

**Activity interference caused by traffic noise:  
Experimental determination and modeling of the number of noticed sound events**

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**Abstract**

Activity interference is widely considered to be a central mechanism linking exposure to noise and emergence of annoyance. Salient sound events in particular may divert attention from the task at hand, thereby reducing task performance. Sound events caused by traffic noise intruding the dwelling are therefore often found to be a main cause of community noise annoyance. In this work, experimental and simulation results on activity interference caused by traffic noise are compared. On the one hand, an experiment on activity interference by traffic noise was conducted in a realistic setting resembling an at-home situation. Subjects were instructed to read, while being exposed to a combination of road and railway traffic noise. The number of train pass-by events, the distance to the railway track and the emergence of train events above the background noise was varied among subjects. After completion of the reading task, the subjects had to evaluate their perceived disturbance due to passing trains and to report how many trains they noticed in retrospective. On the other hand, a computational model of auditory attention was used to determine the number of train pass-by events that subjects would notice, solely based on the acoustic stimuli used in the perception experiment. Using an optimized stochastic function that simulates the attention spend on the reading activity of the subjects, the model was able to replicate trends found in the empirical results, and estimated the number of noticed train events quite well.

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## 1. INTRODUCTION

Selective auditory attention plays an important role in the perception of the wide range of complex sonic environments to which humans are exposed [Fritz:07]. In the long term, the sound to which one pays attention contributes to the creation of a mental image of the sonic environment in a given context, and ultimately shapes the perception of the quality of that sonic environment. In an at-home context, interference of noise with the activity a person is performing is an essential factor in the emergence of noise annoyance [Hall:85] [Zimmer:08]. There is clear evidence that the presence of irrelevant information, such as environmental sound intruding the dwelling, degrades selective attention, and thus impairs the performance on the task at hand [Banbury:01] [Szalma:11].

The impact of noise on task performance depends on the type and characteristics of the noise, as well as on the nature of the task that is affected. For example, Schmid and Hellbruck [Schmid:04] studied the influence of sound sequences (road traffic and speech) on a number of tasks that require cognitive functions. As in previous studies (see e.g. [Tremblay:2000] for an overview), they found that irrelevant speech is the type of sound that most interferes with task performance. For traffic noise in particular, they showed that both the number and the overall sound pressure level of the sound have an influence on task performance. Distraction by sound events was found to be most pronounced for calculation and grammatical reasoning tests [Schmid:04] [Wei:12]. Hygge et al. [Hygge:03] showed that, for text-reading tasks, exposure to road traffic noise can even be as harmful for task performance as irrelevant speech.

The relation between the occurrence of traffic noise events, activity disturbance and annoyance is reflected in a number of studies in which it is found that annoyance is more correlated to the occurrence and strength of noise events (and consequently the number of times people feel disturbed), than to equivalent sound levels [Björkman:91] [Sato:99] [Lam:09] [DeCoensel:09]. Therefore, a good knowledge of the process of auditory attention is essential in order to understand the underlying mechanisms relating noise exposure, task performance and activity disturbance, noise annoyance and soundscape quality. In the present work, the use of a model that estimates the number of noticed events on the basis of the properties of the sonic environment is illustrated. For this, results of a perception experiment on text-reading task performance under noisy conditions (exposure to road and railway traffic noise) are compared with simulation results of a model of auditory attention. In Section 2 literature aspects concerning the choice of parameters which could have an influence on attention, analysis methods and theoretical aspects describing the attention model are presented. In Section 3, the experimental methodology is explained while Section 4 presents the contextualized computational auditory attention model. Finally, in Section 5, laboratory results are presented and compared with simulation results using the computational model. The impact of parameters and their possible interactions on the reported/detected number of train passbys is investigated using an analysis of variance (ANOVA) or Kruskal-Wallis test.

## 2. LITERATURE OVERVIEW AND GENERAL METHODOLOGY

### 2.1 Choice of parameters

In order to study the activity interference due to traffic noise, it is first necessary to determine which parameters should be considered for the scenarios construction. As it has been already mentioned in the introduction, the first parameter which can influence performance is the overall sound pressure level [Miedema:98], but this is not the only one.

Dwellings located near a railway track are often also exposed to noise from road traffic. Depending on the distance to the road and on the road traffic intensity, train noise can be more or less dominant as compared to the background noise. Previous work has shown that interactions between road and railway traffic noise impact reported noise annoyance. Joncourt et al. found that a railway dominant scenario is generally reported as being less annoying than a road dominant scenario or a non-dominant

scenario [Joncourt:00]. Lam et al. found that annoyance and activity disturbance are related to the nature of the source mix. Therefore, for a road dominant scenario, annoyance appears to be linked to the disturbance caused by railway peaks, while for a train dominant scenario, the peaks of train events can induce annoyance without causing disturbance [Lam:09]. The emergence of the train passby noise over the background noise caused by road traffic was therefore selected as the first parameter for the construction of the stimuli of the experiment.

Results from a field survey conducted in Sweden [Öhrström:96] showed that the influence of the train passby density on reported noise annoyance could be linked to the amount of perceived vibrations and to the concern about possible future additional railway lines. In order to study the impact of the spectrum, Sukowski investigated the influence of the amount of low-frequency content (sound energy below 500Hz) of road traffic noise on task performance (calculation and reading tests performed by children) and sound quality perception [Sukowski:04]. A significant relationship between sound quality and annoyance was found. However, due to the experimental design, the spectral shape of the stimuli was correlated to the sound level, and consequently, results remain hard to interpret. In a similar experiment, Schmid & Hellbruck [Schmid:04] used a fixed  $L_{Aeq}$  level (70dB). No significant influence of the amount of low frequency content on road traffic noise annoyance was found, when subjects are carrying out an attention demanding activity. Consequently, in this study it was chosen to vary the sound spectrum through using the recording distance as a second stimulus parameter.

Moehler [Moehler:05] compiled data of several studies on railway noise (during the time period 1996-2000) together with additional data from more recent experiments. He found that, for a given  $L_{Aeq,24h}$  level, the daily traffic rate (ranging from 150-200 trains per 24h up to 350-500 trains per 24h) does not have a significant influence on reported noise annoyance. On the other hand, recent surveys run in Sweden, in the context of the TVANE (Train Vibration And Noise Effects) project [Jerson:10] [Gidlöf:11], do find a significant positive correlation between train traffic density and the percentage of annoyed people, for a given  $L_{Aeq,24h}$  level. Motivated by these conflicting findings, traffic density was included as the third stimulus parameter.

## 2.2 Saliency-based auditory attention model

In order to estimate, on the basis of the properties of the sonic environment, the number of sound events (and in particular, the number of train passbys) that participants would actually notice, a computational model of auditory attention to environmental sound [DeCoensel:10] is applied to the experimental stimuli. This model, inspired by the structure of the human auditory system, simulates how listeners switch their attention over time between the different sounds present in the auditory scene. Below, a short functional description of the model is given, with a focus on the aspects of importance for this paper. A more complete mathematical description of the model is beyond the scope of this paper, but can be found in [DeCoensel:10].

In a complex sound environment, humans base their auditory perception on a detailed analysis of the auditory scene (ASA) [Bregman:94] [Wang:06]. Through this process, the mixture of incoming sounds is decomposed into several auditory streams, each associated to a perceived sound source. This decomposition is based on auditory as well as visual cues. Usually, ASA is considered to be an analysis-synthesis process. Firstly, the sound signal is decomposed into a collection of time-frequency segments; subsequently, auditory streams are created by aggregating time-frequency segments based on their likeness to have been arisen from the same source.

Selective auditory attention implies that mental resources are focused on a single auditory stream; the auditory stream that receives attention may of course change over time. Computational models for selective (auditory) attention are usually based on an interaction between two cues: bottom-up cues (based on the time-dependent saliency of each stream) and top-down cues (based on the amount of volitional focusing on particular streams) [Knudsen:07]. The bottom-up mechanism selectively gates incoming auditory information, enhancing responses to stimuli that are salient. This is considered to be largely a pre-attentive mechanism, independent from the activity of the person or the task at hand. The time-dependent saliency of each auditory stream can be estimated through the calculation of a saliency

map, which provides a weighted representation of the sonic environment, emphasizing those time-frequency elements that are more conspicuous, and thus most likely detected [Kayser:05]. The calculation of a saliency map accounts for the audibility of each sound over time (it could be temporarily masked by the other sounds) as well as the spectro-temporal structure of the sound (e.g., sudden events potentially attract attention). The top-down mechanism focuses mental resources on the treatment of the most relevant information for the current goal-directed behavior of the listener. These mechanisms are guided by information already held in working memory, through sensitivity control (activity or intention). A competitive winner-takes-all process finally balances bottom-up and top-down attention, and determines which stream is selected for entry in working memory, thus receiving attention.

### **2.3 Analysis methods**

The comparison between the results of the perception experiment and the results of the computational model is carried out through the analysis of the influence of the selected parameters on the number of detected events. The normality of the results distribution will be analyzed with the help of the Shapiro-Wilks test for each scenario. This will enable to check if some outlier subjects should be excluded from the analysis. A Levene's test will be performed to check the assumption of equal variance for the results for all scenarios. Finally, once the normality and variance hypothesis are verified, an ANOVA (Analysis of variance) will be performed. If the ANOVA hypotheses are not supported, a Kruskal-Wallis analysis will be done.

## **3. PERCEPTION EXPERIMENT**

The perception experiment described in this work was part of a larger study, in which the influence of the temporal structure of transportation noise on annoyance, cognitive performance and sleep was investigated [Lavandier:09] [Terroir:10] [Margiocchi:10] [Terroir:11]. In light of the ecological validity of the experimental setting [Guastavino:05], sound sequences were constructed to recreate conditions of a daily at-home context as close as possible. The duration of sound sequences was determined such that they would enable immersion, without being too restrictive for subjects. The present paper specifically deals with effects of background noise on activity disturbance.

### **3.1 Sound stimuli**

Passby recordings were made for four different types of trains: TGV (high-speed trains), CORAIL (express trains), TER (regional trains) and FRET (freight trains). Recording campaigns were conducted in 2006 and 2007 on the same site in Chagny (France), with the support of the SNCF (French National Railway Society). Recordings were made in an open landscape with a hill in the back. The 50m recordings were made in the flat part of the landscape whereas the 100m recordings were made on the hilly part. As it has been shown by Lee et al. [Lee:10], the topography of the landscape can impact the temporal structure of the sound pressure level. In the present work, the slope of the sound level increase has been smoothed in order to reduce the differential effect of the topography, as it can be observed in Fig.1 and Table 1. Single-channel recordings for sound level calibration were made with B&K4188 microphones, while ambisonic B-format recordings were simultaneously made with a Soundfield ST250 microphone. Subsequently, the ambisonic recordings were converted to stereo for the purpose of the experiment, using the methodology described in Gerzon's paper [Gerzon:92]. Recordings were done at 50m and 100m distance from the railway track. Finally, one single recording per type of train was selected and used in the construction of 8 one-hour stimuli, in which road traffic noise (a continuous background with no noticeable sound events) was mixed with train passbys. One-hour stimuli have already been used successfully in the past for experiments in which the influence of traffic noise on annoyance or activity disturbance was investigated (see e.g. [Fastl:96] [DeCoensel:07] [Barbot:08]). In the present experiment, three parameters were varied among stimuli (see paragraph 2.1): the distance to the track, the number of passbys and the emergence of the train noise events above the background noise.

### 3.1.1 Distance to the railway track

Although the spectral dimension may appear of less importance, a pilot study on the influence of distance to the track on the temporal envelope and sound quality of train passbys was carried out [Terroir:10]. Variations of temporal (psycho)acoustic characteristics, such as the irregularity of the sound during the passby or the rise speed of the sound level of the approaching train [DeCoensel:07] [Barbot:08], were found to allow people to easily discriminate between train passbys at varying distance. On the one hand, the irregularity of the train sound was especially heard for recordings carried out next to the track (at a distance of 7.5m). However, few people in France (Europe) live within such a short distance from a railway track, making this distance quite unrealistic for the present experiment. On the other hand, the rise time of the sound was found to be a main cue for discriminating train passby events recorded at 50m and 100m (i.e. more common distances between dwelling and railway track), as illustrated in Figure 1. Consequently these two distances to the railway track were selected as the first variable parameter for the construction of the sound stimuli.

Table 1 shows the passby duration  $T_{L_{Amax,125ms-10}}$  (in s), the center of gravity of the spectrum  $SCG_{mean}$  (in Hz), and the rise speed  $L_{ASlopeUp}$  (in dB(A)/s) of the sound level, for 4 train passbys, as a function of the train type and the distance to the railway track. The passby duration is calculated as the time period during which the sound level is at least 10 dB(A) below the maximum. The rise speed is calculated based on the time needed for the sound level to get from 10 dB(A) below the maximum to the maximum. It has to be noted that by varying the distance to the track, for trains of equal length travelling at the same speed, also the perceived passby duration is changed.

INSERT FIGURE 1 ABOUT HERE

INSERT TABLE 1 ABOUT HERE

### 3.1.2 Number of passbys

Typical railway traffic intensities during the evening period are chosen for the experiment, as it is the period of the day that people are most likely to be at home. On average, railways in France carry about 41 trains between 6pm and 10pm (26 CORAIL, 10 FRET, 3 TGV, 2 TER) [Cremezy:07]. For reasons of scheduling, and considering the limits caused by sensory fatigue of participants, it was decided to limit the duration of an experimental session to one hour. Consequently, two scenarios are considered: a scenario with a regular rate of 10 passbys per hour (6 CORAIL, 2 FRET, 1 TGV, 1 TER), and a scenario with a high rate of 20 passbys per hour (12 CORAIL, 4 FRET, 2 TGV, 2 TER). These passby intensities are in line with those considered in earlier studies [Walker:06] [DeCoensel:07]. Passbys are distributed randomly over time, with a 2 to 10 minute time interval between passbys, although previous work has shown that the choice between a randomized or a regular temporal distribution does not have a significant impact on subjects' answers [Walker:06]. Nevertheless, a random temporal distribution reduces the possibility of an expectancy or a habituation effect.

### 3.1.3 Emergence of train passbys above background

Two scenarios are considered in this experiment: a dominant one and a non-dominant one. Situations in which train noise is dominant require a  $L_{Aeq,1h}^{trains}$  level of at least 5 dB(A) above the  $L_{Aeq,1h}^{background}$  level [Champelovier:03]. In this study, a 6dB(A) difference was selected for the dominant scenario and a 3dB(A) difference for the non-dominant scenario:

$$\text{- Dominance: } L_{Aeq,1h}^{trains} = L_{Aeq,1h}^{background} + 6 \text{ dB(A)} \quad (1)$$

$$\text{- Non-dominance: } L_{Aeq,1h}^{trains} = L_{Aeq,1h}^{background} + 3 \text{ dB(A)} \quad (2)$$

### 3.1.4 Scenario properties

Because each of the above considered parameters has 2 levels, 8 stimuli are considered in total. In order to compensate for the influence of sound level on perceived annoyance [Kurra:99a] [Kurra:99b] [DeCoensel:07], all stimuli were normalized to an  $L_{Aeq,1h}$  of about 52.5 dB(A). We opted for  $L_{Aeq}$  normalization rather than loudness since it is the most widely used indicator in noise policy today. Table 2 summarizes the most important acoustical properties of the stimuli. Note that, as the overall sound level was equalized, train noise peak levels vary between scenarios: the higher the number of train passbys, the lower the peak levels.

INSERT TABLE 2 ABOUT HERE

### 3.2 Apparatus

The experiment was conducted in a quasi-sound-proof room (width = 2 m, length = 4.20 m, height = 4 m). Stimuli were played back in stereo through a pair of loudspeakers and a subwoofer. In order to create a relatively realistic indoor situation, a picture of a half-opened window was projected in front of the subjects. Additionally, a filter (cf. Fig. 2) was applied to the stimuli, in order to simulate the outdoor-to-indoor propagation of sound, including the effect of a half-opened window. This filter was based on previous work [Josse:82] [Asselineau:87] [CSTB:01] and on measurements made by the French and German railway companies (SNCF and Deutsche Bahn). The indoor sound level of the traffic background noise was loud enough ( $L_{Aeq,1h}^{Background} = 45$  to  $48$  dB(A) with  $L_{Amax,125ms}^{Background} = 51$  to  $54$  dB(A)) to mask the background noise of the laboratory itself ( $L_{Aeq,1h} = 20$  dB(A)). Overall, the experimental conditions were rated to be quite realistic by the participants of the experiment.

INSERT FIGURE 2 ABOUT HERE

### 3.3 Subjects

In total, 160 subjects (48 females, 112 males) participated in a one-hour experimental session. Each of the 8 experimental stimuli was presented to 20 different subjects. In order to avoid any learning effect, each subject was submitted to only one scenario. The mean age of the subjects was 22.1 years (range 18-31 year). Most subjects were either students or staff working at the Cergy-Pontoise University. The subjects received 20 euro as compensation for their participation in the experiment.

### 3.4 Experimental procedure

In order to recreate a typical at-home situation during the evening, it was necessary to select an activity which is commonly performed by people at home and which does not require an excessive amount of concentration, in order to avoid subjects being disjoined from the sound environment [Kurra:99a] [Kurra:99b] [Kühnkt:08]. The reading of comic books was selected for this purpose. Each test consisted of the following parts: (i) a 10-minute welcoming phase in the laboratory to introduce the test while the background road traffic noise was already playing; (ii) a calibration phase to familiarize the participant with the annoyance scales (this aspect is not tackled in the present paper but is discussed in [Lavandier:09]); (iii) a one-hour reading phase during which a stimulus (trains + background) was played back; and (iv) a 15-minute phase during which the final questionnaire was administered to the participant, while the background road traffic noise was still playing. During the reading phase, the attention of the subject was focused on the reading activity rather than on the sound environment, but the latter may or may not have disturbed the reading activity. It was decided to have the background road traffic noise played back continuously, in order to avoid artificial transitions in the sonic

environment. The final questionnaire contained questions on annoyance, emotional status (not analyzed in this work) and the number of train passbys that were noticed. The aim of this work being to compare the experimental results and the attention model events detection, this paper will specifically focus on activity interference without considering the annoyance results which have been already published by Lavandier et al. [Lavandier:09].

#### 4. COMPUTATIONAL ATTENTION MODEL

The ideas presented in paragraph 2.2 have been implemented in a computational model of auditory attention, specifically targeted at environmental sound [DeCoensel:10]. The model combines the calculation of an auditory saliency map with a functional model of attention switching. As the model is primarily designed to be used for simulation purposes, it bypasses the ASA stage, by assuming that each sound source in the mixture gives rise to a separate auditory stream. More in particular, the model takes as input the separate sound signals of the different sound sources (which are available for the current experiment) and returns the time periods during which particular sounds are likely to be paid attention to. Consequently, the model can be used, on a statistical basis, to estimate which train passages the participants would most likely notice, based on the acoustical properties of the stimuli of the experiment.

Another essential element of the model is that an additional non-auditory stream has to be considered, in order to account for those periods of time during which attention is not directed towards the auditory sense, but towards visual events, thought, the task at hand etc. For simulation purposes, the activation of this stream can be tailored to mimic a predefined activity pattern, or it can be implemented in a stochastic fashion. In this work, we will consider a non-auditory stream representing the attention that is required by the reading activity over time. The activation of this non-auditory stream is modeled as the ad hoc superposition of two stochastic processes: a slow and small modulation of the stationary activation, mimicking the continuous nature of the reading activity, combined with sudden peaks or drops in activation during reading, which are randomized for strength, duration and occurrence in time. An example is shown in Fig. 3. Values for the stationary level of activation, and for the rate and strength of peaks and drops in non-auditory attention are uniformly sampled from a preset range, in order to account for the variance of experimental results due to inter-subject differences. Note that the proposed temporal structure of the non-auditory stream is linked to the activity itself; e.g. a task in which a calculation has to be done every five seconds would probably require a less stochastic structure, in order to achieve reasonable results.

INSERT FIGURE 3 ABOUT HERE

#### 5. RESULTS

##### 5.1 Perception experiment

Fig. 4 shows the dispersion of the responses for each scenario. A Shapiro-Wilks test was run for each scenario, and a normal distribution is observed for all scenarios, except for scenario 6 ( $F= 0.896$ ;  $p= 0.035$ ) and scenario 8 ( $F= 0.824$ ;  $P= 0.002$ ), the non-dominant scenarios with 20 passbys, for which the assumption of a normal distribution can be rejected with 95% confidence. However, if the 2 subjects that reported the largest number of passbys are excluded for these two scenarios, the assumption of a normal distribution holds. These 2 subjects are found to behave differently from the other subjects: they focus on the sound events rather than on the task at hand, and count the number of events they notice. Moreover, a small number of subjects behaving in a similar way can be found in the other scenarios too; e.g. for scenario 5 and 7, some subjects even reported more train passbys than there were actual passbys (12 or 15 noticed passbys while only 10 actual passbys). Therefore, it was decided to consider only 90% of the data for every scenario for the ANOVA analysis, by

excluding the outliers (corresponding to subjects reporting the largest number of noticed events) under the assumption that these subjects focused on counting events instead of reading. Consequently, a normal distribution with 95% confidence is observed for every sound scenario. Secondly, Levene's test was performed and no statistically significant difference amongst the standard deviations at the 95% confidence level were found ( $F= 1.981$  ;  $p=0.062$ ).

INSERT FIGURE 4 ABOUT HERE

Table 3 summarizes the results of the three-way ANOVA. As expected, a significant effect of the actual number of passbys is found on the reported number of train events [ $F(1,134)=4.54$ ;  $p=.035$ ], although the size of the effect is smaller than what could have been expected. Next to this, a significant effect of the distance to the track on the reported number of train events is found [ $F(1,134)=5.38$ ;  $p=.022$ ], which may be due to the temporal and spectral modifications associated to the distance variation. Finally, a significant effect of the emergence of the passbys above the background noise (for equal  $L_{Aeq,1h}$  levels) on the reported number of train events is found [ $F(1,134)=7.76$ ;  $p=.006$ ]. Fig. 5 illustrates the one-way effects.

Next to this, a significant two-way interaction effect is only found between the dominance of the train noise and the actual number of passbys [ $F(1,134)=12.75$ ;  $p<.001$ ], as illustrated in Fig. 6. More in particular, for the non-dominant scenarios, the number of reported train passbys is not found to be significantly related to the actual number of passbys, whereas it is found to be positively related for the dominant scenarios. Because of the normalization of the overall level, the emergence of the train noise events above the background has a significant effect on the reported number of train noise events (more than the peak level itself). Finally, the three-way interaction effect was not found to be significant.

INSERT TABLE 3 ABOUT HERE

INSERT FIGURE 5 ABOUT HERE

INSERT FIGURE 6 ABOUT HERE

## 5.2 Computational auditory attention model

In this section, results for the reported number of train passbys in the laboratory experiment are compared with the number of noticed sound events as estimated by the attention model. For each participant of the experiment, a simulation was run, and the time periods during which the train noise would most likely have attracted attention are counted. Although all participants within the same scenario are exposed to the same sound stimuli, inter-individual differences are taken into account in the simulation through the parameters of the stochastic function that describes the non-auditory stream (as described in paragraph 4). Values for these parameters are uniformly sampled from preset ranges, which were selected during an initial calibration phase of the model. In particular, parameter ranges were optimized to result in a minimal difference in the median value and the confidence interval between the simulated number of noticed sound events and the reported number of train passbys of the experiment, for scenarios 1 and 2. These two dominant scenarios with passby at close distance were chosen for calibration, because these are supposed to be the easiest to evaluate by the participants. Similar results would have been obtained with any other scenario for calibration. It is worth noting



that calibrating the model with data extracted from the experimental corpus can lead to a better agreement of the model than with some independent data. Medians and confidence intervals for these two scenarios after calibration of the parameter ranges are shown in Fig. 7.

INSERT FIGURE 7 ABOUT HERE

Because the distribution and standard deviation assumptions for an ANOVA analysis did not hold for the simulated data, the non-parametric Kruskal-Wallis test was used to analyze the impact of each parameter independently. Consequently, the complete data set could be taken into account. Fig. 8 compares the median and the 95% confidence interval for the laboratory and the simulated results. The influence of each parameter (distance to the track, number of train passbys and dominance) on the median number of reported/detected train passbys appears to be similar for the laboratory experiment and the attention model. The design of the function that governs non-auditory attention thus appears to be well adapted to simulating the reading activity and confirms that with well-chosen values for the model parameter ranges, median simulated results are in accordance with experimental ones. A difference in the dispersion of the results can nevertheless be observed, with the simulated number of noticed sound events having a larger variance, mainly for the 20-train sound sequences. Table 4 shows the P-values for estimating the probability for each parameter to have a statistically significant impact on the median value for both attention model and laboratory results. When a 95% confidence interval is considered, dominance is found to be the only significant parameter for the laboratory results (considering the median value and accounting for the complete data set), whereas the actual number of passbys is found to be the only significant parameter for the attention model results. However, from Fig. 8 it can be concluded that the variance of the results has a large influence on the significance of the three effects: for each parameter, median values are similar for both approaches, but the differences are noticeable on the dispersion of the answers. Note that when a 90% confidence interval is considered, all three parameters are found to have a significant influence on the median reported number of trains in the laboratory experiment, i.e. the same result as with the ANOVA where only 90% of the subjects were taken into account (Section 5.1).

INSERT FIGURE 8 ABOUT HERE

INSERT TABLE 4 ABOUT HERE

An interaction between the dominance of the train noise above the background and the actual number of train passbys was observed for the results of the laboratory experiment (cf. paragraph 5.1). In the same way, Fig. 9 shows the median and the 95% confidence intervals for this interaction for the results of the attention model. Again, the trends in the median value are well estimated by the model, but the confidence intervals for the simulation results are larger, in particular for the scenarios with 20 train passbys. This suggests that one or more processes that would reduce the dispersion of the answers is not taken into account in the model.

INSERT FIGURE 9 ABOUT HERE

The difference between the laboratory experiment and the auditory attention model results can be explained partly by the larger number of reported events by the simulated subjects, as compared to the actual subjects (especially for 20 trains sequences). As it is shown in Fig. 9, this “number” effect can be observed in the model results for the dominant scenarios (mainly for the 20 trains sequences); in the laboratory setting, a considerable number of subjects did not detect events in the non-dominant situation (mean number of detected events = 4 for non-dominant 20 train sequences). Thus, the overestimation of the number of events by the attention model as compared to the experimental results could have masked or reduced the impact of other parameters.

## 6. DISCUSSION AND CONCLUSIONS

In this work, a perception experiment in which subjects were instructed to read a comic book while being exposed to a combination of road and railway traffic noise was discussed. The number of train passbys, the distance to the railway track and the emergence of the train noise above the background were found to have a significant influence on the number of train passbys that subjects remembered, after removal of outliers. Furthermore, an interaction between the actual number of passbys and the emergence of the train noise was found.

Results of the laboratory experiment were subsequently compared with simulation results using a model of auditory attention, that estimated the number of potentially noticed train noise events based on the acoustical stimuli of the experiment. The model accounted for the reading activity of the subjects through the use of an optimized, stochastic non-auditory attention function. To account for interindividual differences, parameters of this non-auditory function were sampled from ranges that were calibrated for median and confidence interval on a part of the experimental data. The model was then found to be able to replicate trends found in the empirical results, and estimated the influence of scenario parameters on the median number of noticed train events quite well.

However, a noteworthy difference between both approaches was found in the dispersion of the results. A first issue was that some people reported to have noticed more train passbys than the number of passbys that was actually played back, a behavior that the attention model could not replicate by design. A more detailed analysis showed that these outliers alone could not explain the differences in variance between the experimental and model results. A possible explanation would be the lack of a memory component in the attention model. Indeed, the subjects were not instructed to count the passbys, but were only asked in retrospect, after one hour, how many trains they noticed. Thus, memory aspects can be expected to influence the reported number of passbys for the majority of subjects. A memory model that would take into account this process would therefore be an interesting addition to the attention model. The results of this paper suggest that the influence of this memory process should increase with the number of events.

In the context of this work, only recorded sounds were used. Consequently the distance parameter was correlated to both spectrum and temporal shape variations. This can lead to question the specific impact of those parameters on the amount of activity interference. The impact of spectral properties has already been tackled in previous works [Sukowski:04] [Schmid:04]. In both cited studies, no significant effect of the low frequency content of the stimuli was found on task performance. To the author’s best knowledge, the specific influence of the temporal shape of railway passby noise on activity interference has not yet been tackled. Therefore, it would be interesting to work with synthetic sounds in future experiments, in order to study the impact of temporal features on activity interference in an independent way for both experimental and computational approaches.

Although previous work has shown a correlation between noise annoyance and the strength and occurrence of noise events [Björkman:91] [Sato:99] [Lam:09] [DeCoensel:09], this paper focused on activity interference, without considering the possible correlation between activity interference and noise annoyance, because of the specific aim of the attention model. For the experiment discussed in this work, the relation between the actual number of events and activity interference has already been tackled in previous papers [Lavandier:09] [Lavandier:11]. The relation between the number of reported/detected events and the reported disturbance/annoyance should be analyzed in future work.

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## TABLE CAPTIONS

*TAB.1 – Passby time  $T_{L_{Amax,125ms-10}}$ , Spectral Center of Gravity  $SCG_{Mean}$  and Rising slope  $L_{ASlopeUp}$  as a function of the train type and the distance to the railway track.*

*TAB.2 – Acoustical properties of the stimuli.*

*TAB.3: Variance analysis of the reported number of trains (laboratory results – 90% data). The F-Ratio value is followed by \* if the probability is below 0.05 and \*\* if the probability is below 0.01.*

*TAB.4: P-values for the Kruskal-Wallis test. If the P-value is less than 0,05, there is a statistically significant difference amongst the medians at the 95,0% confidence level.*

## FIGURE CAPTIONS

*FIG.1 – Temporal shape of a CORAIL train passby simultaneously recorded at two different distances from the railway track. Blue line: recording distance = 50m. Red line: recording distance = 100m.*

*FIG.2 – Filter attenuation used to simulate the outdoor-to-indoor propagation.*

*FIG.3: Example of a non-auditory function shape as a function of the time. '0' value corresponds to a null attention rate, '1' value corresponds to a maximum attention rate.*

*FIG.4: Reported number of trains: results dispersion*

*FIG.5: ANOVA analysis: Influence of (a) the number of train passbys, (b) the distance to the track, (c) the dominance on the mean reported number of perceived train passbys (90% data).*

*FIG.6: ANOVA analysis: Interaction between (a) distance to the track and dominance; (b) distance and number of passbys; (c) dominance and number on the mean reported number of perceived train passbys (90% data).*

*FIG.7: Median and confidence interval for the number of reported trains in the laboratory experiment, and the number of noticed sound events in the attention model, for scenarios 1 and 2, after the calibration phase.*

*FIG.8: Median and 95% confidence interval for reported (Laboratory) and detected (Model) number of train passbys as function of the number of trains, the distance from the track and the dominance of the train noise above the background.*

*FIG.9: Median and 95% confidence interval for reported (Laboratory) and detected (Model) number of train passbys as a function of the number of trains and the dominance of the train noise above the background.*

Figure 1

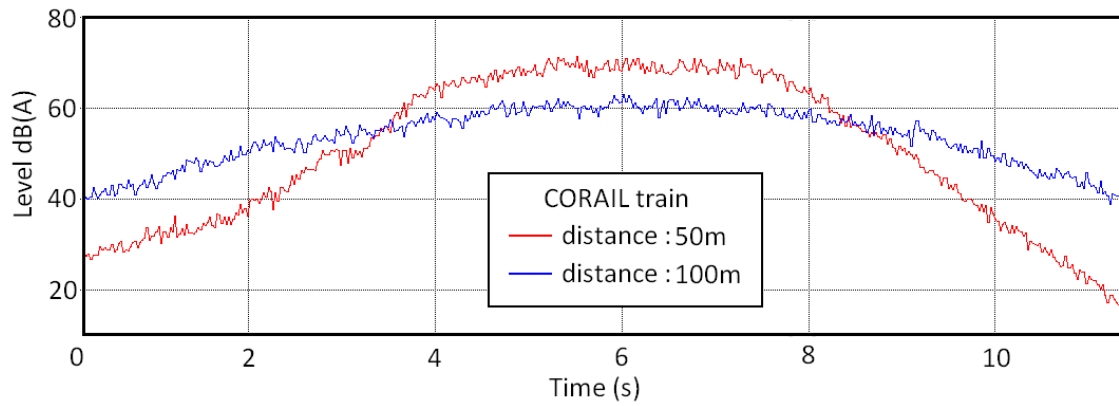


Figure 2

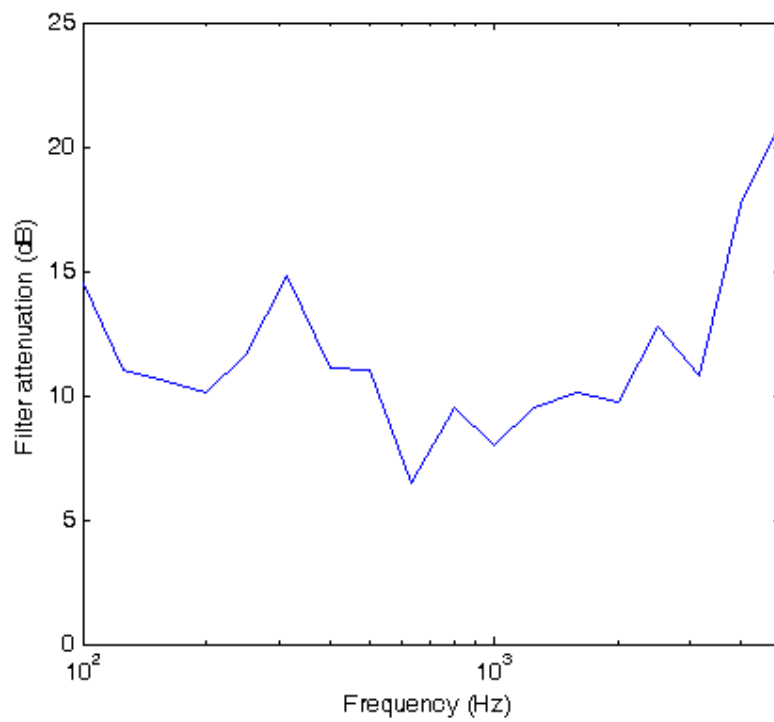


Figure 3

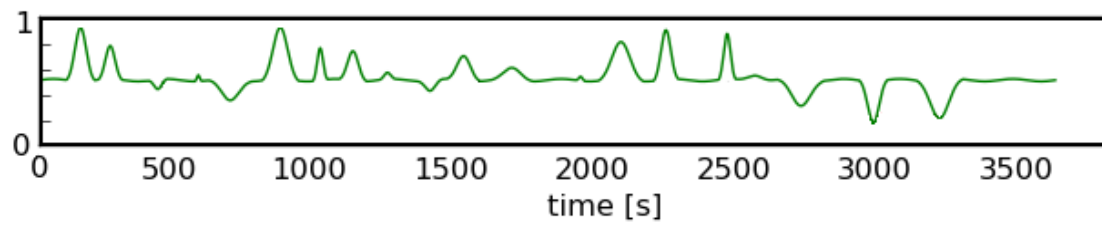




Figure 4

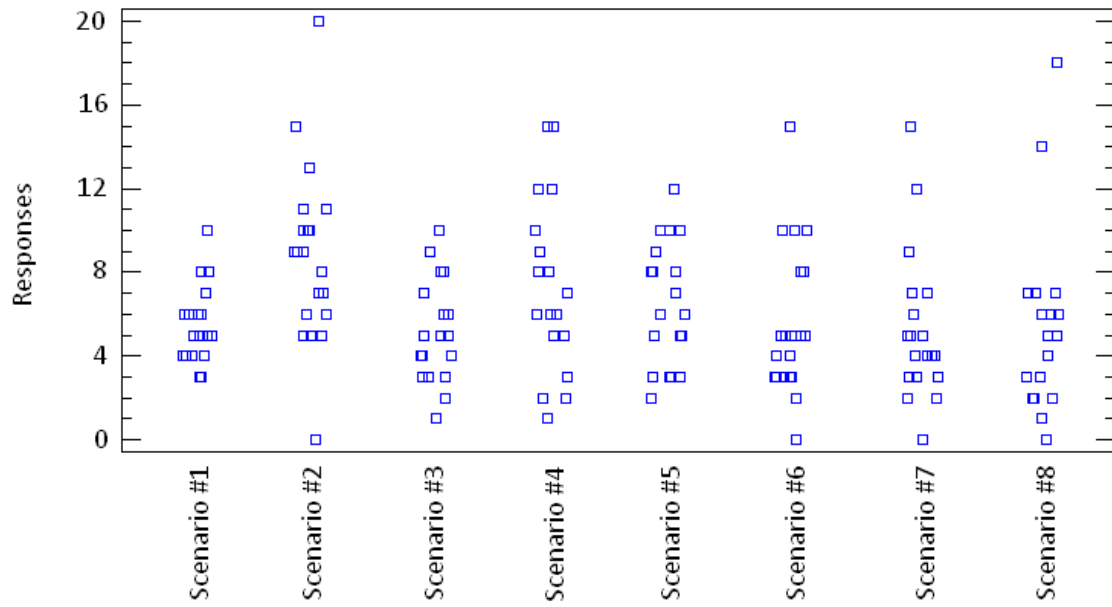


Figure 5

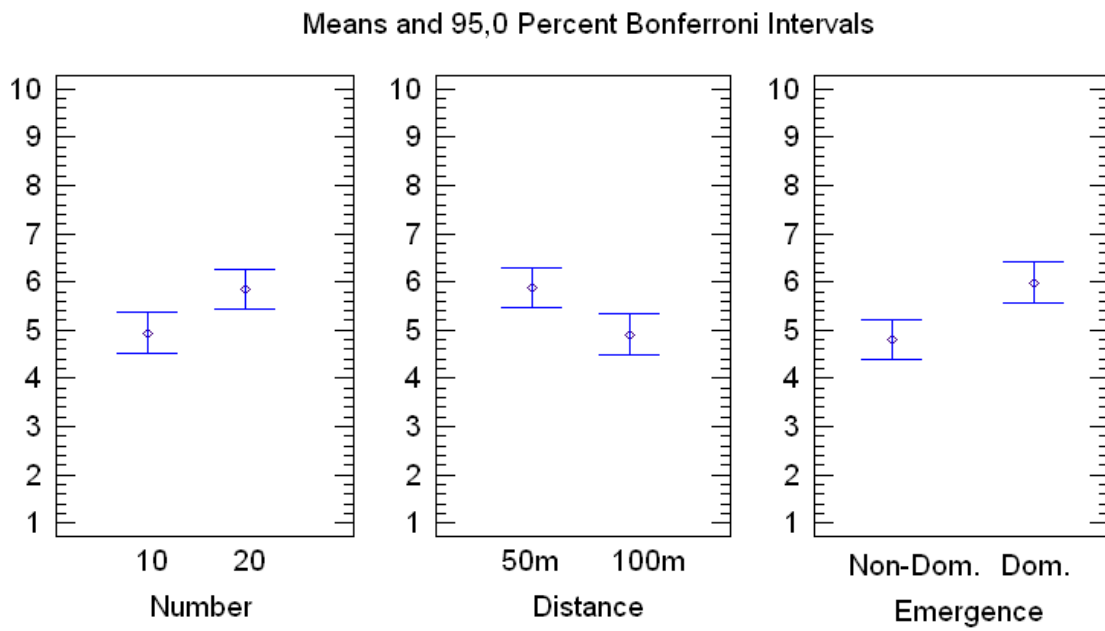


Figure 6

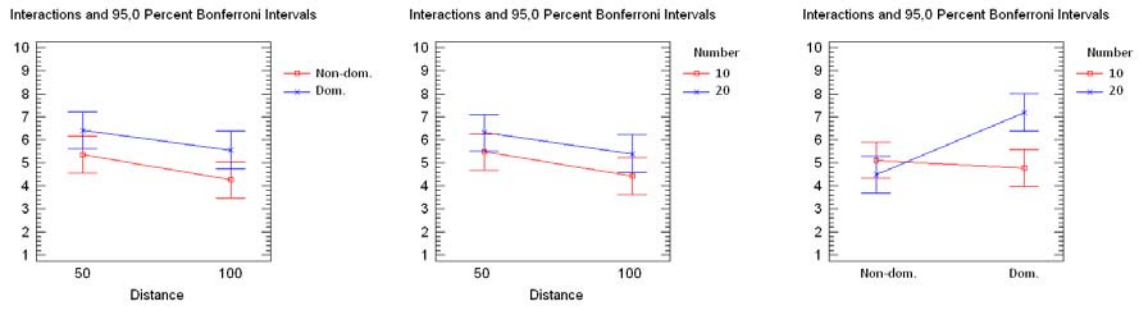


Figure 7

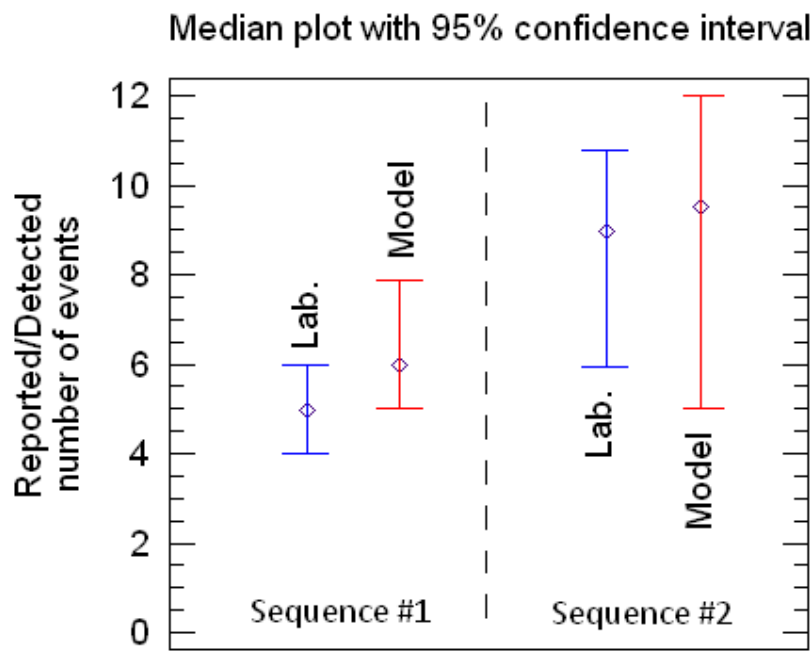


Figure 8

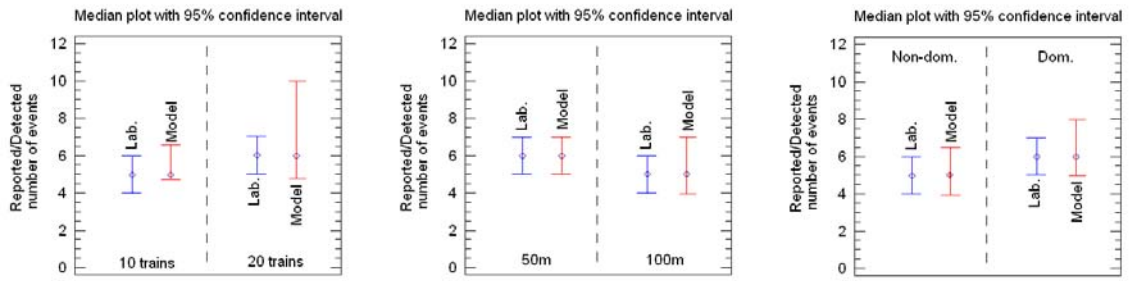


Figure 9

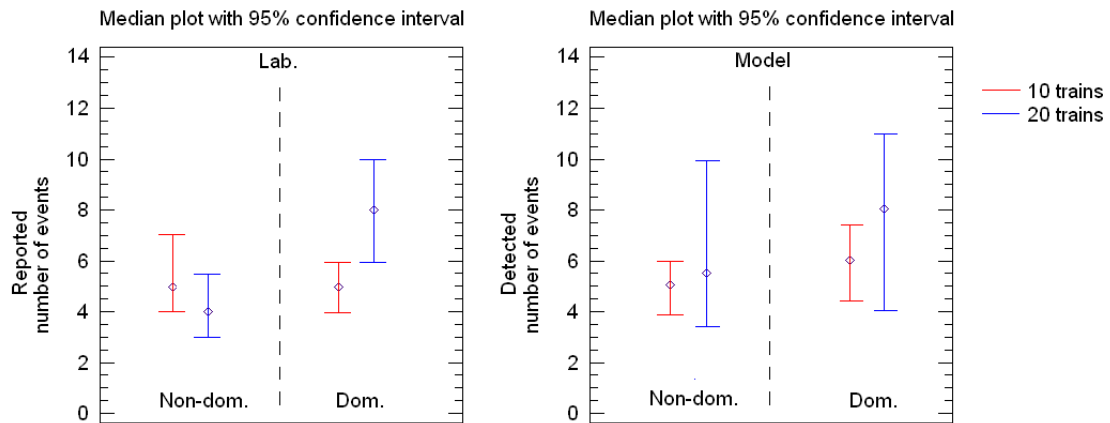


Table 1

	CORAIL		FRET		TER		TGV	
	50m	100m	50m	100m	50m	100m	50m	100m
$T_{L_{AMax},125ms-10dB}$ (s)	4.7	6.9	24.1	28.1	5.2	9.5	5.8	7.9
$SCG_{Mean}$ (Hz)	1038.1	963.2	1007.3	910.3	933.9	255.9	1001.5	698.8
$L_{ASlopeUp}$ (dB(A).s <sup>-1</sup> )	12.5	3.9	5.2	2.35	8.9	3.4	11.8	3.7

Table 2

Scenario	Number of Passbys	Distance	Dominance	$L_{Aeq,1h}$ [dB(A)]			$L_{AMax}^{Trains}$ [dB(A)]	Emergence [dB(A)]
				Total	Trains	Backgr.		
1	10	50m	Dom	52.5	51.5	45.5	72.0	26.5
2	20	50m	Dom	52.2	51.2	45.2	67.7	22.5
3	10	100m	Dom	52.3	51.3	45.3	69.6	24.3
4	20	100m	Dom	52.4	51.4	45.4	66.5	21.1
5	10	50m	Non-Dom	52.4	50.6	47.6	70.0	22.4
6	20	50m	Non-Dom	52.7	50.9	47.9	67.0	19.1
7	10	100m	Non-Dom	52.7	50.9	47.9	69.0	21.1
8	20	100m	Non-Dom	52.8	51.0	48.0	66.0	17.9

Table 3

<i>Source</i>	<i>Sum of Squares</i>	<i>Df</i>	<i>Mean Square</i>	<i>F-Ratio</i>	<i>P-Value</i>
MAIN EFFECTS					
A: Number	29,0001	1	29,0001	4,54*	0,0349
B: Distance	34,3471	1	34,3471	5,38*	0,0219
C: Dominance	49,5471	1	49,5471	7,76**	0,0061
INTERACTIONS					
AB	0,179594	1	0,179594	0,03	0,8671
AC	81,424	1	81,424	12,75**	0,0005
BC	0,569338	1	0,569338	0,09	0,7657
ABC	8,31635	1	8,31635	1,30	0,2558
RESIDUAL	855,66	134	6,38552		
TOTAL (CORRECTED)	1059,46	141			

Table 4

	Laboratory	Model
Number of trains	0,087	0,017
Distance	0,052	0,144
Dominance	0,040	0,087