Using experience sampling method to study railway noise annoyance: a review

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ABSTRACT

The goal of this article is to report on the development of a study of the acoustic factors driving the short-term annoyance experienced by neighbors of high-speed train lines. In fact, annoyance caused by high-speed trains (> 250 km/h) is not completely modeled by current indicators (e.g., L_{DEN}). For example, the suddenness, spectral content, temporal fluctuations of pass-by noises, and the density of train passages seem to significantly impact annoyance in a way that is not fully understood [1]. To investigate these aspects, we first review different approaches used to study annoyance caused by transportation noise. For railway noise, two main approaches are reported in the literature: in-situ social surveys exploring the contributions of acoustic and non-acoustic factors to long-term annoyance; laboratory experiments, in which controlled stimuli (individual pass-by noises) are played back to participants who rate their annoyance. Another approach is also used in transportation noise studies, but not yet for railway noise: diary, or experience sampling methods, whereby neighbors report their annoyance, at home, at different times over a longer time span (usually several weeks) while noise exposure is simultaneously recorded [2]. Such in situ approach allows experimenters to focus on the precise characteristics of each pass-by noise and consider annoyance in the context of participants' real environment and activities. Thus, this article then proposes an adaptation of the experience sampling method (ESM) to study annoyance caused by the passage of high-speed trains.

Keywords: *Annoyance – Railway – Indicators – Experience Sampling Method*

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. Still, it has an environmental impact: the noise exposure imposed to the surrounding communities. Even if this impact is lower than for road or air transportation, the social cost of railway noise has still been estimated to be 11.2 billion euros per year in France [3]. Furthermore, public acceptance of 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 utterly important for train operators, infrastructure managers and transportation authorities to understand precisely how the acoustic characteristics of these trains influence annoyance experienced by residents living nearby railway infrastructures, in order to design effective mitigation measures.

Noise emitted by high-speed trains (>250 km/h) is dominated by aero-acoustic sources, generating louder low frequencies than classical-speed trains. Moreover, higher speeds create specific temporal characteristics (see below). However, current indicators and thresholds used in French

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and European 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, it appears that these indicators may be insufficient to account for more detailed aspects of the noise signatures that may influence annoyance, and regulations may evolve to include new indicators more representative of noise annoyance [4].

This article is part of a study aimed at better understanding the acoustic factors driving annoyance experienced by neighbors of HST lines. To this aim, next paragraphs review current methods used to assess railway noise annoyance, and list the main results gathered using these methods.

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

2.1.1 Method

In situ social surveys ask residents living alongside railway tracks to rate annoyance experienced at home over a certain, long time period (hence the term *long-term annoyance*). Their judgment is therefore retrospective (e.g., the last 12 months), global (not related to a specific event), and contextualized [5]–[8]. Social surveys usually use standardized response scales [9], [10]. For example, two of these standardized response scales are recommended by the International Commission on Biological Effects of Noise (ICBEN [9]): 11-point numerical and 5-point verbal rating scales. Respondents judge annoyance by selecting one of 11 (or 5) categories from 0 (not annoyed at all) to 10 (or 4, extremely annoyed). Some other questions, such as demographic factors, disturbance during the activities and their locations, sleep disturbance, attitudes towards the noise source, main windows position during the study, may be asked [5], [7], [11], [12].

These 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.

2.1.2 Examples of results

Social surveys allow experimenters to consider a large range of factors influencing annoyance. Importantly, several social surveys have reported that acoustic factors may account for about a third of the variance of annoyance judgements, whereas non-acoustic factors (individual, social and situational) may account for another third, and the remaining third of the variance is unaccounted for [8], [13].

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 [13]. Beyond these thresholds, railway noise is considered to have an impact on health and/or sleep.

For example, Miedema and Oudhsoorn have compiled many different surveys to provide dose-response relationships for various transportation modes [14]. These relationships have been revised over the years to provide a basis for local regulations [15]. Some examples of thresholds used in French regulations are reported in Tab. 1.

Table 1. Examples of thresholds used in current French regulations for railway noise exposure.

	L_{DEN} (dBA)	L_N (dBA)	$L_{Aeq,\ 6h\text{-}22h}$	$L_{Aeq,\ 22h\text{-}6h}$
HT lines	68	62	70	65
Conventional lines	73	65	73	68

It should be noted that the thresholds applied to HS lines are lower than those for conventional lines. This acknowledges the fact that, for a same noise level, exposure to HS trains appears to cause more annoyance than conventional trains.

In another example, Lambert et al. used a social survey to assess the annoyance caused by HST noise, at the time of the introduction of a new HS line in France [8]. In their study, two hundred and sixty residents were interviewed by a questionnaire about their long-time noise annoyance. Analysis of noise annoyance levels and noise exposure levels suggests that, in addition to energetic noise levels, the number of train passages is also an important factor contributing to annoyance, particularly during evening and morning periods.

The impact of the number of events on annoyance has also been reported in other studies of other transportation modes. For example, Schreckenberg and Schuemer showed that the number of aircraft flyovers better models annoyance than the mean maximum sound level, in particular with regard to the hourly annoyance [7].

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, laboratory experiments are designed to focus on the characteristics of a small number of acoustic events, in a laboratory setting. 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.

2.2.1 Methods

There are in fact two types of laboratory approaches. First, 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 response methods such as rating scales or pairwise comparisons [16]. In this approach, participants listen attentively to the sounds and judge them individually or by comparisons. In another approach, participants are not instructed to listen to the sounds, but to relax or perform some task (watch a movie, read a book) while being exposed to some noise [1]. In this case, noise annoyance is considered as the disturbance to the participants' activities. The disturbance can be measured either subjectively by the participants themselves [17], by measuring their performance at a cognitive task, or by measuring some physiological indicators. Because this approach does not require the participants to focus on the sounds but to perform some cognitive tasks, it is sometimes referred to as the "*distracted listening*" or "*cognitive tasks*" approaches.

The results of laboratory experiments are usually analyzed with multifactorial regression analyses or general linear mixed models (a generalization of the multifactorial regression), allowing experimenter 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 (e.g., selected, synthesized, or processed to reach a specific statistical distribution of acoustic characteristics).

2.2.2 Examples of results

Terroir and Lavandier conducted a laboratory experiment to assess the influence of perceptual factors on HST noise quality [18]. Their study showed that, although sound level appears to be the most representative factor of annoyance due to pass-by noise, temporal fluctuations (i.e., passage length, rhythm) also play a significant role on noise quality. However, they warn about the relevance 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 [1], [8], [9], [19]–[21];
- Annoyance due to high-speed and Maglev trains is higher than conventional trains [1], [17], [22], [23];
- When considering a sequence with several train passages, the number of passages also influences annoyance [8], [24]–[26];
- There is no clear consensus as to whether indicators based on averaged or maximal levels better model long-term annoyance [1], [27], [28];

3. ANOTHER APPROACH: THE EXPERIENCE SAMPLING METHOD

Laboratory experiments allow a tight and parametric control over the acoustic parameters of the stimuli, but the artificial setting used in these experiments raises concerns about ecological validity and the generalizability of the results outside of the laboratory. In contrast, social surveys are designed to consider the real-life experiences of residents and a variety of 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 been applied yet to railway noise, it combines an ecological setting with a precise measurement of the noise exposure related to each annoyance judgement. This method consists of sampling participants' experiences (sound exposure, activities, perceptions) i.e., asking participants about their annoyance in their daily life, while noise exposure is simultaneously recorded.

3.1 Definition of the experience sampling method

According to 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.)" [29]. It is a form of diary studies whereby participants fill in a questionnaire in response to notifications. These notifications can be sent at random intervals, fixed predetermined intervals or at fixed times. These parameters will be detailed later (c.f. 4.1).

This method has been used to study annoyance caused by transportation noise. In this case, the responses are associated with data on sound exposure. For example, in aircraft noise annoyance assessment studies, noise exposure was recorded at each subject's home with an outdoor recording system [2], [30]–[32].

3.2 ESM applied to assess aircraft noise annoyance

So far, the ESM has mostly been used to asses aircraft noise annoyance [33]–[35]. These studies have yielded the following points:

- There is a significant negative association between noise level and both happiness and relaxation [33];
- The number of overflights has a strong impact on short-term annoyance, especially regarding on the period of the day [2], [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" [37]. Setting up an ESM study to assess railway noise annoyance thus requires careful consideration.

4. DESIGNING AN EXPERIENCE SAMPLING PILOT TO STUDY RAILWAY NOISE ANNOYANCE

In fact, and to the best of our knowledge, the ESM has not yet been applied to railway noise. Therefore, the following paragraph will outline a set of methodological considerations for adapting this method to railway noise research.

To this aim, we start with discussing the recommendations of Christensen et al., who have discussed the different techniques available to the experience sampling researcher in their practical guide to experience sampling procedures [38]. These discussions and techniques also form the bases of the noise assessment studies reported by Schreckenberg [29]. The following checklist is proposed: (A) decide whether you need experience sampling, (B) determine your resources, (C) set study parameters, (D) choose software and equipment, (E) implement security measures, (F) implement the study, (G) data issues.

4.1 Decide whether you need experience sampling

This method is time- and resource-intense for researchers and participants. It is thus important to consider how useful an ESM study is. For example, it may not be necessary to assess annoyance repeatedly. It depends on the research question and the characteristics of the exposure, which are specific to the particular noise source being investigated. Here, we want to conduct a study to assess annoyance caused by railway noise in the participants' real environment, considering the influence of the number of train passages, and the trains' acoustic characteristics. The ESM seems a promising approach to reach this goal.

4.2 Determine your resources

The financial resources to provide incentives to the participants and to use the necessary devices for data collection (e.g., computerized vs. paper and pencil instruments) has also to be considered. The more time-consuming an experience-sampling study is for the participants, the more substantial the remuneration should be. These incentives help maintain participants' motivation throughout the duration of long studies.

4.3 Set study parameters

The study parameters are determined by the sampling protocol and the sampling period. Three types of sampling protocols can be distinguished: interval-contingent, signal-contingent, and event-contingent. Interval-contingent protocols involve assessing annoyance at fixed times (either by the participant or not) throughout the day (e.g., at 10 am and 10 pm on a daily basis). These protocols are well suited for studying relatively frequent events as the event is likely to occur at the time of the report. Reports are made at predictable times, enabling participants to configure their schedule around them and prepare themselves cognitively and emotionally. The predictability of the requests makes the interval-contingent protocols the least burdensome for the participants.

Signal-contingent protocols involve reporting experiences in response to a signal at various times throughout the day. They are appropriate for studying experiences that are susceptible to retrospective memory bias, or cognitive or emotional regulation if they were reported on later from memory. In noise annoyance research, signal-contingent protocols seem to be suitable for assessing noise responses to sources with a higher number of events per day (e.g., road traffic noise) and during ongoing activities is of interest. However, the main disadvantage of this protocol is its burden to participants, who are interrupted by the signal and must stop their activities to report their experience.

Even-contingent protocols involve reporting experiences immediately or within a short-time after the event of interest. This protocol is appropriate for studying events that are less common in daily life. In noise annoyance research, it is suitable when the single noise event that the annoyance judgment refers to is distinct and detectable from the background noise. These procedures also minimize the retrospective bias that might occur when the judgment is from memory, but only to the extent that reports are made close in time to the event. Event-contingent protocols can be challenging to participants, especially if the events are frequent.

4.4 Choose software and equipment

Nowadays, the number of ESM studies that use mobile devices for collecting data has increased [39]. Purchasing the devices and handing them out to the participants can be quite cost-intensive but allows the researcher to control the software that is used.

4.5 Implement security measures

Considering the high cost of the equipment, this point aims to protect it from damages, by setting up a deposit for example.

4.6 Implement the study

The implementation of an ESM survey involves the development of a pilot study. This pilot includes thorough extensive testing of the procedure and the equipment, an easy-to-read document to guide the installation and use of the ESM devices and procedure.

4.7 Data issues

The data collection and storage process must comply with applicable data protection regulations, such as the EU General Data Protection Regulation (GDPR). All data should be uploaded to a secure server as soon as possible, and the research team must ensure that appropriate measures are in place to prevent data loss and protect the privacy of research participants in accordance with GDPR requirements.

5. DISCUSSION

The experience sampling method allows experimenters to assess noise annoyance *in-situ* as it is experienced in real life. Associated with concomitant recordings of noise exposure, this method also allows a precise measurement of the acoustic factors potentially influencing annoyance. To the best of our knowledge, these studies have been applied to assess annoyance caused by aircraft noise, but never for rail transportation. Nevertheless, some of the parameters listed in paragraph 4 can be readily decided depending on the goal of this study. For example, to associate the participants' responses with the acoustics characteristics of the pass-by noises, the best sampling protocol would be the event-contingent. Moreover, incentives strategies are a powerful tool to encourage participants to remain in the study. According to Musthag et al., micro-incentives strategies seem to have a strong impact on the truthfulness of the answers and on participants behaviors [40]. However, ethical committees may require that all participants be compensated equally, which forbids such strategies. Other parameters such as the study's length, the time slots, the daily number of notifications and their delay, or the design of weekly interviews have an impact on participants motivation and on data's quality and quantity, but strongly depends on the specificities of the communities being studied [39], [41], [42]. Thus, deciding of these parameters has to rely on a pilot experiment. Despite these methodological difficulties, using the ESM to assess railway noise annoyance seems a promising way to get a realistic insight into people's everyday noise experience.

6. ACKNOWLEDGMENTS

This study was funded by the Europe's Rail Joint Undertaking (ERJU) and the Rail4EARTH project under the Horizon Europe programme. This work was performed within the framework of the LABEX CeLyA (ANR-10-LABX-0060) of Université de Lyon, within the program « Investissements d'Avenir » operated by the French National Research Agency (ANR).

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