuracy were analyzed. When subjects are exposed to low intensity white noise (the baseline condition), no statistically significant differences were found between the two language groups. Regarding the calculation task, the distance to the interfering speech source (and as such the level of the speech) caused significant differences in task accuracy; tasks were performed slightly more accurately for the receiver in the “far” position. For the verbal task, no parameters with a significant influence on task accuracy were found. A possible explanation could be the difference in amount of attention needed for both tasks. For the calculation task, forgetting the intermediate sum would result in an error for the whole 11-number sum, while for the verbal task, forgetting a single sentence would not impact the results for other sentences. Hence, the influence of interfering speech was expected to be lower for the verbal task than for the calculation task. Secondly, results regarding task duration were analyzed. Significant differences in average task duration between subjects with Dutch and Chinese mother tongue were found, for both calculation and verbal tasks. A possible moderating factor could be the slight difference in educational background between both groups of subjects: although all subjects were students, the group of Chinese speaking subjects contained a larger fraction of postgraduate students (80.4 %) as compared to the group of Dutch speaking subjects (46.0 %).

The level and type of the high-speed train noise was not found to have a significant influence on task performance, for both types of tasks considered. Moreover, although the range of train noise levels considered in this study was rather small, there were no significant differences as compared to the baseline condition with low-level white noise. The train noise is rather stationary, and although it is high in noise level, it did not draw attention away from the task at hand.

Acknowledgement

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