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Short-Term Annoyance Due to Tramway Noise: Determination of an Acoustical Indicator of Annoyance Via Multilevel Regression Analysis, A. Trollé, C. Marquis-Favre and A. Klein, Acta Acustica **vol. 100** (Number 1), 2014, pp. 34-45

DOI
https://doi.org/10.3813/AAA.918684

Acta Acustica united with Acustica
Vol. 100 (2014) 34 – 45

DOI 10.3813/AAA.918684

Short-Term Annoyance Due to Tramway Noise: Determination of an Acoustical Indicator of Annoyance Via Multilevel Regression Analysis

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Summary
The tramway is a source of noise annoyance. Noise exposure levels proved not to be sufficient to account for this annoyance. Other acoustical factors linked to temporal and frequency features could further explain noise annoyance. Using a psychoacoustical approach, this study aims at determining an acoustical indicator of short-term annoyance due to tramway noise. A laboratory experiment is carried out in order to identify and characterize the influential acoustical factors. Subjects are asked to rate the short-term annoyance caused by 61 tramway pass-by noises, recorded *in situ* for different operating situations. A psychoacoustical analysis using verbalization task data and the annoyance data shows that the overall level, the irregular / continuous character and the bass / treble character of tramway noises influence noise annoyance. These acoustical features are taken into account through the following indices: the A-weighted equivalent sound pressure level ($L_{A,eq,T}$), the variance of time-varying A-weighted pressure normalized by RMS A-weighted pressure (*VAP*) and a proposed index, the total energy of the tonal components within critical bands from 12 to 24 Barks (*TETC*). A multilevel regression model combining $L_{A,eq,T}$ and *TETC* proves to be satisfactory to account for short-term annoyance due to tramway noise.

PACS no. 43.50.Qp, 43.50.Rq, 43.66.Lj

1. Introduction

In the past decades, the interest of local authorities in tramway was renewed because this means of transportation is of reasonable cost, energy-saving and does not cause much pollution. In France, tramway networks were reintroduced in many cities (Paris, Lyon, Grenoble, Nantes, etc.) in the framework of a sustainable transportation policy. One environmental advantage of tramway put forward by local authorities is its relative silence, compared with other means of transportation such as bus. However, in the light of residents' adverse reactions observed in France and in Europe, the introduction of tramway tracks can create particularly annoying situations for the residents.

Yet, very few research works focused on annoyance due to tramway noise. Rylander *et al.* [1] carried out a field investigation of annoyance due to tramway noise. These authors pointed out that some parameters of tramway traffic such as the number of tramways could influence the extent of noise annoyance. Miedema and Van Den Berg [2] also carried out a field study about tramway noise annoyance. Their results suggested that noise exposure levels were not sufficient to account for tramway noise annoyance. These two research teams agree to say that other acoustical characteristics of tramway noise may be of importance regarding noise annoyance. This assumption was investigated by other authors more recently. In particular, Sandrock *et al.* [3] conducted experimental studies on annoyance caused by noises from trams and buses. Besides a possible bonus for the tram, the authors pointed out that psychoacoustical features such as loudness and sharpness could be responsible for differences in annoyance ratings. Pallas *et al.* [4] carried out a field investigation in which residents were asked to assess noise annoyance due to a tramway pass-by. The authors proposed a perceptive model based on an instantaneous noise exposure level index ($L_{A,max}$ or SEL) and descriptive variables (semantic differential adjectives – short / long, bass / treble, distant / nearby – and numbers of occurrences of terms describing the tramway noise – rumbling, squealing). The predictive power of this model was shown to be greater than that of a model only based on an instantaneous noise exposure level index. These first findings need to be confirmed by further investigations.

The present work is a further contribution to the study of annoyance due to tramway noise. It aims at determining an acoustical indicator of annoyance due to tramway noise by identifying and characterizing the acoustical factors that influence noise annoyance. This is achieved by carrying out an experiment in laboratory conditions. Hence, this study deals with short-term annoyance due to tramway

Received 5 April 2013,
accepted 27 October 2013.

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noise. In the experiment, subjects are asked to rate the annoyance caused by 61 tramway noises. Each involves one single tramway pass-by. The samples stem from sound recordings carried out *in situ* for different tramway operating situations. At the end of the experiment, subjects are asked to freely describe the noises they heard. Furthermore, they are asked to rate their noise sensitivity as this non-acoustical factor is usually known to influence noise annoyance judgments (e.g. [5, 6]). A psychoacoustical analysis is carried out from the free verbalizations and the annoyance ratings in order to determine the acoustical characteristics that influence noise annoyance. The influential acoustical factors are characterized, either by indices from the literature or by a proposed index. Then, the effect of noise sensitivity on mean annoyance ratings and its moderating effect on the relationship between each index and noise annoyance are tested. Finally, an acoustical indicator based on a combination of two indices is proposed to account for short-term annoyance due to tramway noise.

The paper is organized as follows. Section 2 presents the sample collection and preparation. The experiment is described in section 3. Results are presented and discussed in sections 4 and 5, respectively.

2. Sample collection and preparation

2.1. Measurement sites

The sites are set in Lyon. A location was carried out along the four existing tramway lines in order to list the different tramway operating situations. The operating situations can differ according to numerous criteria. Four criteria likely to influence the noise emitted from the tramway were identified: i) the type of track installation (classical, with insulating flange, on floating slab, on ballast), ii) the type of surface (coating, concrete, grass, cobblestone, fine gravel – only for an installation on ballast, rough gravel – only for an installation on ballast), iii) the type of operating configuration (straight line, in curve, arrival at station / departure from station), and iv) the type of street (open, U-shaped).

Thirty-four sites were selected for noise recordings; these sites entailed different combinations of the modalities of the four above-mentioned criteria.

2.2. Noise recordings

For each site selected, two types of noise recordings were simultaneously performed: monophonic recordings and stereophonic recordings. Stereophonic recordings were intended for sound reproduction during the experiment; monophonic recordings were used for the sole purpose of calibrating the stereophonic recordings.

2.2.1. Apparatus

The stereophonic recordings were performed *via* an ORTF couple Schoeps MSTC 64, equipped with Schoeps BBG windscreens. The ORTF couple was chosen because it provides a good compromise between spatialization and localization of sound sources [7]. Moreover, this technique, associated with a sound reproduction on loudspeakers, is known for its good representation, readability, plausibility and overall quality of reproduction when studying fixed or moving acoustical sources [8]. This technique was also used in other research works dealing with sound perception in order to record noises emitted from moving sources such as road vehicles (e.g. [9]). The sound sequences were recorded on a portable recorder (TASCAM HD-P2) with a sampling frequency equal to 44.1 kHz and a 24-bit resolution.

The monophonic recordings were performed using an omnidirectional microphone (GRAS 40AE). The sound sequences were also recorded on a portable recorder (TASCAM HD-P2). The omnidirectional microphone was calibrated using a pistonphone (B&K 4231) in order to assess the recording levels.

2.2.2. Measurement procedure

According to standard ISO 1996-1 [10], the ORTF couple was placed at a height of 1.5 m and at least 2 m from any reflecting wall surface. The axis of the ORTF couple was positioned perpendicularly to the axis of the tramway track. The omnidirectional microphone was placed slightly above the center of the ORTF couple. The distance between the microphones and the tramway track was imposed by the urban architecture and the recommendations of the above-mentioned standard; it also depended on the tramway traffic direction. This distance thus ranged from 4 m to 14 m.

2.3. Samples

From the sound sequences recorded across the 34 sites, 61 tramway pass-by noises were extracted. Attention was paid to selecting sound excerpts without any unwanted sound (wind, voices, birds, road vehicles, etc.). Their level ranged from 67 to 84 dB in terms of L_{eq} (from 62.4 to 77.8 dB(A) in terms of $L_{\mathrm{A,eq}}$). Their duration ranged from 8 to 25.5 s as the pass-by duration depends on the tramway operating situation. According to previous studies on noise annoyance in laboratory conditions, stimulus duration has a limited influence on short-term annoyance. For instance, for highway road traffic noises, Paulsen [11] showed that a variation of duration ranging from 20 to 80 s had almost no influence on the judgment of annoyance. Also, for urban road traffic pass-by noises, Morel *et al.* [12] found that duration, ranging from 3 to 9 s, was not a criterion to formulate annoyance judgments. Finally, in their review paper, for aircraft noises, Parry and Parry [13] concluded that duration was not an inherent factor in the noisiness judgments. Consequently, in the present study, the choice of keeping the original pass-by durations was done.

3. Experiment: Methods

3.1. Subjects

Fourty subjects, 21 men and 19 women, participated in the experiment (mean age = 34; standard deviation = 13.5). All the participants declared normal hearing abilities. They were paid for their participation.

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3.2. Stimuli

The 61 samples were selected. No filtering simulating facade transmission was applied. Actually, the choice of one wall material and window type would be a particular case of dwelling facade, which may have an effect on subjects' judgments [14]. The stimuli were reproduced at a sound level 21 dB lower than their recording level, so that the levels could be comfortable for a listening by subjects in laboratory conditions [3]. Moreover, such a reduction made it possible to simulate the worst situations of noise exposure at home [15] (e.g. being in indoor private spaces with an open window or in outdoor private spaces at several dozens of meters from the tramway tracks). This reduction kept the original differences in L_{eq} between the samples, which finally ranged from 46 to 63 dB. The corresponding $L_{\mathrm{A,eq}}$ values ranged from 38 to 57 dB(A).

Prior to the experiment, the stimuli were reproduced and recorded (in the test room, see section 3.3) using an omnidirectional microphone (GRAS 40AE) in order to compute acoustical and psychoacoustical indices (see section 4.2.1). These indices were computed using the software dBSONIC (01dB-Metravib) and Matlab routines.

3.3. Apparatus

The experiment took place in a quiet room (4.4 × 2.8 × 2.3 m^3), with a background noise lower than 20 dB(A). The pass-by noises were reproduced through a high quality PC sound card (LynxTwo studio interface), using two active loudspeakers (Dynaudio Acoustics BM5A Active), and one active subwoofer (Dynaudio Acoustics BM9S) for a good reproduction of low frequencies. The listener and loudspeaker positions complied with Bech and Zacharov's [16] recommendations: the center of the listener's interaural axis and the loudspeakers formed an equilateral triangle. The loudspeakers were placed at a height of 1.2 m. The subwoofer was placed on the floor between both loudspeakers. The experiment was computer-controlled using Matlab scripts.

3.4. Procedure

3.4.1. Outline

At the beginning of the experiment, overall instructions were presented to the subjects. The subjects were asked to imagine themselves at home while relaxing (e.g. reading, watching television, discussing, gardening or doing other relaxing activities they are used to). Thus, annoyance is understood as short-term annoyance as defined by Berglund *et al.* [17]. Then, the subjects performed a training test. Afterwards, the subjects began the experiment. The stimuli were presented one by one in random order. For each stimulus, the subjects were asked to give an annoyance judgment (see section 3.4.2). At the end of the experiment, the subjects filled in a questionnaire that aimed to collect additional information about certain non-acoustical factors, e.g. noise sensitivity. The latter was assessed on a continuous scale ranging from "0" to "10", with two verbal labels ("not at all" and "extremely") at its ends. The subjects also carried out a free verbalization task. They were asked to describe the tramway noises they heard during the experiment. The experiment lasted approximately 30 minutes.

3.4.2. Annoyance rating

For each stimulus, a reminder of the imaginary situation was presented to the subjects, and the following question was asked: "How much would this noise annoy you?". The response scale was inspired by the recommendations given in the standard ISO 15666 [18]. To answer, the subjects were asked to move a cursor along a continuous scale going from "0" to "10", with 11 numerical labels evenly spaced out and two verbal labels ("not at all" and "extremely") at its ends in order to facilitate its use. Before giving their judgment, the subjects could listen to the stimulus as often as they wanted.

3.5. Data analysis

Data analysis comprises two successive main steps: i) analysis of inter-stimulus differences, and ii) construction of an acoustical indicator of annoyance due to tramway noise.

3.5.1. Analysis of inter-stimulus differences

Before determining any indicator of annoyance, it is of importance to establish whether the differences in annoyance ratings between the stimuli are significant. This objective is achieved by carrying out a repeated measures analysis of variance (RM ANOVA) [19]. This RM ANOVA implies one within-subject factor: factor "stimulus", with K levels ($K = 61$). Afterwards, if the results of the RM ANOVA show significant differences in annoyance ratings between the stimuli, a further goal is to constitute groups of stimuli for which the annoyance ratings are not significantly different. This goal is achieved by carrying out a post-hoc analysis, using Tukey's HSD test [19]. From the groups, it is then possible to discuss *a posteriori* the effects on annoyance of the different criteria of the operating situations (see section 2.1).

3.5.2. Determination of an acoustical indicator of annoyance due to tramway noise

The determination of an acoustical indicator of annoyance due to tramway noise comprises two steps: identification and characterization of influential acoustical features and determination of an indicator *via* regression analysis.

Identification and characterization of influential acoustical features. The annoyance ratings are analyzed using the M.D.S. model MDPREF [20]. This model provides a multidimensional space which consists in a configuration of stimulus points and unit subject vectors passing through the origin, located so that the projections of the stimuli on the vectors are in maximum agreement with the subjects' judgments. A vector endpoint represents the point of maximum annoyance of a subject. In addition, the direction towards which a vector points shows the way a

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subject mixes the acoustical features of stimuli in producing his/her annoyance judgments [21]. In order to help to identify these features, acoustical and psychoacoustical indices are fitted as unnormalized vectors into the space using a PREFMAP procedure [22]. To be considered as relevant, an index must i) be highly correlated with one space dimension, and ii) represent an acoustical feature whose variation among the stimuli sorted according to their coordinate along this dimension can be noticed when listening.

Construction of an indicator via regression analysis. In order to determine an acoustical indicator of annoyance due to tramway noise, a regression analysis between the annoyance ratings and the relevant indices (highlighted at the previous step) is carried out.

To analyze the collected repeated measures data, multilevel regression models are used. This regression method appears not to be used for modeling annoyance data collected in laboratory conditions; it has been used for meta-analysis of *in situ* noise annoyance studies [23]. Multilevel regression has advantages over classical regression for the modeling of repeated measures data: i) multilevel regression formulation strictly complies with the hierarchical structure of repeated measures data which consists in observations nested within individuals; it thus takes into account the fact that the observations are not independent, ii) multilevel regression is a statistical method suitable for modeling annoyance judgments which generally show inter-individual differences; the latter can be taken into account through the multilevel formulation that involves both individual and stimulus levels, and iii) multilevel regression makes it possible to test non-acoustical factors as variables at the individual level, which may have an effect on the dependent variable. For all these reasons, this type of regression is used to investigate the effects of explanatory variables on short-term annoyance due to tramway noise. For an introduction to multilevel regression models, the reader can refer to Gelman and Hill's [24] and Hox's [25] textbooks.

Model specification. First, null models (that include no explanatory variable at the stimulus level) are fitted. These models serve as a baseline for model comparisons. They can be written as

$$Y_{jk} = \pi_{0j} + e_{jk}, \tag{1}$$

$$\pi_{0j} = \beta_{00} + \beta_{01} sens_j + u_{0j}, \tag{2}$$

$$u_{0j} \sim N(0, \sigma^2_{u_0}) \text{ for } j = 1,\ldots,J,$$

$$e_{jk} \sim N(0, \sigma^2_e) \text{ for } j = 1,\ldots,J \text{ and } k = 1,\ldots,K.$$

Equation (1) is the regression equation at the stimulus level. In this regression equation, Y_{jk} are the annoyance ratings, π_{0j} is the intercept, e_{jk} is the usual residual error term. The subscript j is for the individuals ($j = 1, \ldots, J$) and the subscript k is for the stimuli ($k = 1, \ldots, K$). The residual errors e_{jk} are assumed to have a mean of zero, and a variance σ^2_e to be estimated.

Equation (2) is the regression equation at the individual level. An explanatory variable, noise sensitivity ($sens_j$), can be introduced to explain the variation of the intercepts π_{0j}. This non-acoustical factor, known to usually influence noise annoyance judgments (e.g. [5, 6]), can be taken into account at the individual level in the multilevel regression. In the model, this explanatory variable does not vary across the stimuli. The random u-terms u_{0j} are residual error terms at the individual level. These residual errors are assumed to have a mean of zero and a variance $\sigma^2_{u_0}$, and to be independent from the residual errors e_{jk} at the stimulus level. The regression coefficients β_{00} and β_{01} are not assumed to vary across individuals. Thus, they are referred to as fixed coefficients [25].

The relevant indices are inserted in two-level models as explanatory variables at the stimulus level. For each explanatory variable, the regression slope can be either fixed or random[1]. The two-level models can be written as

$$Y_{jk} = \pi_{0j} + \sum_{p=1}^{P} \pi_{pj} X_{pk} + \sum_{q=1}^{Q} \pi_{qj} X_{qk} + e_{jk}, \tag{3}$$

$$\pi_{0j} = \beta_{00} + \beta_{01} sens_j + u_{0j}, \tag{4}$$

$$\pi_{pj} = \beta_{p0}, \tag{5}$$

$$\pi_{qj} = \beta_{q0} + \beta_{q1} sens_j + u_{qj}, \tag{6}$$

$$\begin{bmatrix} u_{0j} \\ u_{1j} \\ \vdots \\ u_{qj} \\ \vdots \\ u_{Qj} \end{bmatrix} \sim N\left(\mathbf{0}, \begin{bmatrix} \sigma^2_{u_0} & \sigma_{u_{10}} & \ldots & \sigma_{u_{q0}} & \ldots & \sigma_{u_{Q0}} \\ \sigma_{u_{10}} & \sigma^2_{u_1} & \ldots & \sigma_{u_{q1}} & \ldots & \sigma_{u_{Q1}} \\ \vdots & \vdots & \ddots & \vdots & \ldots & \vdots \\ \sigma_{u_{q0}} & \sigma_{u_{q1}} & \ldots & \sigma^2_{u_q} & \ldots & \sigma_{u_{Qq}} \\ \vdots & \vdots & \ldots & \vdots & \ddots & \vdots \\ \sigma_{u_{Q0}} & \sigma_{u_{Q1}} & \ldots & \sigma_{u_{Qq}} & \ldots & \sigma^2_{u_Q} \end{bmatrix} \right)$$

$$\text{for } j = 1,\ldots,J,$$

$$e_{jk} \sim N(0, \sigma^2_e) \text{ for } j = 1,\ldots,J \text{ and } k = 1,\ldots,K.$$

Equation (3) is the regression equation at the stimulus level. In this regression equation, Y_{jk} are the annoyance ratings; π_{0j} is the intercept; π_{pj} is the regression slope for index p ($p = 1, \ldots, P$), assumed to be fixed; X_{pk} is the value of index p for stimulus k; π_{qj} is the regression slope for index q ($q = 1, \ldots, Q$), assumed to be random; X_{qk} is the value of index q for stimulus k; e_{jk} is the usual residual error term. The residual errors e_{jk} are assumed to have a mean of zero, and a variance σ^2_e to be estimated.

Equations (4), (5) and (6) are the regression equations at the individual level. The noise sensitivity ($sens_j$) is introduced as an individual-level explanatory variable to explain the variation of both the intercepts π_{0j} and slopes π_{qj}. The random u-terms u_{0j} and u_{qj} ($q = 1, \ldots, Q$) are residual error terms at the individual level. These u-terms are assumed to have a multivariate normal distribution of mean 0. The variance of the residual errors u_{0j} is specified as $\sigma^2_{u_0}$, and the variance of the residual errors u_{qj} is specified as $\sigma^2_{u_q}$. The covariances between the residual errors at

[1] When the regression slope is assumed to be fixed (conversely random), it means that the regression slope does not vary (conversely varies) across individuals.

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Table I. Results of the RM ANOVA. dof: degrees of freedom, SS: Sum of Squares, MS: Mean Square, F: test statistic, p: p-value, η^2: measure of the magnitude of the experimental effect.

Source	dof	SS	MS	F	p	η^2
Subject	39	5987.43				
Stimulus	60	4363.05	72.72	38.97	<0.001	0.297
Subject × Stimulus	2340	4366.02	1.87			
Total	2439	14716.5				

the individual level are denoted by $\sigma_{u_{rs}}$ ($r = 0, \ldots, Q$; $s = 0, \ldots, Q$; $r \neq s$).

Computations. The computation of multilevel regression is Bayesian and inferences about the studied parameters are made using their Bayesian posterior distribution [24]. Gamma distributions are used as non-informative prior distributions for the variances / covariances. The posterior distributions of the model parameters are approximated *via* MCMC simulation, with 20000 iterations. This simulation is performed using the software MLwiN (e.g. [26, 27]). For each model parameter, a median value and a 95% credibility interval are determined from its posterior distribution.

Model selection. The matter is to select the model with the combination of indices that makes it possible to predict at best the annoyance ratings. The selection of the best model is based on three criteria:

i) R_1^2 – The proportion of variance explained at the stimulus level. This criterion provides a measure of goodness-of-fit of the model to the collected data [24]. R_1^2 varies between 0 and 1; the closer R_1^2 is to 1, the better is the goodness-of-fit of the model to the collected data.

ii) $R_{2.q}^2$ ($q = 0, \ldots, Q$) – The proportion of variance explained at the individual level. This criterion is computed for each random coefficient at the stimulus level (intercept π_{0j} or slope π_{qj}, $q = 1, \ldots, Q$, see equations (4) and (6)) [24]. It is useful for determining whether noise sensitivity can explain some variation of the random coefficient. $R_{2.q}^2$ varies between 0 and 1. The closer $R_{2.q}^2$ is to 1, i) the more noise sensitivity has an effect on the subjects' mean ratings, if the random coefficient is the intercept, and ii) the more noise sensitivity has a moderating effect on the relationship between an index and noise annoyance, if the random coefficient is a slope.

iii) DIC – Deviance Information Criterion. This criterion provides a measure of out-of-sample predictive error [24]. The lower the DIC is, the better is the predictive power of the model. When comparing two models, differences in DIC greater than 10 might rule out the model with the higher DIC; differences between 5 and 10 are substantial; for differences in DIC less than 5, it could be misleading to report the model with the lower DIC [28].

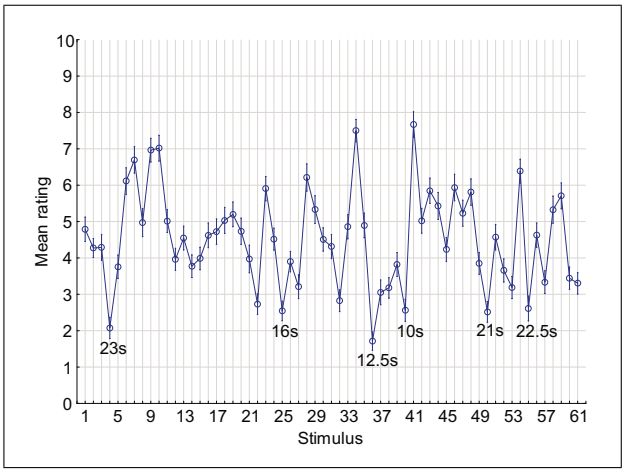

Figure 1. Mean ratings for the 61 stimuli. ∘: mean value; —: standard error.

4. Results

4.1. Analysis of inter-stimulus differences

Table I shows the results of the RM ANOVA. The differences in annoyance ratings due to "Subject" and "Subject × Stimulus" are important, as highlighted by the corresponding sums of squares. However, the differences in annoyance ratings due to "Stimulus" remain non negligible. The proportion of variance [19] explained by "Stimulus" is equal to 29.7%. There are clear differences in annoyance ratings between stimuli. This can notably be seen through Figure 1, which shows the mean ratings for the 61 stimuli. As for some previous studies on noise annoyance in laboratory conditions, one can notice that the stimulus duration does not seem to be a criterion for the subjects in their annoyance judgments: for instance, among the least annoying stimuli, stimuli n°4, 25, 36, 40, 50 and 55 present different durations (23, 16, 12.5, 10, 21 and 22.5s, respectively).

The post-hoc analysis (Tukey's HSD test) reveals 30 groups of stimuli for which the annoyance ratings are not significantly different[2]. An analysis of these groups shows no obvious effect of the four physical criteria (type of track installation, type of surface, type of street and type of operating configuration). Indeed, for each criterion, one can find several of its modalities within a same group. One can observe that, among the most annoying stimuli, there

[2] These groups are not detailed here for the sake of brevity.

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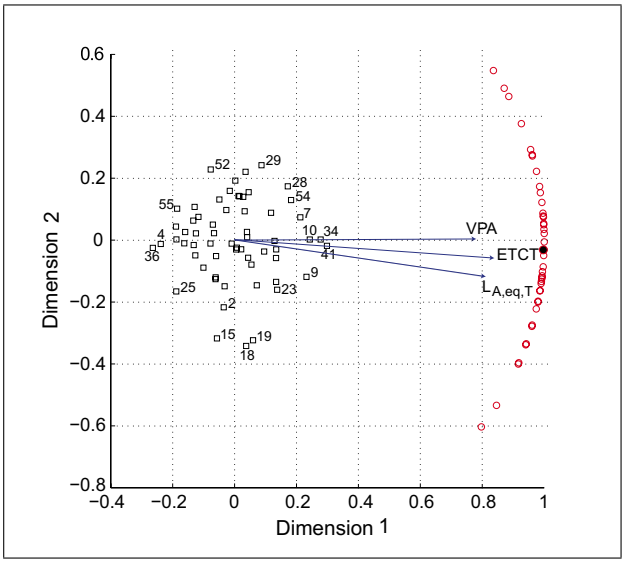

Figure 2. Two-dimensional MDPREF space. □: stimulus points; ∘: endpoints of subject vectors; →: index vectors ($L_{A,eq,T}$: A-weighted equivalent sound pressure level, *VAP*: variance of time-varying A-weighted pressure normalized by RMS A-weighted pressure, *TETC*: total energy of the tonal components within critical bands from 12 to 24 Barks).

are in particular some stimuli corresponding to the operating configurations "in curve" (e.g. stimulus n°34) and "straight line" (e.g. stimuli n° 9, 10 and 41).

4.2. Determination of an acoustical indicator of annoyance from tramway noise

4.2.1. Identification and characterization of influential acoustical features

First, the data obtained from the free verbalization task (see section 3.4.1) were analyzed. The free verbalizations mainly refer to three acoustical features. Actually, the highest numbers of occurrences of words (adjectives or substantives) were: 25 occurrences for the soft / loud character (e.g. "loud" (10), "intensity" (6), "soft" (4) and "volume" (4)), 23 occurrences for the irregular / continuous character (e.g. "continuous" (9), "irregular" (2),"variable" (1) and "jerky" (1)), and 62 occurrences for the bass / treble character (e.g. "treble" (17), "squealing" (15), "piercing" (7) and "bass" (6)). These last verbalizations are in agreement with the findings of Pallas *et al.* [4]: these authors showed that the semantic differential bass / treble and the number of occurrences of the term "squealing" were relevant to describe noise annoyance due to a tramway pass-by.

The second step was to propose indices that depict the acoustical features which influence the annoyance judgments. To that end, the annoyance ratings were analyzed using the M.D.S. model MDPREF. The data can be represented in a 2-D MDPREF space. The space is drawn in Figure 2; for more readability, only the endpoints of the subject vectors are reported. The dispersion of the subject vectors around the unit circle appears to be limited within a 90-degree angle; this shows a relatively good consensus among the subjects' responses. The consensus precisely takes place along the first dimension (accounting for 57% of the total variance): all the subject vectors have positive components along this dimension. Inter-individual differences – nevertheless moderate – emerge along the second dimension (accounting for 5% of the total variance): along this dimension, some subject vectors have negative components; other ones have positive components.

Three acoustical indices turn out to be most relevant for explaining the first dimension: two classical indices, namely the A-weighted equivalent sound pressure level ($L_{A,eq,T}$) and the variance of time-varying A-weighted pressure normalized by RMS A-weighted pressure (*VAP*), and a new psychoacoustical index, namely the total energy of the tonal components within critical bands from 12 to 24 Barks (*TETC*). *VAP* is defined as

$$VAP = \frac{V\left(p_A(t)\right)}{p_A^{RMS}}, \tag{7}$$

where V represents the finite-sample variance operator, $p_A(t)$ is the time-varying A-weighted pressure and p_A^{RMS} represents the RMS A-weighted pressure, defined as

$$p_A^{RMS} = \sqrt{\frac{1}{T}\int_0^T p_A^2(t)\,\mathrm{d}t}, \tag{8}$$

where T is the length of the stimulus and $p_A(t)$ is its time-varying A-weighted pressure. The new proposed psychoacoustical index *TETC* is defined as follows:

$$TETC = 10\log_{10}\left(\int_{11}^{24} 10^{L(z)/10}\,\mathrm{d}z\right), \tag{9}$$

where $L(z)$ represents the maximal (across time) level of the tonal components as a function of the critical-band rate z, computed using the software dBSONIC (01dB-Metravib).

These three indices are highly correlated with the first dimension (respectively $r = 0.82$, $p < .001$; $r = 0.77$, $p < .001$; $r = 0.83$, $p < .001$). Moreover, these indices represent distinct acoustical features whose variation among the stimuli sorted according to their coordinate along dimension 1 can be noticed when listening. $L_{A,eq,T}$ refers to the soft / loud character of the noises[3]. *VAP* may depict their irregular / continuous character or the overall pressure rise. *TETC* denotes their bass / treble character. These three influential acoustical features are in agreement with the free verbalizations of the subjects. In this study, the index *TETC* has been especially created to reflect the piercing character of squeal noise, due to tonal components in high frequencies. This squeal noise is often present in tramway pass-by noises corresponding to an "in curve" operating configuration (see below) or to a "departure from the station" operating configuration.

[3] A psychoacoustical index, the mean loudness, was also tested to account for the soft / loud character of the noises. This index turned out to be as correlated with the first dimension ($r = 0.81$, $p < .001$) as $L_{A,eq,T}$.

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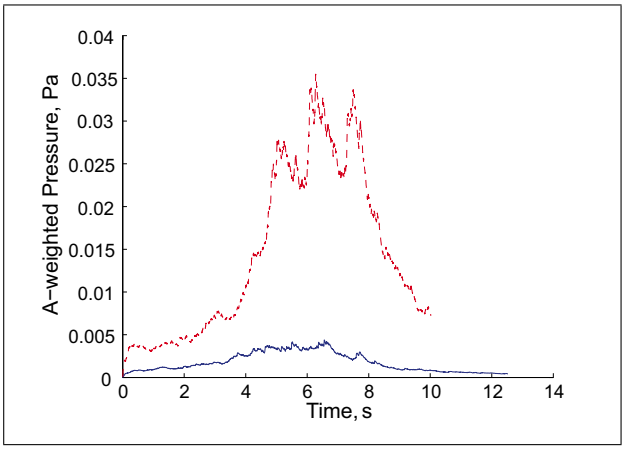

Figure 3. A-weighted pressure versus time. —: stimulus n°36; – –: stimulus n°41.

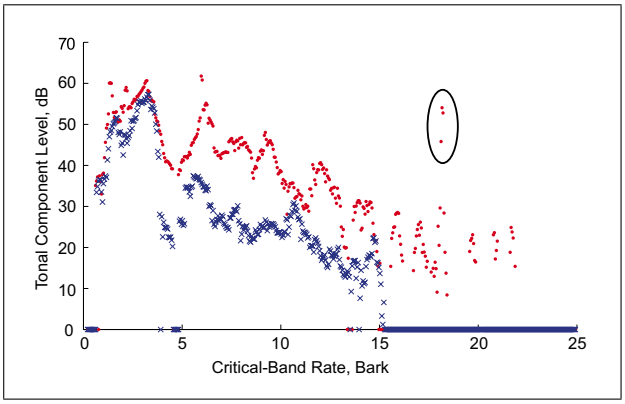

Figure 4. Maximum tonal component level versus critical-band rate. x: stimulus n°4; •: stimulus n°34.

The most annoying stimuli, located in the extreme right part of the space, are particularly loud, irregular (or with a high pressure rise) or with much energy at high frequencies. On the contrary, the least annoying stimuli, located in the extreme left part, are particularly soft, continuous (or with a low pressure rise) or with low / no energy at high frequencies. For instance, Figure 3 shows the pattern of A-weighted pressure versus time for stimuli n°36 and n°41 (recorded in the test room), respectively located in the extreme left and right parts of the space.

For stimulus n°36, for which *VAP* is low, one can observe very few irregularities as well as a low pressure rise. For stimulus n°41, for which *VAP* is high, one can observe several irregularities as well as a high pressure rise. Figure 4 shows the maximum (across time) tonal component level versus critical-band rate for stimuli n°4 and n°34 (recorded in the test room), respectively located in the extreme left and right parts of the space.

For stimulus n°4, one can observe no tonal component in the high-frequency domain above Bark 15. On the contrary, for stimulus n°34, one can observe high tonal component levels in the high frequencies, especially for critical-band rates around 18 Barks (circled in Figure 4). These tonal components notably refer to squeal noise, present in this stimulus corresponding to an in-curve operating configuration. The squeal noise can be visualized in the auditory spectrogram [29] of stimulus n°34, shown in Figure 5. Around a time abscissa of 2.5 s, one can observe high levels around Bark 18 (circled in Figure 5), which correspond to squeal noise.

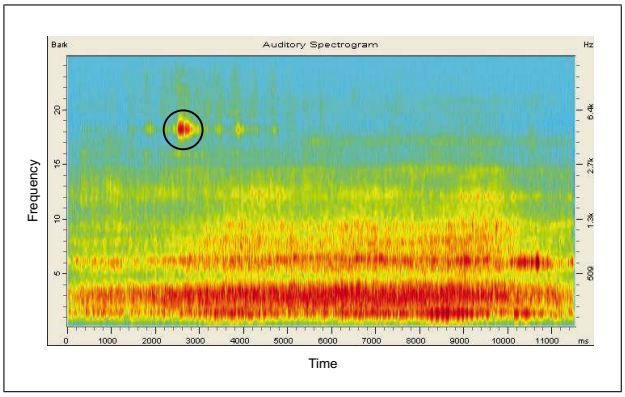

Figure 5. Auditory spectrogram of stimulus n°34.

The pattern of maximum tonal component level versus critical-band rate is determined from the auditory spectrogram (e.g. [30, 31]). The maximum tonal component levels related to squeal noise are thus captured by this representation. Afterwards, the index *TETC*, computed from this pattern by summing the energy of the tonal components within critical bands from 12 to 24 Barks, makes it possible to reflect the piercing character of tramway squeal noise, which was negatively judged by most subjects (34 subjects associated the piercing character of tramway squeal noise with the adjectives “annoying”, “disturbing” and “unpleasant”).

No acoustical or psychoacoustical index turns out to be relevant for explaining the second dimension. This lack of dimension identification is of limited consequence as the proportion of variance explained by this dimension is low (only 5%) compared to that explained by the first dimension.

4.2.2. Construction of an indicator via regression analysis

Two null models are tested: a first one without noise sensitivity at the individual level (model $M0a$), a second one with noise sensitivity at the individual level (model $M0b$).

The results are shown in Table II. One can note that noise sensitivity has an effect on the intercepts π_{0j}, i.e. on the subjects’ mean ratings. Indeed, for model $M0b$, $R^2_{2,0}$ reaches 21%. Furthermore, in model $M0b$, the regression coefficient for noise sensitivity, i.e. β_{01}, is significantly different from zero, and positive: sensitive persons tend to express higher annoyance. Thus, noise sensitivity shall be kept for modeling the intercepts π_{0j} in what follows; model $M0b$ shall serve as a baseline for further comparisons.

Then, two-level regression models with one single index as a stimulus-level explanatory variable ($L_{A,eq,T}$ or *VAP* or *TETC*) are fitted. A first step is to test, for each index,

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Table II. Null models $M0a$ and $M0b$, respectively without and with noise sensitivity as an individual-level explanatory variable. 95% CI: 95% Bayesian credibility interval; β_{00}: intercept; β_{01}: regression coefficient for noise sensitivity; σ_e^2: variance of the residual errors at the stimulus level; $\sigma_{u_0}^2$: variance of the residual errors u_0 (for the intercept) at the individual level; R_1^2: proportion of variance explained at the stimulus level; $R_{2,0}^2$: proportion of variance explained at the individual level, for the intercept; DIC: Deviance Information Criterion.

Null model	$M0a$ without sensitivity	$M0b$ with sensitivity
	Coef. (95% CI)	Coef. (95% CI)
Fixed part		
β_{00} (Intercept)	4.52 (4.01; 5.03)	1.96 (0.35; 3.60)
β_{01} (Sensitivity)	–	0.435 (0.170; 0.699)
Random part		
Stimulus level σ_e^2	3.64 (3.44; 3.85)	3.64 (3.44; 3.85)
Individual level $\sigma_{u_0}^2$	2.50 (1.62; 4.08)	1.97 (1.28; 3.26)
Explained variance		
Stimulus level R_1^2	0.40	0.40
Individual level $R_{2,0}^2$	0	0.21
DIC	10116	10115.9

whether a fixed or random slope is preferable for modeling the data. The models with $L_{A,eq,T}$ ($M1a$: fixed slope; $M1b$: random slope), *VAP* ($M2a$: fixed slope; $M2b$: random slope) and *TETC* ($M3a$: fixed slope; $M3b$: random slope) are shown in Table III.

For the 3 indices, making the slope random leads to an improvement in goodness-of-fit (R_1^2 is increased by 3%, 2% and 2% for $L_{A,eq,T}$, *VAP* and *TETC* respectively) and in predictive power (DIC is decreased by 112.7, 99.3 and 119.9, respectively for $L_{A,eq,T}$, *VAP* and *TETC*). Furthermore, one can note that i) models $M1b$, $M2b$ and $M3b$ clearly outperform null model $M0b$, and ii) $M3b$ outperforms model $M1b$ (ΔDIC=30.1), which in turns outperforms model $M2b$ (ΔDIC=173.5). A second step is to test, for each index, whether noise sensitivity has a moderating effect on the relationship between the index and noise annoyance. To that end, random-slope models in which noise sensitivity is inserted as an individual-level explanatory variable are fitted. The models with $L_{A,eq,T}$ ($M1c$), *VAP* ($M2c$) and *TETC* ($M3c$) are shown in Table IV. For the 3 indices, $R_{2,1}$ does not exceed 2%. Moreover, the regression coefficient for the cross-level interaction between the index and noise sensitivity, i.e. β_{11}, is not significantly different from zero. Thus, noise sensitivity does not appear to have any moderating effect on the relationship between each index and noise annoyance. Noise sensitivity shall not be kept for modeling the slopes π_{1j} in what follows.

Finally, a two-level random-slope regression model with $L_{A,eq,T}$ and *TETC* as stimulus-level explanatory variables (model $M4$) is fitted. Indeed, *VAP* cannot be inserted into a multiple regression model simultaneously with $L_{A,eq,T}$ and *TETC*, owing to a multicollinearity issue: *VAP* covariates with $L_{A,eq,T}$ ($r = 0.81$, $p < .001$), even if the respective phenomena these two indices depict are not the same. But the stimuli with a strongly irregular character may also have a high sound pressure level. The final results of the multilevel regression are shown in Table V. One can observe that the slopes for both indices, β_{10} and β_{20}, are significantly different from zero, and positive. That is, the higher $L_{A,eq,T}$ and *TETC* are, the higher the annoyance rating is, which is consistent with the findings highlighted in section 4.2.1. Also, one can note that model $M4$ outperforms models $M1b$, $M2b$ and $M3b$: R_1^2 is increased by 5%, 8% and 5% in comparison with models $M1b$, $M2b$ and $M3b$ respectively; DIC is decreased by 308.2, 499.9 and 296.1 in comparison with models $M1b$, $M2b$ and $M3b$ respectively. Furthermore, it should be noted that a two-level random-slope regression model with $L_{A,eq,T}$, *VAP* and *TETC* as stimulus-level explanatory variables does not outperform model $M4$: in comparison with model $M4$, R_1^2 is the same and DIC is increased by 1.7. Thus, model $M4$ provides an acoustical indicator that makes it possible to better account for short-term annoyance due to tramway noise. The acoustical indicator is based on a classical index, $L_{A,eq,T}$, and a proposed psychoacoustical index, *TETC*, depicting the piercing character of tramway noise. Furthermore, this indicator is an attempt to take into account non acoustical factors which may influence noise annoyance ratings: it notably includes noise sensitivity at the individual level which turned out to have an effect on subjects' mean ratings.

5. Discussion

The RM ANOVA showed that the differences in annoyance ratings between the stimuli were substantial; this legitimizes the carrying out of a further analysis to construct an acoustical indicator of annoyance from tramway noise. But these differences could not be clearly explained by the four criteria (i.e. type of track installation, type of surface, type of operating configuration and type of street) that were identified as influential on the noise emitted from the tramway. These differences could be due to other physical parameters, whose modalities were not known in this study (e.g. the state of the rolling stock).

Actually, these differences were explained by acoustical features which were in link with some above-mentioned criteria and, likely, with non controlled physical parameters as well. The analysis of the MDPREF space revealed that three acoustical features of tramway noises could influence the subjects' annoyance ratings. These features were identified with the help of the results of the free verbalization task carried out during the experimentation. First, the overall level, here depicted by the A-weighted equivalent sound pressure level, seems to play an important role in noise annoyance. The louder tramway noise is, the more it is annoying. This – unsurprising – finding is in agreement with the results from other studies dealing with tramway noises. Notably, in their laboratory study, Sandrock *et al.* [3] showed that loudness of tramway

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Table III. Multilevel models involving one single index, with a fixed slope and with a random slope, respectively: $M1a$ and $M1b$ for $L_{A,eq,T}$, $M2a$ and $M2b$ for *VAP*, $M3a$ and $M3b$ for *TETC*. 95% CI: 95% Bayesian credibility interval ; β_{00}: intercept; β_{01}: regression coefficient for noise sensitivity; β_{10}: regression slope for the index; σ_e^2: variance of the residual errors e_{jk} at the stimulus level; $\sigma_{u_0}^2$ and $\sigma_{u_1}^2$: variance of the residual errors u_{0j} (for the intercept) and u_{1j} (for the index slope) at the individual level; R_1^2: proportion of variance explained at the stimulus level; $R_{2,0}^2$ et $R_{2,1}^2$: proportions of variance explained at the individual level, for the random intercept and slope respectively; DIC: Deviance Information Criterion. The covariances between residual errors at the individual level are not shown.

Model	$M1a$	$M1b$	$M2a$
Index involved	$L_{A,eq,T}$	$L_{A,eq,T}$	*VAP*
Index slope	fixed	random	fixed
	Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)
Fixed part			
β_{00} (Intercept)	1.97 (0.298; 3.58)	2.07 (0.436; 3.69)	1.96 (0.336; 3.57)
β_{01} (Sensitivity)	0.433 (0.173; 0.703)	0.417 (0.149; 0.681)	0.435 (0.171; 0.697)
β_{10} (Index)	0.266 (0.251; 0.281)	0.267 (0.234; 0.300)	853.7 (799.7; 906.7)
Random part			
Stimulus level σ_e^2	2.42 (2.28; 2.56)	2.28 (2.15; 2.42)	2.58 (2.44; 2.74)
Individual level $\sigma_{u_0}^2$	1.98 (1.29; 3.31)	2.03 (1.33; 3.34)	1.98 (1.30; 3.24)
$\sigma_{u_1}^2$	–	0.008 (0.005; 0.015)	–
Explained Variance			
Stimulus level R_1^2	0.60	0.63	0.58
Individual level $R_{2,0}^2$	0.21	0.21	0.21
$R_{2,1}^2$	–	0	–
DIC	9120	9007.3	9280.1

Model	$M2b$	$M3a$	$M3b$
Index involved	*VAP*	*TETC*	*TETC*
Index slope	random	fixed	random
	Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)
Fixed part			
β_{00} (Intercept)	2.06 (0.417; 3.69)	1.96 (0.335; 3.56)	2.08 (0.456; 3.70)
β_{01} (Sensitivity)	0.418 (0.156; 0.685)	0.435 (0.172; 0.698)	0.414 (0.154; 0.679)
β_{10} (Index)	853.7 (741.4; 966.7)	0.241 (0.228; 0.254)	0.241 (0.211; 0.271)
Random part			
Stimulus level σ_e^2	2.45 (2.31; 2.59)	2.40 (2.27; 2.54)	2.25 (2.13; 2.39)
Individual level $\sigma_{u_0}^2$	2.03 (1.33; 3.32)	1.99 (1.30; 3.24)	2.04 (1.33; 3.32)
$\sigma_{u_1}^2$	97177 (55323; 173147)	–	0.007 (0.004; 0.012)
Explained Variance			
Stimulus level R_1^2	0.60	0.61	0.63
Individual level $R_{2,0}^2$	0.21	0.21	0.21
$R_{2,1}^2$	0	–	0
DIC	9180.8	9097.1	8977.2

noises was responsible for differences in mean annoyance ratings. Furthermore, in their survey, Pallas *et al.* [4] showed that people living close to a tramway line were particularly annoyed by the intensity of tramway pass-by noise. Secondly, the irregular / continuous character (as well as the pressure rise), here depicted by the variance of time-varying A-weighted pressure normalized by RMS A-weighted pressure, also has an effect on noise annoyance responses. The more irregular the tramway pass-by noise is (or the higher the pressure rise is), the more annoying it is. The irregularities can be due to the occurrence of sound events such as impact noise (e.g. when the tramway goes over the ballast). This finding is in agreement with the outcomes from other studies. Notably, Rylander *et al.* [1] pointed out that irregularities in certain octave bands could lead to a high extent of annoyance. Furthermore, Miedema and Van Den Berg [2] suggested that impact noise could contribute to increase noise annoyance. Thirdly, the bass / treble character also influences noise annoyance responses. Notably, tramway noises with much high-frequency content are particularly annoying. This high-frequency content is linked to the presence of squeal noise, that can appear for operating configurations "in curve" (where the wheels rub against the curved track) and "departure from the station" (when the brakes are released). This squeal noise is due to tonal components in high frequencies which were taken into account by a proposed index adding their maximum level within critical

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Table IV. Test of the moderating effect of noise sensitivity on the relationship between each index and noise annoyance: random-slope models with one single index at the stimulus level and with noise sensitivity at the individual level, respectively $M1c$ (for $L_{A,eq,T}$), $M2c$ (for *VAP*) and $M3c$ (for *TETC*). 95% CI: 95% Bayesian credibility interval ; β_{00}: intercept; β_{01}: regression coefficient for noise sensitivity; β_{10}: regression slope for the index; β_{11}: regression coefficient for the cross-level interaction between the index and noise sensitivity; σ_e^2: variance of the residual errors e_{jk} at the stimulus level; σ_{u0}^2 and σ_{u1}^2: variance of the residual errors u_{0j} (for the intercept) and u_{1j} (for the index slope) at the individual level; R_1^2: proportion of variance explained at the stimulus level; $R_{2,0}^2$ et $R_{2,1}^2$: proportions of variance explained at the individual level, for the random intercept and slope respectively; DIC: Deviance Information Criterion. The covariances between residual errors at the individual level are not shown.

Model	$M1c$	$M2c$	$M3c$
Index involved	$L_{A,eq,T}$	*VAP*	*TETC*
	Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)
Fixed part			
β_{00} (Intercept)	1.98 (0.340; 3.61)	1.96 (0.320; 3.60)	1.96 (0.313; 3.59)
β_{01} (Sensitivity)	0.432 (0.166; 0.699)	0.434 (0.171; 0.699)	0.434 (0.171; 0.700)
β_{10} (Index)	0.204 (0.086; 0.320)	640.6 (240.4; 1038.2)	0.193 (0.086; 0.299)
β_{11} (Sensitivity × Index)	0.011 (-0.008; 0.030)	36.2 (-28.3; 101.1)	0.008 (-0.009; 0.025)
Random part			
Stimulus level σ_e^2	2.28 (2.16; 2.41)	2.45 (2.31; 2.59)	2.25 (2.13; 2.38)
Individual level σ_{u0}^2	2.04 (1.33; 3.33)	2.03 (1.33; 3.30)	2.04 (1.33; 3.31)
σ_{u1}^2	0.008 (0.005; 0.015)	96422 (54351; 173135)	0.007 (0.004; 0.013)
Explained variance			
Stimulus level R_1^2	0.63	0.60	0.63
Individual level $R_{2,0}^2$	0.21	0.21	0.21
$R_{2,1}^2$	0.02	0.02	0.01
DIC	9007.8	9181	8977.4

Table V. The proposed two-level regression model with $L_{A,eq,T}$ and *TETC* as stimulus-level explanatory variables, and with noise sensitivity as an individual-level explanatory variable. 95% CI: 95% Bayesian credibility interval; β_{00}: intercept; β_{10}: slope for $L_{A,eq,T}$; β_{20}: slope for *TETC*; σ_e^2: variance of the residual errors at the stimulus level; σ_{u0}^2: variance of the residual errors u_0 (for the intercept) at the individual σ_{u1}^2: variance of the residual errors u_1 (for $L_{A,eq,T}$ slope) at the individual level; σ_{u2}^2: variance of the residual errors u_2 (for *TETC* slope) at the individual level; R_1^2: proportion of variance explained at the stimulus level; $R_{2,0}^2$: proportion of variance explained at the individual level, for the random intercept; DIC: Deviance Information Criterion. The covariances between residual errors at the individual level are not shown.

	Coefficient (95% CI)
Fixed part	
β_{00} (Intercept)	1.98 (0.370; 3.62)
β_{01} (Sensitivity)	0.431 (0.168; 0.694)
β_{10} ($L_{A,eq,T}$)	0.158 (0.065; 0.251)
β_{20} (*TETC*)	0.148 (0.057; 0.242)
Random part	
Stimulus level σ_e^2	1.97 (1.87; 2.09)
Individual level σ_{u0}^2	2.09 (1.37; 3.38)
σ_{u1}^2	0.084 (0.056; 0.136)
σ_{u2}^2	0.083 (0.055; 0.134)
Explained variance	
Stimulus level R_1^2	0.68
Individual level $R_{2,0}^2$	0.21
DIC	8699.1

bands from 12 to 24 Barks. The finding that such high-frequency content influences noise annoyance is also in agreement with the results from other works. In particular, in their survey, Rylander *et al.* [1] pointed out that clanking noise could play a role in noise annoyance. Furthermore, Miedema and Van Den Berg [2] reported that special sound characteristics of squeal noise could explain why noise annoyance is higher for curved portions. Lastly, Pallas *et al.* [4] highlighted that the piercing character of squeal noise was perceived as particularly annoying by people living close to tramway curved portions.

In order to determine an acoustical indicator of annoyance due to tramway noise, a multilevel regression analysis was carried out. Null models (i.e. without any explanatory variable at the stimulus level), models with one single relevant index as a stimulus-level explanatory variable and then a model with two indices ($L_{A,eq,T}$ and *TETC*) as stimulus-level explanatory variables were fitted to the noise annoyance ratings. The results notably showed that noise sensitivity had an influence on the subjects' mean annoyance ratings. This finding matches the results of Sandrock *et al.* [3], who showed that sensitive persons tend to express higher noise annoyance. But the results showed that noise sensitivity had no moderating effect on the relationship between each of the relevant indices tested ($L_{A,eq,T}$, *VAP* and *TETC*) and noise annoyance. Finally, a two-level random-slope model involving noise sensitivity at the individual level and two relevant indices at the stimulus level, i.e. the A-weighted equivalent sound pressure level and the total energy of the tonal components within critical bands from 12 to 24 Barks, proved to be satisfac-

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tory to account for short-term annoyance due to tramway noise. Noise sensitivity, a non-acoustical factor, is known to usually influence noise annoyance judgments in addition to acoustical factors (e.g. [5, 6]). Including this non-acoustical factor at the individual level makes it possible to better predict the individual intercepts. The proportion of variance explained at the stimulus level reaches 68%, that is, 5% more than the random-slope model only including the A-weighted equivalent sound pressure level. The proportion of variance explained by the latter model (63%) is comparable to that explained by the classical regression model proposed by Kim *et al.* [32] (56%) in their laboratory study of short-term annoyance due to railway noise. The higher proportion of variance explained by the model based on $L_{A,eq,T}$ and *TETC* supports the premise endorsed by several authors (Rylander *et al.* [1]; Miedema and Van Den Berg [2]; Sandrock *et al.* [3]; Pallas *et al.* [4]) that, in addition to the overall level, frequency characteristics of tramway noise play a non negligible role in noise annoyance.

6. Conclusions

Based on previous works suggesting that acoustical factors linked to temporal and frequency characteristics of tramway noise could have an influence on noise annoyance, the main purpose of this laboratory experiment was to determine an acoustical indicator of short-term annoyance due to tramway noise. The following conclusions are drawn from the results:

1) There are substantial differences in annoyance ratings between tramway pass-by noises corresponding to different operating situations encountered *in situ*; but it is not clear whether the four criteria that were identified as influential on the noise emitted from the tramway (type of track installation, type of surface, type of street and type of operating configuration) directly influence noise annoyance responses.
2) Free verbalizations collected during the experiment showed that the overall level, the irregular / continuous character and the bass / treble character of tramway noises were likely to influence short-term annoyance. These acoustical features were characterized by the A-weighted equivalent sound pressure level, the variance of time-varying A-weighted pressure normalized by RMS A-weighted pressure and an index proposed in this work, i.e. the total energy of the tonal components within critical bands from 12 to 24 Barks, respectively.
3) The measured noise sensitivity turned out to influence the subjects' mean annoyance ratings. But it has no moderating effect on the relationship between each of the relevant indices above-mentioned and noise annoyance.
4) An acoustical indicator based on a combination of $L_{A,eq,T}$ and *TETC* and taking noise sensitivity into account proved to be satisfactory to account for noise annoyance ratings.

A first sequel to this work would be to test the proposed acoustical indicator on a small data set stemming from a pilot field investigation, in order to assess its predictive power. This investigation would consist of i) noise measurements, in order to determine the values of the relevant noise indices ($L_{A,eq,T}$ and *TETC*), and ii) questionnaires submitted to a sample of residents who live in different areas along the tramway tracks, in order to measure noise annoyance and noise sensitivity. Noise sensitivity scores could be easily collected by using a continuous scale ranging from "0" (not at all sensitive) to "10" (extremely sensitive), such as that used in the present laboratory experiment. Afterwards, the sample noise sensitivity scores and the values of the relevant noise indices could be inserted in the indicator to predict the individual annoyance ratings. Finally, to assess its predictive power, these predicted annoyance ratings could be compared with the actual annoyance ratings uttered by the residents.

After testing it, this acoustical indicator could be applied to a large-scale acoustical data set stemming from a vast campaign of noise measurements (from which the values of the relevant noise indices, i.e. $L_{A,eq,T}$ and *TETC*, could be determined), in order to predict noise annoyance felt by residents. The noise sensitvity scores of a representative population sample could be assumed to follow a given probability distribution, e.g. with one third of the population sample onsidering oneself rather sensitive to very sensitive to noise [33]. Afterwards, regarding this population sample, by using this acoustical indicator, annoyance ratings could be determined for each exposure to tramway noise defined in terms of $L_{A,eq,T}$ and *TETC*.

Acknowledgments

This work was supported by the French Ministry of Ecology, Sustainable Development and Energy. This paper only commits the authors; the Ministry is not responsible for further uses of its content. This work was performed within the framework of the LABEX CeLyA (Lyon Acoustics Centre, ANR-10-LABX-0060) of Université de Lyon, within the program "Investissements d'Avenir" (ANR-11-IDEX-0007) operated by the French National Research Agency (ANR). The authors thank Mr. Négrier (SYTRAL), Mr. Vial (KEOLIS) and Mr. Copan (KEOLIS) for their helpful information about the tramway of Lyons, and the reviewers for their helpful comments on the earlier version of this paper.

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