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Results of a pilot study using experience sampling method to assess railway noise annoyance

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ABSTRACT

This article reports on the development of a method to study the acoustic factors driving the short-term annoyance experienced by neighbors of high-speed train lines (> 250 km/h). In fact, current indicators (e.g., L_{DEN}) only partially explain annoyance caused by high-speed train noise. They could potentially be improved by considering some event-related aspects (e.g., the suddenness, spectral content, temporal fluctuations), whose role remains not fully understood. The development of a protocol dedicated to these issues is an essential prerequisite. A review of the different methods used to study railway noise annoyance highlights the benefits of the experience sampling method, not yet used for railway noise assessment. This method allows participants to report their annoyance right after a train pass-by with a remote device while noise exposure is simultaneously recorded. We report on a pilot study testing an experimental protocol by proposing an adaptation of the experience sampling method to study annoyance caused by the passage of high-speed trains.

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Residents were recruited to take part in the study and received two protocols in two different periods. The most efficient experience sampling method parameters were determined, and further possibilities offered by this new methodology are discussed.

1. INTRODUCTION

Railway transportation has many environmental advantages: in countries (such as France) where electricity production mainly relies on nuclear energy or renewable energy sources, train operations have a very low carbon footprint compared to other transportation means. However, one drawback of railway transportation is noise pollution for communities living close to railway infrastructures. In France, the social cost of railway noise pollution has been estimated to be 11.2 billion euros per year [1]. After years of constant progress in decreasing noise levels around railway infrastructure (rolling stock design, noise barriers, dwelling insulation), further global level reductions are becoming increasingly costly. Furthermore, public acceptance of noise annoyance caused by railway noise appears to decline, particularly in the case of high-speed trains (HST), potentially creating hurdles to the development of new projects. It is thus important for railway stakeholders to better understand which aspects of noise emissions influence annoyance experienced by people living near high-speed lines (HSL), to focus noise abatement measures more precisely.

Current indicators and thresholds used in French regulations are only based on energy noise levels which are calculated by averaging the equivalent sound pressure level over several hours, with different weights for different periods of the day (e.g., L_{den}). Thus, these indicators may be insufficient to strongly model noise annoyance experienced by the surrounding communities. French authorities have thus decided to include new indicators more representative of noise annoyance [2].

This article is part of a larger project aimed at better understanding the acoustic factors contributing to annoyance experienced by people living alongside a HSL. The first part reviews the existing methods used to study railway noise annoyance, and lists the main results gathered using these methods. Then, it reports on the development of a pilot study whose goal was to compare different parameters of an experience sampling method (ESM). Particularly, we sought to identify the best method to send notifications to participants so that they can assess the annoyance of specific train passages. More precisely, we wanted to select protocol settings that: generate enough data, allow to study the influence of the number of passages on perceived annoyance, allow to combine annoyance judgements with trains' acoustical characteristics, are acceptable for participants (not too burdensome, not too intrusive), are easy to use, and do not interfere with participants' daily life. Therefore, two protocols (A and B) with different parameters were compared in a pilot study.

2. CLASSICAL METHODS USED TO STUDY RAILWAY NOISE ANNOYANCE

Two main approaches are reported in the literature to assess annoyance caused by railway noise: in-situ social surveys and laboratory experiments.

2.1. In situ social surveys

In situ social surveys ask residents living alongside railway lines to rate annoyance experienced (retrospectively) at home over some long time period. Their judgment is therefore global (not related to a specific event) and contextualized [3-6]. Social surveys usually use standardized response scales [7-8] such as numerical scales whereby respondents rate annoyance from 0 (not annoyed at all) to 10 (extremely annoyed) [7]. Some other questions, such as demographic factors, disturbance during the activities, sleep disturbance, main windows position during the study, may be asked [3], [5], [9-10]. Annoyance judgements are then related to acoustic indicators (and

particularly energetic noise levels such as L_{Aeq} , L_{den} , etc.) and other non-acoustic factors (such as those gathered in the socio-demographic surveys) through statistical analyses.

Social surveys allow researchers to explore a multitude of factors influencing annoyance. For example, several social surveys have reported the significance of acoustic factors, attributing approximately one-third of the variance in annoyance judgements to these factors, while another third is attributed to non-acoustic factors (individual, social and situational). However, a remaining third of the variance remains unaccounted for [6], [11]. Regarding acoustic factors, the results of such surveys are often summarized with dose-response relationships, modeling the percentage of highly annoyed residents as a function of noise exposure. These dose-response relationships are often used to determine the exposure thresholds in national and international regulations [11]. Beyond these thresholds, railway noise is considered to have an impact on health and/or sleep. For example, Miedema and Oudhsoorn have compiled data from many different surveys to construct dose-response relationships for various transportation modes [12]. These relationships have been revised over the years to provide a basis for local regulations [13]. The indicator used in current French regulation is the L_{Aeq} , measured at 2 meters in front of the façade. Two periods are defined: the day (from 6 a.m. to 10 p.m.) and the night (from 10 p.m. to 6 a.m.). Thresholds are defined based on the type of project, of traffic, on the pre-existing sound level and on the type of infrastructure concerned. This diversity of thresholds is detailed in the circular of February 28, 2002, [14]. These values are between:

- For the daytime: 60 to 68 dB(A) in L_{Aeq} (6 a.m. – 10 p.m.);
- For the nighttime: 55 to 63 dB(A) in L_{Aeq} (10 p.m. – 6 a.m.);

This indicator is calculated by averaging the equivalent sound pressure level over several hours. The thresholds are different for HST lines and conventional lines. Notably, the thresholds applied to HSL are observed to be lower, which acknowledges the fact that exposure to high-speed trains noise appears to cause more annoyance compared to conventional trains, at a same noise level.

In another example, Lambert et al. conducted a social survey to assess the annoyance caused by HST noise, at the time of the introduction of a new HSL in France [6]. In their study, two hundred and sixty residents were interviewed by a questionnaire about their long-time noise annoyance. Analysis of noise annoyance and noise exposure levels revealed that, in addition to the energetic noise levels, the number of train passages emerged as a significant factor contributing to annoyance, particularly during morning and evening hours. This finding echoes similar observations in studies of other transportation noise. For example, Schreckenber and Schuemer showed that the number of aircraft flyovers better predicts annoyance levels compared to the average maximum sound level, especially concerning hourly annoyance [5].

In situ social surveys are designed to encompass a variety of factors that influence the annoyance experienced by residents in their daily environments [11].

2.2. Laboratory experiments

In contrast to field studies, laboratory experiments are designed to focus on the characteristics of a limited number of acoustic events within a controlled environment. Due to their focus on a shorter duration, annoyance in these experiments is usually described as short-term. The duration can vary from a single pass-by noise to a few hours. There are in fact two types of laboratory approaches. In the first approach, known as the psychoacoustics approach, requires participants to focus their attention toward short stimuli (pass-by noises) and rate the pleasantness or unpleasantness of each stimulus using classical psychoacoustical methods like rating scales or pairwise comparisons [15]. In this approach, participants attentively listen to the sounds and judge them individually or by comparisons. In the second approach, participants are not specifically instructed to focus on the sound but rather to relax or perform some cognitive task (e.g., watch a movie or read a book) while being exposed to noise [16]. In this case, noise annoyance is viewed as the disturbance to the

participants' activities. The disturbance can be subjectively self-reported by participants [17], assessed through their performance at a cognitive task, or measured using physiological indicators. As this approach does not require direct attention to the sounds but rather involves engaging in cognitive tasks, it is sometimes referred to as the "distracted listening" or "cognitive tasks" approach.

The results of laboratory experiments are usually analyzed with multifactorial regression analyses or general linear mixed models (a generalization of the multifactorial regression), allowing researchers to quantify the influence of various acoustic factors on the pleasantness judgements or the disturbance measures. To ensure the statistical relevance of these analyses, stimuli are usually manipulated – selected, synthesized, or processed – to achieve specific statistical distributions of acoustic characteristics.

Terroir and Lavandier conducted a laboratory experiment to assess the impact of perceptual factors on HST noise quality [18]. Their study revealed that while sound level appears to be the most representative factor influencing annoyance due to pass-by noise, temporal fluctuations (such as passage length or rhythm) also significantly contribute to noise quality. However, they warn about the generalizability of these results in conditions close to residents' daily life.

2.3. Summary of the main results of social surveys and laboratory experiments

Despite their dissimilarities in scope and methods, both social surveys and laboratory experiments have yielded the following results:

- Noise level indicators (with different frequency weightings, averaged over one pass-by noise or over longer periods of times, etc.) are often the main factor contributing to annoyance models [6-7], [12], [14-16];
- Annoyance due to high-speed and Maglev trains is higher than conventional trains [12-13], [17-18];
- When considering a sequence with several train passages, the number of passages also influences annoyance [6], [19-20];
- There is also no clear consensus as to whether indicators based on averaged or maximal levels better model long-term annoyance [12], [21-22].

3. ANOTHER APPROACH: THE EXPERIENCE SAMPLING METHOD

Laboratory experiments allow a tight and parametric control over the acoustic parameters of the stimuli. However, the artificial nature of these settings raises concerns regarding ecological validity and the generalizability of the results beyond the laboratory environment. In contrast, social surveys are designed to capture real-life experiences and diverse factors but are not targeted to assess the impact of fine-grained acoustical factors.

Next paragraphs review another type of method: the experience sampling method (ESM). Although this method has not yet been applied to railway noise, it combines an ecological setting with a precise measurement of the noise exposure related to each annoyance judgement. This method involves sampling participants' experiences (sound exposure, activities, perceptions) by asking participants about their daily life, while noise exposure is simultaneously recorded.

3.1. Definition of the experience sampling method

As described by Schreckenberg et al., "the experience sampling method is a method for the assessment of event-related, acute or short-term self-reports. ESM involves the repeated measurements of human beings' daily-life experiences, perceptions, or behavior in situ in different moments across a period of time (e.g., at different times of day, on several different days, etc.)" [28]. It is a form of diary studies in which participants complete questionnaires in response to

notifications. These notifications may occur at random intervals, fixed predetermined intervals, or at fixed times.

This method has been used to study annoyance caused by transportation noise. In this case, participants' responses are associated with data on sound exposure. For example, in aircraft noise annoyance assessment studies, noise exposure was recorded at each participant's home using an outdoor recording system [24-27].

3.2. ESM applied to assess aircraft noise annoyance

So far, the ESM has mostly been used to assess aircraft noise annoyance [28-30]. These studies have yielded the following points:

- A significant negative association exists between noise level and both happiness and relaxation [33];
- The number of overflights has a strong influence on short-term annoyance, especially regarding on the period of the day [29], [31];

Therefore, the ESM appears particularly well-suited to assess the impact of the number of events.

However, Großarth describes an ESM study as “a demanding exercise. Many steps in the process are methodical-specific and bear pitfalls, if not considered carefully. [...] There is reason to assume that a diary study can explain more variety in data than the usual retrospective surveys combined with regression derived approaches, by considering in-situ raised data and the discrimination of fixed and random effects when calculating the models” [36]. Setting up an ESM study to assess railway noise annoyance thus requires careful consideration.

4. DEVELOPMENT OF AN ESM PILOT STUDY: MATERIALS AND METHODS

The study reported here is part of a larger project aimed at better understanding the acoustic factors contributing to annoyance experienced by people living alongside an HSL. Overall, its goal was to compare different parameters of an ESM. Particularly, we sought to identify the best method to send notifications to participants so that they could assess the annoyance of specific train passages. More precisely, we wanted to select protocol settings that: generate enough data, allow to study the influence of the number of passages on annoyance, allow to combine annoyance judgements with trains' acoustical characteristics, are acceptable for participants (not too burdensome, not too intrusive), are easy to use, and do not interfere with participants' daily life. Therefore, two protocols (A and B) with different parameters were compared in a pilot study.

4.1. Selection of participants

This pilot study was conducted in the vicinity of the French HSL “Atlantique” (West of France). We selected 122 residential buildings with a railway noise exposure $L_{DEN} > 55$ dB(A) (corresponding to a maximum of distance of about 1 km). The selected dwellings had also to be not exposed to other sources of transportation noise. Topography and noise barriers were also considered in the selection. A recruitment agency contacted potential participants by phone or by visiting them in person. As the aim of this pilot was purely methodological, we were not looking for significant quantitative results. We were therefore aiming for around ten participants. Some of the selected dwellings were in fact not canvassed. Eight people between 26 and 67 years old with no reported hearing issue were finally hired (3 women and 5 men). Each participant received financial compensation of 150 €.

4.2. Setup

A remote response device made with a smart LCD with Bluetooth Low Energy and a passive buzzer was used to send out notifications at predefined times based on theoretical train passages.

Participants used it to fill in an annoyance questionnaire, either by scanning an-online QR code that sent them to a web page (protocol A), or directly on the device (protocol B).

4.3. Procedures

The first 3 days, participants used protocol A. On the 4th day, a telephone interview took place to debrief the first three days. The next 3 days, participants used protocol B. A last telephone interview was scheduled at the end of this week. The whole study lasted 7 days for each participant.

Protocol A was designed to interfere as little as possible with participants' daily lives. They selected a two-hour slot each day, and notifications were sent after certain train passages (that were preselected) during these slots. The notification times were selected to vary the number of train passages experienced before each judgement. Participants were instructed to carry on their daily activities as usual. When they received a notification, they were invited to fill in a brief online questionnaire. The first two questions concerned whether the participant heard the train passing before the notification, and whether they were inside their home. Then, the questionnaire presented an ISO 11-points numerical scale of annoyance (focused on the last train passage), on which participants can assess their annoyance by rating it from 0 (not annoyed at all) to 10 (extremely annoyed) [8]. Three additional questions concerned the activity being carried out at the time of the passage, whether the window was opened or closed, and the level of noise inside the dwelling.

Protocol B required participants to stop their activities during a 15-min slot each day and listen carefully and assess noise annoyance for every train passing by during this slot. It used only the annoyance scale. In this protocol, participants answered directly on the remote response device, using physical buttons to move a cursor on the ISO 11-points numerical scale.

5. RESULTS AND DISCUSSION

5.1. Amount of data and statistics

For protocol A, considering only participants who had no impediments or technical issues (5 participants out of 8), 74 notifications were sent during the study. Sixty-five answers were obtained (87.8%). Forty-two answers (64.6%) mentioned that the participant had not noticed the train (and hence could not rate annoyance). It may be partly due to the poor synchronization of the notification with the actual train passages, based only on train schedule. Details are given in Table 1. For protocol B, a total of 20 quarter-hours were studied and 38 annoyance ratings were collected. Details are given in Table 2.

5.2. Acceptability, ease of use and interference with daily-life activities

The analysis of the interviews highlighted that asking for two hours a day may have scared participants away (protocol A). This protocol can be perceived as more restrictive as it requests participants to stay in their main room during the whole time slot. Moreover, seven participants expressed a preference for protocol B, because of the shorter time slot, the careful listening, and the response directly on the device.

During the interviews, six out of eight participants mentioned that the notification was not loud enough, so they had to change their habits (e.g., not listening music or TV) to detect it. Discussions with the participants also revealed that most of them have become accustomed to the noise of trains and hardly notice them at all in their daily life. Only certain passages were perceived as very annoying. In their opinion, the potential sources of annoyance are the weather, the speed, the vibrations, and the type of train.

Table 1: Quantitative results for protocol A.

Participant	Number of notifications received	Numb. of answers provided	Numb. of “no train heard” answers	Numb. of annoyance ratings
1	13	13	7	6
2	12	12	12	0
5	21	16	10	6
6	12	8	3	5
8	16	16	10	6
Total	74	65	42	23

Table 2: Quantitative results for protocol B.

Participant	Numb. of slots	Numb. of ratings
1	3	5
2	3	7
3	2	4
4	1	2
5	2	5
6	3	8
7	3	1
8	3	6
Total	20	38

6. DEVELOPMENT OF A NEW PROTOCOL

Results of the pilot study allow us to develop a new protocol for an in-situ study of the acoustic factors driving the short-term annoyance experienced by residents living close to HSL. The pilot study compared two variations of the Experience Sampling Method. Protocol A was designed to interfere as little as possible with the situation: it requested participants to carry out their daily activities as usual and rate the annoyance of train passages signaled by notifications sent throughout 2-hour periods, whenever they had noticed them (signal contingent). In contrast, protocol B requested participants to stop their daily activities for 15 minutes, listen carefully and rate the annoyance of every train passing by (event contingent). The main methodological results are:

- Protocol A seems to be more representative of participants’ real-life annoyance than protocol B. It allows to consider the number of passages that participants did not notice, and thus, to study its influence on annoyance, considering not only the scheduled number of train

passages but also the number of passages heard by participants. This will allow us to determine the acoustic characteristics of the passages heard by the residents as well as other external factors such as weather conditions.

- Consequently, in protocol A, many notifications did not yield any annoyance rating, as participants had not noticed the train passage. In contrast, in protocol B, participants rated every single passage. This striking contrast suggests that protocol B was clearly not representative of the annoyance experienced by participants.
- However, protocol A also has some drawbacks: for example, participants were often not in the same room as the response device when they received notifications. In addition, participants found it difficult to be available 2 hours each day (and preferred the shorter protocol B).

Based on these methodological results, we recommend the use of the following protocol to refine the assessment of railway noise annoyance. Such a protocol should be based on protocol A, to be as close as possible of participants' short-term annoyance. However, the drawbacks it presents could be improved in the future:

- Participants should be able to choose their experiment slots from day to day. Thus, they should not have to schedule their availability in advance.
- The annoyance judgement can be made from several rooms. The experimenters can either measure transfer functions or at least measure the distance between these rooms and the most exposed façade, in order to have a reference of the sound level heard by participants in each room.
- A louder notification has to be developed to ensure that participants' lifestyle is not changed.
- Annoyance responses should be synchronized to trains' passages thanks to a microphonic device (equipped with a Raspberry Pi) that automatically detects trains' passages.
- Finally, the response device should allow participants to notify the experimenters when a train passage has been perceived as particularly annoying. All the trains passages need consequently to be recorded.

Moreover, and to our knowledge, no scientific study has established a link between short-term annoyance judgements and long-term annoyance judgements. It seems appropriate to assess the impact of introducing event-related acoustic indicators (as proposed in the Mobilities Orientation Law, [2]) on long-term annoyance. It is thus important to study the articulation between short-term and long-term annoyance. To answer this problem, it will be necessary to include additional data, such as annoyance judgements at different timeframes (e.g., immediate, short-term, long-term) combined with acoustic data. These judgements can be made in situ. One possibility is to:

- Ask participants to assess their long-term annoyance (over one year) at the beginning of the protocol, using the ISO 10-points numerical scale.
- Then, to record every train passage during the first week of the experiment, and to ask participants to fill simultaneously a daily diary, in order to provide information about participant's hourly presence at home and thus, their exposure level. At the end of the first week, participants could be invited to answer a question concerning their annoyance perceived over the week.
- The ESM protocol would take place on the second week of experiment, with the dwellings selected on several HSL, allowing to study the variation of the daily number of passages, and the trains' speed.

Such a protocol would end up with the following data gathered:

- Long-term annoyance judgement (over a year).
- Annoyance judgement over a week, with the recording of the train passages and the participant's exposure level.

- Short-term annoyance judgements, with the recording of the train passages corresponding to the judgements, and some contextual data (e.g., activity being carried out, windows position, etc.).

This new protocol will make it possible to determine which acoustic factors have the greatest impact on railway noise annoyance (e.g., suddenness, temporal fluctuations, spectral content, number of passages), and then evaluate longer-term annoyance (the weekly one). The next step of this research is to implement and evaluate this new protocol in the field, and then to analyze the impact of the acoustical characteristics of the trains passing-by on annoyance judgements.

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