Laboratory Methods with Imaginary and Simulated Contexts to Assess Noise Annoyance: A Comparison in Terms of Annoyance Model Testing

Catherine Marquis-Favre

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Short title: **Laboratory methods to assess noise annoyance**

Catherine Marquis-Favre

Univ Lyon, Ecole Nationale des Travaux Publics de l'Etat (ENTPE), Laboratoire Génie Civil et Bâtiment, 3 rue Maurice Audin, F-69518 Vaulx-en-Velin, France

catherine.marquisfavre@entpe.fr

Summary

Noise annoyance models using only mean energy-based indices provide weak prediction. Actually various factors influence noise annoyance. Different studies from the literature are carried out in laboratory conditions to understand some factors with the long-term aim of enhancing noise annoyance models. Laboratory experiments of assessing noise annoyance are based on imaginary or simulated context. The method with imaginary context is often questioned as participants listen to noise sequences. The current study aims at comparing the two methods in terms of total annoyance model testing. It revealed that annoyance models, respectively built within imaginary and simulated contexts, provided similar prediction when they were tested using in-field annoyance responses. Thus, the laboratory method with imaginary context seems to be as suitable as the method with simulated context to assess annoyance in laboratory conditions.

I. Introduction

In contrast to many other environmental problems, noise pollution is still growing [1]. Noise annoyance models solely based on mean energy-based indices did not enable good prediction of annoyance measured in field [2].

It is known that noise annoyance responses are influenced by various acoustical and non-acoustical factors. More influential factors have to be taken into account in noise annoyance models. To that aim, investigations are carried out in laboratory conditions to better understand influential factors (*e.g.* [3]). For laboratory experiments of assessing noise annoyance, two main methods are well-known in the literature: the method with imaginary context (*e.g.* [4-6]), denoted below by method IC, and the method with simulated context (*e.g.* [7-9]), denoted by method SC.

For method IC, stimulus duration is short (a few seconds). Imaginary contexts with activities carried out at home are proposed to participants (*e.g*. "Subjects may imagine reading a book, watching TV, or any similar activity" [10]). This measurement of annoyance relies on an instantaneous judgment collected after listening to short stimuli. The advantage of method IC is to study various acoustical factors using a large number of stimuli due to their short duration (*e.g.* [11]). This method is well-adapted for the characterization of influential acoustical factors and for the proposition of indices to be taken into account in noise annoyance models.

For the method in simulated context (method SC), participants carry out activities (*e.g*. reading) during noise exposure in a laboratory room simulating a living room (*e.g*. [12]). Some studies considered loudspeakers placed in the simulated living room (*e.g.* [12]) or outdoors, in front of the room window (e.g. [8], [13]), considering noise transmission through the façade of the cottage used for the experiment. Stimuli are usually about several minutes long. Due to the longer duration of stimuli, method SC is limited in the number of stimuli, and thus in the number of acoustical factors under study (*e.g.* [13]). This method is well-adapted to study activity disturbance due to noise (*e.g*. [14]) which influence noise annoyance (*e.g*. [15]). Method SC is closer to field studies than method IC, as participants attempt to concentrate on activities whereas participants in experiments with method IC focus on stimuli. So Zimmer *et al*. [16] mentioned assertion from the literature that annoyance can only be assessed in relation to an activity with which the noise, potentially or factually, interferes.

But both methods IC and SC are recommended in NordTest method NT ACOU 111 [17] to correlate annoyance responses gathered in laboratory conditions with long-term noise annoyance responses collected in field.

Thus the question may arise whether experiments with method IC, *i.e*. with participants concentrating on the listening to noise sequences are relevant for the assessment of annoyance in laboratory conditions?

Answering to this question is of great interest as method IC is used in the literature with the purpose of contributing to noise annoyance model enhancement.

The current study aims at answering this question by comparing results obtained from laboratory experiments based on methods IC and SC. The comparison was carried out in terms of total noise annoyance model testing. The paper is organized as follows. Section II compares results of experiments undertaken with method IC (Exp. A) and with method SC (Exp. B). The same stimuli were considered in Exp. A and B in order to limit experimental differences. The comparison in terms of total noise annoyance model testing considered models built from laboratory data and their testing using long-term noise annoyance responses collected in field. Section III is dedicated to discussion and conclusions.

II. Experiments and comparison

Two experiments were carried out to assess annoyance with methods IC and SC, respectively. From the respective laboratory data of measured annoyance responses, total annoyance models were built. Noise sequences used in the two laboratory experiments simulated the in-field combined noise exposure studied by Pierrette *et al*. [18-19] through a socio-acoustic survey in the area of Lyon. The in-field combined noise exposure was urban road traffic noise (with the day-evening-night level index (denoted by L_{den}) which ranged from 43 dB(A) to 70 dB(A)), heard in presence of a steady and permanent industrial noise (L_{den} values ranging from 27 dB(A) to 51.7 dB(A)) [18-20]. The urban road traffic noise was due to various urban vehicle types (light vehicles, powered-two-wheelers including scooters, buses and heavy vehicles) at various driving conditions (acceleration, deceleration, constant speed) on urban roads with traffic lights and bus stop. The industrial noise was emitted by a whole industrial pharmaceutical site [18-20]. The survey considered during face-to-face interviews partial annoyance due to road traffic noise (*i.e*. annoyance due to road traffic noise heard within the combined noise exposure), partial annoyance due to industrial noise (*i.e*. annoyance due to industrial noise heard within the combined noise exposure), and total annoyance due to the combined noises [18-19]. Among the 99 respondents of the survey, it appeared that ratings obtained for total annoyance and road traffic annoyance were in general higher than ratings collected for industrial noise annoyance. This was consistent with sound pressure levels in the survey area. But 27% of people found the industrial and the road traffic noises equally annoying. This was explained by the fact that from an acoustical point of view, during the day and the evening the industrial noise is mainly masked by the road traffic noise, whereas at night the road traffic is lighter, and the continuous and steady industrial noise remains mainly unmasked.

The annoyance responses collected during this survey [20] were used in the current study to test the total annoyance models respectively built in laboratory conditions within imaginary and simulated contexts.

A. Experiment A: imaginary context

1. Stimuli

Stimuli simulated the urban road traffic noise heard in presence of the steady industrial noise in the area of the survey. The urban road traffic noise excerpt and the steady industrial noise excerpt stemmed from in-field stereophonic recordings and a previous study [13] related to the socio-acoustic survey [18-19] under consideration. The third octave band sound pressure levels of the excerpts are displayed in figure 1. The relative high sound intensity at high frequency (around 8 kHz and 10 kHz) for the urban road traffic noise was due to the high frequency content of scooter pass-by in acceleration and vehicles in deceleration with breaking noise at the location (close to the traffic light and the bus stop) where recordings were carried out.

For sound reproduction in laboratory conditions, the sound pressure level (SPL) of the road traffic noise excerpt ranged from 44 to 53 dB(A) with 3 dB(A)-steps and the SPL of the industrial noise excerpt was equal to 42 and 44 dB(A) in order to comply with the dynamic range of the in-field noise exposure observed during the socio-acoustic survey [18-20]. Eight combined noise sequences were studied (4 “SPLs of the urban road traffic noise” x 2 “SPLs of the industrial noise”). Duration of each stimulus was 2 mins 34 secs. This choice of number of acoustical factors and stimulus duration corresponds to the one classically considered in method SC used in the literature studies. In the current study, this choice is made for method IC stimuli in order to limit experimental differences and compare method IC with method SC.

Noise transmission through walls and dwelling windows was not simulated by filtering stimuli. Noise annoyance was thus assessed for the worst noise exposure case (*i.e.* indoor with open window or in outdoor private spaces).

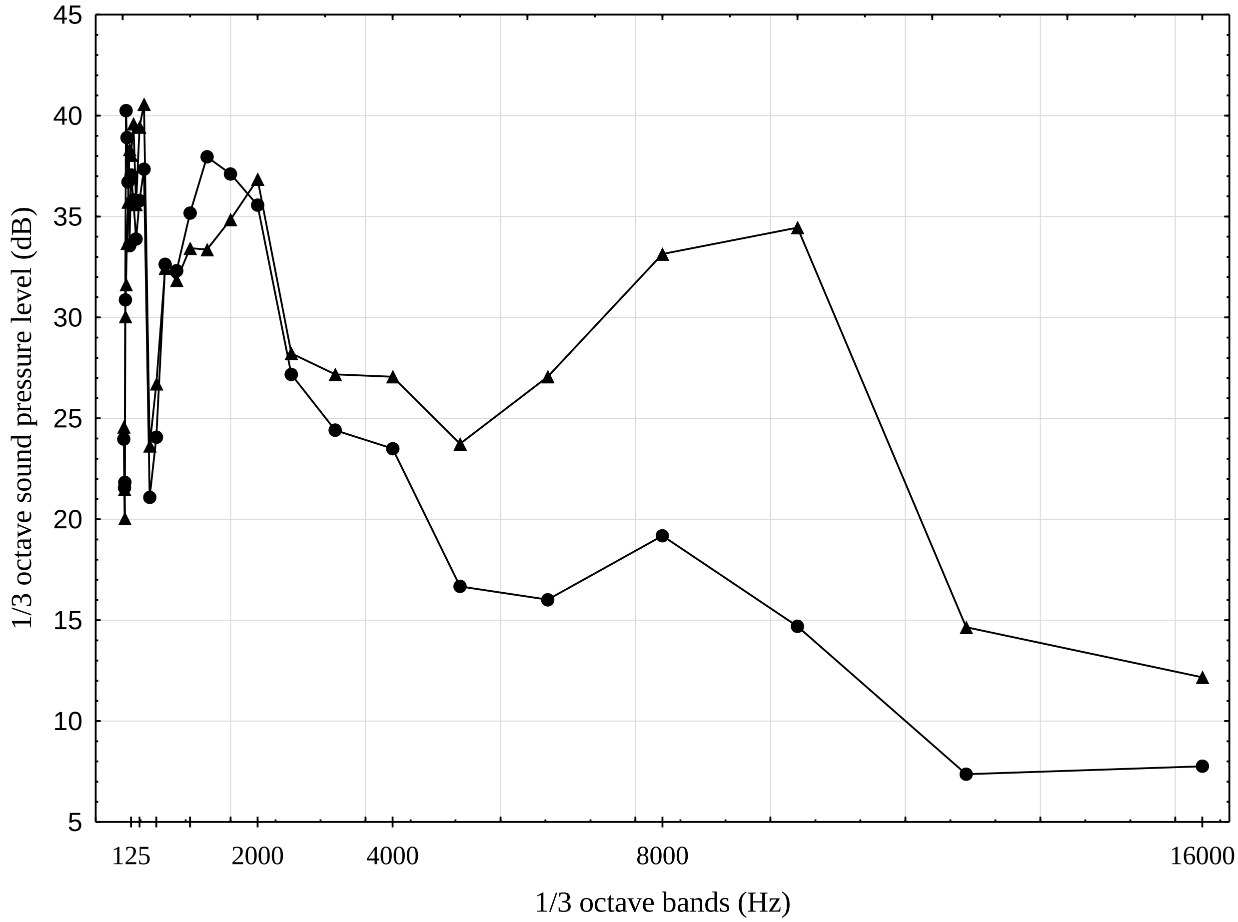

Figure 1: Third octave spectra of the road traffic noise (▲) and industrial noise (●) at the same SPL value [44 dB(A)]

2. Procedure

Instructions to participants were: “During this experiment, you will be in presence of different sound environment sequences composed of industrial and road traffic noises. Imagine yourself relaxing at home (*e.g.* reading, watching television, discussing, gardening or doing other relaxing activities you are used to)”. After each stimulus, participants were asked: “While you were imagining yourself being at home in the presence of this sound environment sequence, how much did the road traffic noise annoy you?" The questions and scaling method were based on recommendations from the ISO standard 15666:2003 [21]. On a page, they were asked to rate noise annoyance due to road traffic noise by giving a value between 0 and 10 on a continuous scale with numerical and verbal labels at its ends (respectively "0", "not at all" and "10", "extremely"). The question was repeated for the rating of annoyance due to the industrial noise, and then for the rating of annoyance due to the combined noise situation. Thus after each combined noise situation played back in the experiment to simulate the in-field exposure where residents lived in the area of the survey [18-20], the ratings corresponding to road traffic noise annoyance, industrial noise annoyance and annoyance due to combined noises were collected as partial and total annoyances were collected from each respondent of the survey under consideration [18-20]. Combined noise sequences were presented one by one in random order. Participants began with a training test to familiarize themselves as is often the case with method IC. The test lasted around 30 minutes.

3. Apparatus

Exp. A took place in a quiet room (background noise inferior to 18.5 dB(A)). Stimuli were reproduced through a high quality PC sound card (Lynx Two studio interface), using two active loudspeakers and one active subwoofer (Dynaudio Acoustics BM5A Active and BM9S). The loudspeakers were placed at a height of 1 m 20 and the subwoofer was placed on the floor between the loudspeakers. Each participant was sitting on a chair facing the computer interface to play sound excerpt as usually carried out in method IC (*e.g.* [5]). The center of the participant's interaural axis and the loudspeakers formed an equilateral triangle of 2 m side.

4. Participants

Twenty-eight participants (17 men and 11 women; mean age=33 years; standard deviation =11.6 years) took part in Exp. A as is often the case for laboratory experiments (*e.g.*

Kaczmarek and Preis [22] for method IC; Ota *et al*. [23] for method SC). They declared normal hearing abilities and were paid for their participation.

B. Experiment B: simulated context

1. Stimuli

Noise sequences were the ones used in Exp. A (*cf*. section II.A.1).

2. Procedure

A scenario in a simulated living room was proposed to the participants: “During this experiment, you will be in presence of different sound environment sequences composed of industrial and road traffic noises. Imagine yourself at home with friends or colleagues. You are doing a quiet and relaxing activity. For example, you can be having a conversation, reading, drinking, *etc*. Outdoor there is an intersection. On the other side of the road, there is an industrial site emitting noise.” They were invited to perform such a quiet activity. After each combined stimulus, participants were asked: “When you were imagining yourself at home in the presence of this sound environment sequence, how much did the road traffic noise annoy you?” In the procedure, questions and the scaling method were based on recommendations from the ISO standard 15666:2003 [21]. On a page they were asked to rate annoyance due to road traffic noise by giving a value between 0 and 10 on a continuous scale identical to the one used in Exp. A (*cf*. section II.A.2). The question was repeated for the assessment of annoyance due to the industrial noise, and then for the assessment of annoyance due to the combined noise situation. Combined noise sequences were presented one by one in random order. There was no training, as is often the case with method SC experiments. The test lasted around 30 minutes.

3. Apparatus

Exp. B took place in the quiet room used for Exp. A. The room was furnished as a living room, including three comfortable armchairs and a table. The sound reproduction was the one used in Exp. A, with loudspeakers at a height of 1 m 20 and the subwoofer on the floor between the loudspeakers. The loudspeakers formed an equilateral triangle of 2 m side with the center of the table in front of which 3 participants were sitting. As for method SC experiments in the literature (*e.g.* [8]), one receiver point is considered to define the noise exposure.

4. Participants

The same 28 participants involved in Exp. A took part in Exp. B (*cf.* section II.A.4). In order to evaluate a potential effect of experiment order (Exp. A then Exp. B, or the reverse), the participant panel was divided into two equal groups. One group first participated in Exp. A, and then participated in Exp. B. The second group participated in the two experiments in reverse order.

C. Results

1. Does the experiment order have an effect on noise annoyance responses?

To investigate whether there was an effect caused by the chronological order of the experiment on noise annoyance responses collected during Exp. A and B, mixed-design ANOVAs with one within-subject factor (stimulus) and one between-subject factor (experiment order) were carried out.

All the mixed ANOVAs showed a non-significant effect of the experiment order and a significant effect of stimuli on noise annoyance responses. Table I details ANOVA results obtained for partial road traffic noise annoyance, partial industrial noise annoyance and total noise annoyance from Exp. A.

Table I: Results of the three mixed ANOVA for annoyance responses from Exp. A. O: the experiment order factor, S: the stimulus factor, SS: Sum of Squares, dof: degrees of freedom, F: test statistic, p: p-value.

Annoyance responses		SS	dof	F	p
partial road traffic noise annoyance	O	5,63	1	0,38	0,54
	S	113,24	7	20,03	<0,001
	O*S	3,49	7	0,62	0,74
partial industrial noise annoyance	O	88,75	1	3,47	0,07
	S	20,73	7	3,02	<0,05
	O*S	5,76	7	0,84	0,56
total noise annoyance	O	20,06	1	1,54	0,22
	S	51,99	7	11,07	<0,001
	O*S	1,93	7	0,41	0,89

Table II shows the results from ANOVA carried out on partial road traffic noise annoyance, partial industrial noise annoyance and total noise annoyance responses from Exp. B.

Table II: Results of the three mixed ANOVA for annoyance responses from Exp. B. O: the experiment order factor, S: the stimulus factor, SS: Sum of Squares, dof: degrees of freedom, F: test statistic, p: p-value.

Annoyance responses		SS	dof	F	p
partial road traffic noise annoyance	O	22,98	1	1,26	0,27
	S	73,14	7	4,72	<0,001
	O*S	4,10	7	0,26	0,97
partial industrial noise annoyance	O	272,36	1	8,68	0,07
	S	22,58	7	2,31	<0,05
	O*S	8,26	7	0,84	0,55
total noise annoyance	O	81,24	1	4,02	0,06
	S	24,39	7	2,64	<0,05
	O*S	8,73	7	0,94	0,47

As there was no effect of the experiment order on noise annoyance responses, the ratings given by the two groups of participants could then be aggregated for further analyses.

2. Goodness-of-fit of the annoyance models built from Exp. A and B

Four total noise annoyance models, highlighted to have the best goodness-of-fit [18-19], were considered in the current study. They were perceptual models (*i.e.* using partial annoyances as variables): i) the strongest component model (total annoyance is equal to the maximum of the partial annoyances [24]), ii) the perceptual linear regression model (total annoyance is a linear regression of partial annoyance due to each noise in the combination [25]), iii) the perceptual mixed model (it corresponds to the perceptual linear regression model with an interaction term composed of the two partial annoyances [18-19]), and iv) the vector summation model (total annoyance results from a vector addition of the partial annoyances of the combined noises [24]). Equations of these models (*cf.* Tables III and IV) were respectively obtained from partial annoyances of Exp. A and B. The goodness-of-fit of these models is given in Tables III and IV. The value of the angle α determined to optimize the goodness-of-fit of the vector summation model was respectively equal to 109° and 110° (*cf.* Tables III and IV). The 4 models built from partial annoyances of Exp. A and B fitted well to the measured total annoyance (with a determination coefficient superior or equal to 0.7).

Table III: Goodness-of-fit of total annoyance models built from annoyance responses collected in Exp. A (imaginary context). A_{ind} and A_{road} are partial annoyances respectively due to industrial and road traffic noises. A_T is the total noise annoyance. All coefficients are significant ($p<0.05$). $R_{adj.}^2$: the adjusted determination coefficient, Std Err.: the standard error of the estimate.

Model	Equation	$R_{adj.}^2$	Std Err.
Strongest	$A_T = 0.92\max(A_{ind}, A_{road}) + 0.19$	0.81	0.68

component			
Linear regression	$A_T = 0.26A_{ind} + 0.63A_{road} + 1.46$	0.71	0.85
Mixed	$A_T = 0.41A_{ind} + 0.52A_{road} + 0.41\lvert A_{ind}-A_{road}\rvert + 0.51$	0.82	0.67
Vector Summation	$A_T = 0.65\sqrt{(A_{ind}^2 + A_{road}^2 + 2A_{ind}A_{road}\cos\alpha)} + 1.34 \quad (\alpha=109°)$	0.70	0.85

Table IV: Goodness-of-fit of total annoyance models built from annoyance responses collected in Exp. B (simulated context). A_{ind} and A_{road} are partial annoyances respectively due to industrial and road traffic noises. A_T is the total noise annoyance. All coefficients are significant ($p<0.05$). $R_{adj.}^2$: the adjusted determination coefficient, Std Err.: the standard error of the estimate.

Model	Equation	$R_{adj.}^2$	Std Err.
Strongest component	$A_T = 0.91\max(A_{ind}, A_{road}) +0.34$	0.91	0.64
Linear regression	$A_T = 0.39A_{ind} + 0.60A_{road} +0.84$	0.82	0.90
Mixed	$A_T = 0.44A_{ind} + 0.49A_{road} + 0.40\lvert A_{ind}-A_{road}\rvert + 0.32$	0.91	0.64
Vector Summation	$A_T = 0.72\sqrt{(A_{ind}^2 + A_{road}^2+ 2A_{ind}A_{road}\cos\alpha)} +0.59 \quad (\alpha=110°)$	0.87	0.75

3. Total annoyance model prediction quality using in-field data

These models, built from laboratory data respectively collected under imaginary and simulated contexts, were tested using in-field data collected during the survey [18-20]. Model prediction quality is illustrated in Table V using the correlation coefficient r calculated between the predicted total noise annoyance and the in-field measured total noise annoyance, the slope and the intercept of the corresponding regression line. All the 4 models built from Exp. A and B led to a good prediction ($r \geq 0.85$. *Cf*. Table V, figures 2 and 3).

Table V: Testing of models (respectively built from Exp. A and B) using in-field data. The prediction quality is assessed with the correlation coefficient r calculated between the predicted total noise annoyance and the in-field measured total noise annoyance, the slope and the intercept of the corresponding regression line ([a]: $p<0.001$).

	Perceptual Model	r^a	slope	Intercept
Imaginary context (Exp. A) equations tested using in-field data	Strongest component	0.96	0.90	0.58
	Linear regression	0.85	0.65	1.85
	Mixed	0.96	0.89	0.91
	Vector summation	0.94	0.72	1.71
Simulated context (Exp. B) equations tested using in-field data	Strongest component	0.96	0.89	0.72
	Linear regression	0.86	0.70	1.26

	Mixed	0.96	0.87	0.71
	Vector summation	0.94	0.80	1.0

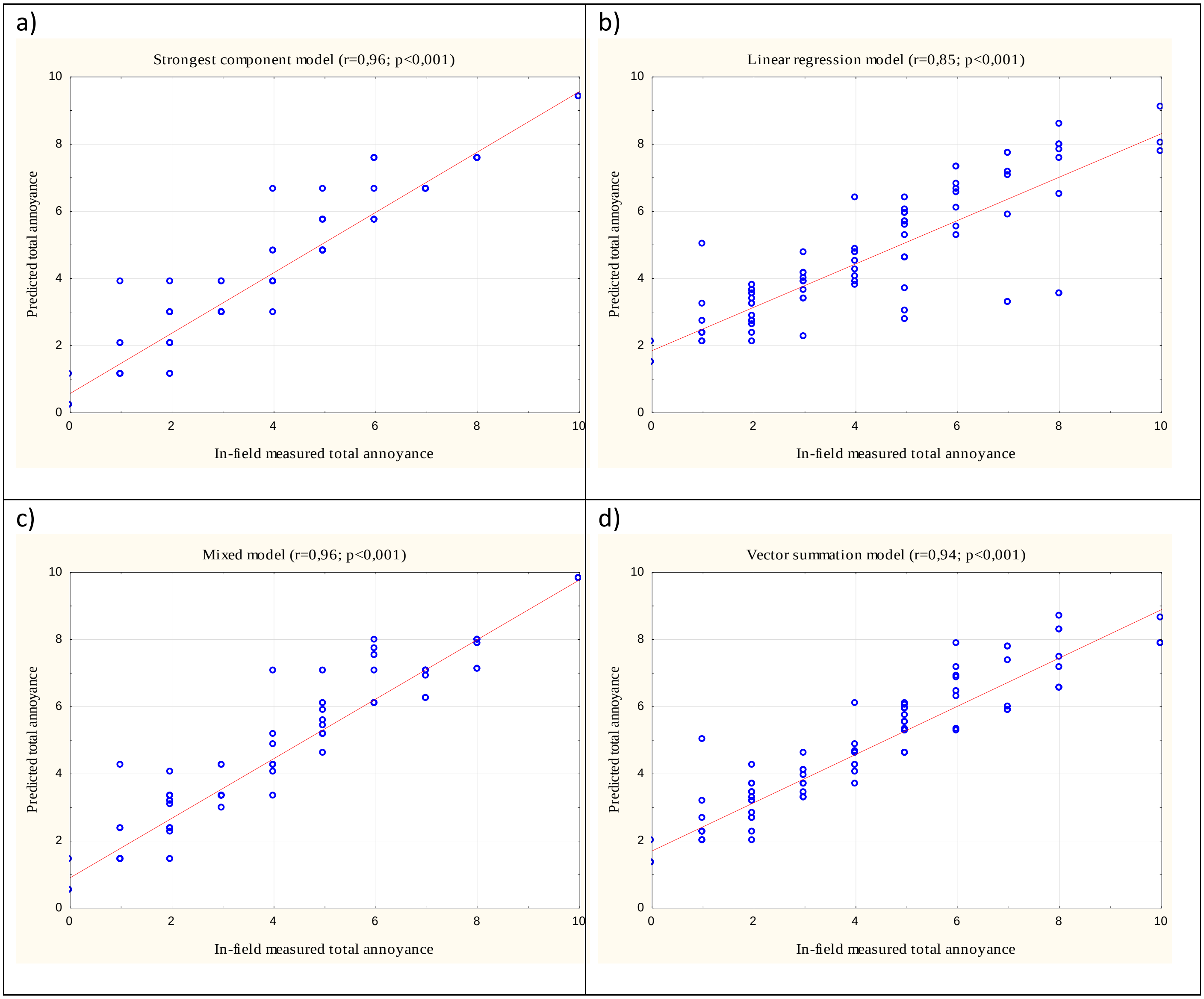

Figure 2: Predicted total annoyance responses from imaginary context (Exp. A) equations versus in-field measured total annoyance responses. r: correlation coefficient between predicted and measured responses. a) Strongest component model, b) linear regression model, c) Mixed model, d) Vector summation model.

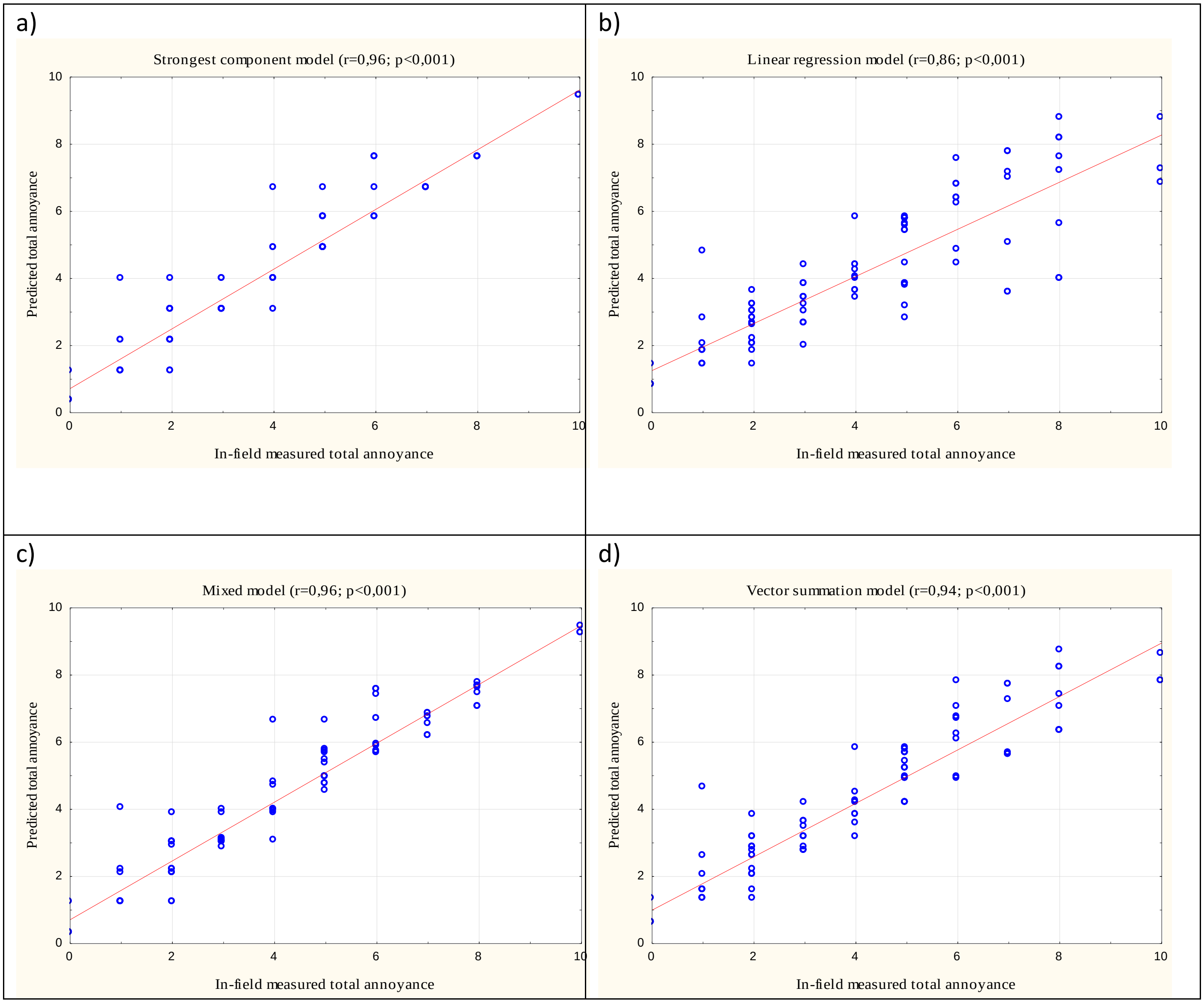

Figure 3: Predicted total annoyance responses from simulated context (Exp. B) equations versus in-field measured total annoyance responses. r: correlation coefficient between predicted and measured responses. a) Strongest component model, b) linear regression model, c) Mixed model, d) Vector summation model.

The strongest component model, the mixed model and the vector summation model led to slightly better results, compared to the perceptual linear regression model.

Concerning the comparison between Exp. A and B in terms of model prediction, a t-test carried out on differences between correlation coefficients showed non-significant results [26] for all the 4 perceptual models ($t_{obs}(94)=1.01$, $p=0.32$ for the mixed model; $t_{obs}(94)=1.99$, $p=0.05$ for the linear regression model; $t_{obs}(94)=0.0$, $p>0.05$ for strongest component and vector summation models).

Thus the two experiments A and B with context-related differences (imaginary context and simulated context) led to results with no significant differences in terms of prediction quality of annoyance models built respectively from these experiments and tested using in-field data.

III. Discussion and conclusions

This work presents a comparison between two methods carried out to assess noise annoyance in laboratory conditions. One method used an imaginary context (method IC), and the other one performed a simulated context (method SC). The method IC may be considered as not relevant for the assessment of annoyance in laboratory conditions as participants are concentrated on the listening to noise sequences. On the contrary, method SC seems to be more relevant to assess noise annoyance in laboratory conditions as participants are concentrated on activities. The comparison of these 2 methods was undertaken in terms of total annoyance model testing. Total annoyance models were respectively built from data collected under conditions of each method. Then, the total annoyance models were tested using annoyance responses collected during a survey [18-20].

First, models respectively built from annoyance responses collected with methods IC and SC showed a satisfactory goodness-of-fit (determination coefficient ≥ 0.7). Such goodness-of-fit of perceptual total annoyance models was in agreement with findings of in-field studies (*e.g.* for combined road traffic and industrial noise sources [18-19], for combined railway and road traffic noise sources [27] or for combined aircraft and road traffic noise sources [28]). This highlighted the relevance of the results obtained from the two laboratory experiments. Such relevance is in agreement with the relevance of method SC highlighted by Izumi [12] when results from annoyance responses gathered in laboratory conditions were satisfactorily compared with results stemming from in-field annoyance responses for combined railway and road traffic noise sources.

In the current study, equations of the models built from laboratory data were tested using survey data[18-20]. The prediction quality was assessed using the correlation coefficient r calculated between in-field measured total annoyance and predicted total annoyance. The model prediction quality was good ($r \geq 0.85$) and in agreement with model goodness-of-fit previously obtained for laboratory conditions or from in-field studies (*e.g.* [18-19]).

The prediction quality of total noise annoyance models built from laboratory data and tested using long-term annoyance responses showed the relevance of the two laboratory methods for annoyance assessment in laboratory conditions.

Concerning the comparison of the two methods IC and SC, the correlation coefficients r between the in-field measured total annoyance and the predicted total annoyance led to the same conclusions: the strongest component model, the vector summation model and the mixed model slightly better performed the prediction in comparison with the linear regression model. These results are in agreement with the ones obtained from in-field data (*e.g.* [27]).

Furthermore for each tested model, no significant differences were statistically observed between correlation coefficient values respectively obtained with method IC and method SC. Thus no significant differences were observed between methods IC and SC in terms of total annoyance model prediction. Thus the laboratory method with imaginary context seems to be as relevant as the method with simulated context to assess noise annoyance in laboratory conditions with the aim of contributing to noise annoyance model enhancement. The comparison between the two contexts has been carried out in terms of annoyance model prediction considering only differences in contexts. As perspectives, it might be interesting to also investigate comparisons when experiments present various differences as it might be observed in the literature between some experiments with simulated and imaginary contexts (*e.g.* outdoor loudspeakers for simulated context in a cottage and indoor loudspeakers for imaginary context in a quiet room). Further comparisons in terms of annoyance models might also be carried out using analyses of covariance on consequent sample sizes to deeply investigate potential differences.

Aknowledgements

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