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► **To cite this version:**

Philéas Maigrot, Catherine Marquis-Favre, Etienne Parizet. Two laboratory methods of assessing annoyance due to railway noise and vibration. *Journal of the Acoustical Society of America*, 2017, 142 (5), pp.3284. 10.1121/1.5012739 . hal-01711226

**HAL Id: hal-01711226**

**<https://hal.science/hal-01711226>**

Submitted on 16 Feb 2018

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# Two laboratory methods of assessing annoyance due to railway noise and vibration

## Running title: Combined noise and vibration: methodological issues

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(Dated: February 16, 2018)

### Abstract

In laboratory experiments, *total annoyance* due to combined noise and vibration, and *partial annoyances* due to each source in the presence of the other, can be assessed in two ways: during separate sessions dedicated to the evaluation of each kind of annoyance, and during the same session. This paper examines the difference between annoyance responses provided by the two methods. No differences were found between partial (respectively total) annoyance responses measured during separate sessions and those measured during the same session. The latter procedure allows reducing the number of stimuli to which the participants are subjected.

PACS numbers: 43.50.Qp, 43.50.Sr, 43.40.Ng

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## 1 I. INTRODUCTION

2 Railway traffic has been increasing in Europe over the last few decades, especially in large  
3 urban areas. Annoyance due to railway noise has been widely studied, as has annoyance due  
4 to combined noise sources, i.e. when railway noise is heard in the presence of other noise  
5 sources (e.g. road traffic, cf. [1] for a review on the topic of combined noises). Railway noise  
6 is often linked to building vibration caused by passing trains. This vibration propagates  
7 through the ground, from the tracks to inside adjacent houses. It may be perceptible and  
8 cause annoyance ([2]). Until now, only a small number of studies have been conducted to  
9 investigate annoyance due to combined noise and vibration (cf. [3] for a review). More  
10 laboratory and *in situ* studies are needed to further understand perceptual mechanisms  
11 when both types of exposure are involved.

12 Studies dealing with annoyance due to combined sources distinguish specific annoyance,  
13 partial annoyance and total annoyance. Specific annoyance refers to the annoyance due to  
14 one source in isolation. Partial annoyance (primarily defined by [4]) refers to annoyance due  
15 to one source (e.g. noise) in the presence of another one (e.g. vibration). Annoyance due  
16 to all sources combined is referred to as total (or overall) annoyance. Annoyance responses  
17 can be collected during *in situ* and laboratory studies, making it possible to understand the  
18 phenomena involved and to propose annoyance models.

19 During *in situ* studies ([5]), partial and total annoyance responses are commonly assessed  
20 within the same questionnaire. In the literature, one question asked is whether the order  
21 of the questions on annoyance affects annoyance responses ([6]). In studies conducted in  
22 the laboratory on combined noise sources, participants are asked during the same session  
23 to rate partial and total annoyance after each stimulus has been presented (e.g. [7]). In  
24 this case, it is interesting to know whether participants compromise between the different  
25 annoyance responses. For combined noise and vibration exposures, partial annoyances and  
26 total annoyance are commonly assessed during separate sessions. To our knowledge, no  
27 studies have been conducted to determine a potential difference between partial and total  
28 annoyance responses collected during the same session and during separate sessions.

29 The goal of this study was to measure the influence of two laboratory methods used to assess  
30 partial and total annoyances due to railway noise and vibration on the participants' answers.  
31 The initial hypothesis was that both methods would lead to similar results. The stimuli

32 were a set of 16 combinations of railway noise and vibration recorded in a dwelling close to a  
33 railway track. Partial and total annoyance responses were collected during separate sessions  
34 dedicated to evaluating each kind of annoyance after which they were assessed during the  
35 same session.

## 36 II. METHOD

### 37 A. Participants

38 Thirty-two adults (20 males, 12 females; mean age = 33.2 years, standard deviation =  
39 9.7 years) took part in this experiment. An audiogram was measured before the experiment  
40 to ensure that they had normal hearing abilities. They were naive concerning the goal of the  
41 study and could ask any question about the experiment if it was not related to the objective  
42 of the study. Participants' written consent was obtained in accordance with the Helsinki  
43 declaration.

### 44 B. Stimuli

45 The noise and vibration stimuli were recorded simultaneously inside a house during a  
46 train passage. The noise was recorded using a stereophonic system, along with an om-  
47 nidirectional microphone to calibrate recordings, as in previous studies ([8]). Vibration  
48 was recorded using an accelerometer Piezotronics 393B12 (PCB Piezotronics, Depew, NY,  
49 www.pcb.com) operating in the frequency range of interest (*i.e.* between 1 and 80  $Hz$  for  
50 whole-body vibration). The railway track was approximately 10 meters from the building  
51 facade. Recordings took place in the center of a bedroom where the inhabitant reported the  
52 strongest vibration, in conformity with ISO 2631-2 ([9]). The position of the microphones  
53 was approximately 1.5 meters above the ground.

54 The duration of the extracted pass-by was 13.5 seconds. The spectrum of the extracted  
55 acoustic signal was broad band and the frequency range varied between 40  $Hz$  and 20  $kHz$   
56 while the dominant frequency of the vibration signal was 55  $Hz$ . Based on these acoustic  
57 and vibration signals, noise stimuli and vibration stimuli were presented at 4 different levels.  
58 The equivalent sound levels,  $L_{A_{eq}}$ , of the 4 noise stimuli  $N_1$ ,  $N_2$ ,  $N_3$  and  $N_4$ , were 44, 50,  
59 56 and 62  $dB(A)$ , respectively. The lowest level of 44  $dB(A)$  corresponded to the level of

60 the recorded pass-by with no gain applied. The unweighted root-mean-square (r.m.s.) ac-  
61 celerations of the 4 vibration stimuli  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$ , averaged over the total duration of  
62 the pass-by, were 0.0299, 0.0543, 0.0714 and 0.0943  $m.s^{-2}$ , respectively. The lowest r.m.s.  
63 acceleration of 0.0299  $m.s^{-2}$  corresponded to the acceleration measured on site. These levels  
64 were chosen according to the literature ([10],[11]). Therefore, there were 16 combinations  
65  $N_iV_j$  of noise and vibration ( $i = 1 : 4$ ,  $j = 1 : 4$ ).

### 66 C. Apparatus

67 Vibration was generated in the vertical direction by an electrodynamic shaker LDS-V650  
68 (B&K, Nærum, Denmark, www.bksv.com). The participants sat on a rigid stool secured  
69 to a platform mounted on the shaker. A guardrail was placed around the platform as a  
70 safety precaution for the participants. They were told not to lean against it and to maintain  
71 their bodies in a vertical posture during the experiment. Noise was presented through  
72 two loudspeakers (Tapco S5) placed in front of each participant so that they formed an  
73 equilateral triangle with the participant’s head. The experiment was performed in a semi-  
74 anechoic chamber with background noise below 30  $dB(A)$ . Lastly, a touch screen was placed  
75 in front of the participant to display instructions and annoyance scales.

### 76 D. Procedure

77 At the beginning of the experiment, the participants were trained so that they could  
78 familiarize themselves with the stimulus range and annoyance scale. A numerical continuous  
79 scale was used, ranging from 0 (“not at all”) to 10 (“extremely”), adapted from the ICBEN  
80 recommendations ([12]). Four stimuli were presented during this training period: a “weak”  
81 combination of the lowest noise and vibration levels, a “strong” combination of the highest  
82 noise and vibration levels, a stimulus composed of noise alone and a stimulus composed of  
83 vibration alone. After this training period, the experiment consisted of four sessions: A, B,  
84 C and D. The participants engaged in each session in random order. During each of these  
85 sessions, they were exposed to the 16 combinations of noise and vibration, also in random  
86 order. The participants had to rate their annoyance after each stimulus:

- 87 - During session A, the participants had to evaluate partial annoyance due to the noise

88 heard within each of the 16 combined stimuli  $N_iV_j$ . During this session, specific  
89 annoyance due to the 4 noise stimuli  $N_i$  in isolation was also assessed (a total of 20  
90 stimuli:  $16 N_iV_j + 4N_i$ ).

91 - During session B, the participants had to evaluate partial annoyance due to the vi-  
92 bration felt within each of the 16 combined stimuli  $N_iV_j$ . During this session, specific  
93 annoyance due to the 4 vibration stimuli  $V_j$  in isolation was also assessed (a total of  
94 20 stimuli:  $16N_iV_j + 4V_j$ ).

95 - During session C, the participants had to evaluate total annoyance due to combined  
96 noise and vibration (16 stimuli  $N_iV_j$ ).

97 - During session D, the participants were asked to evaluate partial annoyance due to  
98 noise, partial annoyance due to vibration and total annoyance due to combined noise  
99 and vibration (16 stimuli  $N_iV_j$ ).

100 A stimulus could be played as many times as necessary before the annoyance response was  
101 given. This response could not be modified once the next stimulus had been played. At the  
102 end of each session, the participants were asked to rate the difficulty of the task on the same  
103 continuous numerical scale. The experiment lasted approximately 45 minutes.

### 104 III. RESULTS

105 The results were analyzed to evaluate potential differences between the annoyance mea-  
106 sured using both procedures. Repeated-measures analyses of variance (RM-ANOVA) were  
107 carried out on the annoyance responses. All the *post hoc* analyses were carried out using  
108 Tukey's Honest Significant Difference (HSD) test. In order to focus on the comparison of  
109 both procedures, specific annoyance responses will not be considered in this paper. FIG. ??  
110 indicates the mean noise annoyance responses ( $A_N$ ), mean vibration annoyance responses  
111 ( $A_V$ ) and total annoyance responses ( $A_T$ ), collected during sessions A and D, during sessions  
112 B and D and during sessions C and D, respectively.

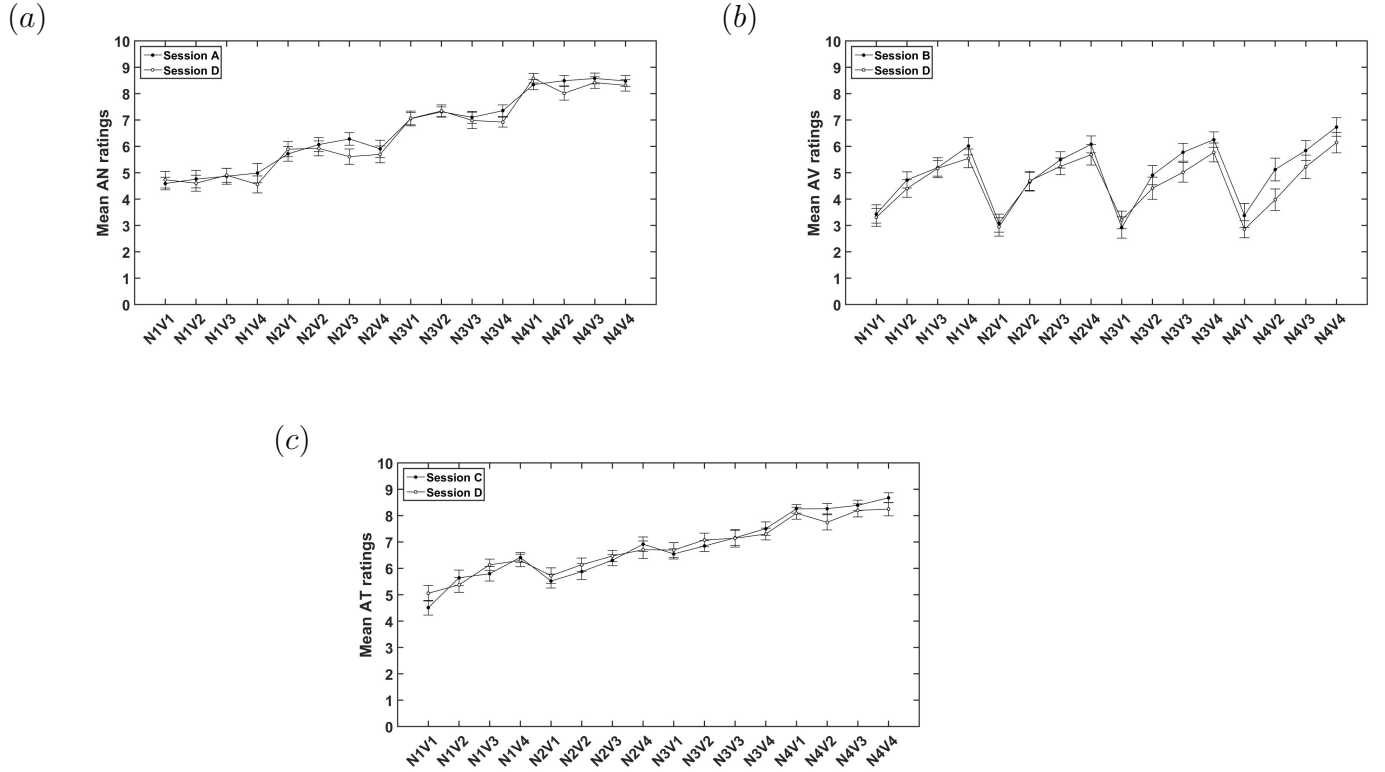


FIG. 1. Mean annoyance ratings and standard errors: (a) partial noise annoyance, (b) partial vibration annoyance and (c) total annoyance.

#### 114 **A. Influence of the method on annoyance responses**

115 In order to study the influence of the method of collecting annoyance responses on the  
 116 participants' answers, three one-factorial RM-ANOVAs were carried out, considering the  
 117 factor *SESSION*. The results indicated that the effect of the session was not significant on  
 118  $A_N$  responses [ $F(1, 31) = 1.12, p > 0.29$ ],  $A_V$  responses [ $F(1, 31) = 3.55, p > 0.06$ ] and  $A_T$   
 119 responses [ $F(1, 31) = 0.01, p > 0.91$ ].

#### 120 **B. Influence of the method on task difficulty**

121 The difficulty ratings expressed at the end of each session were also analyzed using an one-  
 122 factorial RM-ANOVA with the factor *SESSION*. The effect of the method on task difficulty  
 123 was significant [ $F(3, 93) = 5.7364, p < 0.01$ ]. The proportion of variance  $\eta^2$  explained by  
 124 the factor *SESSION* was 2.4%, giving information on the small size of the effect. A *post*  
 125 *hoc* analysis confirmed that the difficulty responses were significantly higher for session D

126 than for session A ( $p < 0.001$ ) and than for session C ( $p < 0.05$ ). However, mean difficulty  
127 ratings remained below 5 out of 10 for the four sessions.

### 128 C. Effects of noise and vibration levels on annoyance responses for both methods

129 The effects of noise and vibration levels on  $A_N$ ,  $A_V$  and  $A_T$  were analyzed to investigate  
130 the similarity of trends between sessions A, B and C on the one hand, and session D on  
131 the other hand. Six two-factorial RM-ANOVAs were conducted with factors *NOISE* and  
132 *VIBRATION* levels (four levels per factor).

#### 133 1. Partial noise annoyance responses

134 The effect of noise level on  $A_N$  was significant, whether the responses were collected during  
135 session A [ $F(3, 93) = 157.49$ ,  $p < 0.001$ ,  $\eta^2 = 47.5\%$ ] or during session D [ $F(3, 93) = 146.20$ ,  
136  $p < 0.001$ ,  $\eta^2 = 44.8\%$ ]. The effect of vibration level on  $A_N$  collected during sessions A  
137 and D was not significant, [ $F(3, 93) = 2.70$ ,  $p > 0.05$ ] and [ $F(3, 93) = 1.13$ ,  $p > 0.34$ ],  
138 respectively.

#### 139 2. Partial vibration annoyance responses

140 The effect of vibration level on  $A_V$  collected during sessions B and D was significant  
141 with a large effect size, [ $F(3, 93) = 75.47$ ,  $p < 0.001$ ,  $\eta^2 = 24.2\%$ ] and [ $F(3, 93) = 77.83$ ,  
142  $p < 0.001$ ,  $\eta^2 = 19.7\%$ ], respectively. On the one hand, the effect of the noise level on  $A_V$   
143 collected during session B was significant [ $F(3, 93) = 3.75$ ,  $p < 0.015$ ,  $\eta^2 = 0.6\%$ ], but the  
144 effect size was very small. The result of a *post hoc* analysis indicated that when the noise  
145 level was 62  $dB(A)$ ,  $A_V$  differed significantly from  $A_V$  when the noise level was below 56  
146  $dB(A)$ . On the other hand, no influence of the noise level on  $A_V$  collected during session D  
147 was observed [ $F(3, 93) = 0.11$ ,  $p > 0.95$ ].

#### 148 3. Total annoyance responses

149 The effects of both the noise and vibration levels on the  $A_T$  responses collected during  
150 session C were significant, [ $F(3, 93) = 127.85$ ,  $p < 0.001$ ,  $\eta^2 = 35.9\%$ ] and [ $F(3, 93) = 28.94$ ,



151  $p < 0.001$ ,  $\eta^2 = 5.8\%$ ], respectively. The effects of both the *NOISE* and *VIBRATION* levels  
152 on the  $A_T$  responses collected during session D were also significant, [ $F(3, 93) = 92.86$ ,  
153  $p < 0.001$ ,  $\eta^2 = 25.1\%$ ] and [ $F(3, 93) = 18.21$ ,  $p < 0.001$ ,  $\eta^2 = 2.9\%$ ], respectively. There  
154 was a significant interaction between the two factors on the  $A_T$  responses collected during  
155 sessions C and D, [ $F(9, 279) = 3.13$ ,  $p < 0.002$ ,  $\eta^2 = 1.5\%$ ] and [ $F(9, 279) = 2.34$ ,  $p < 0.016$ ,  
156  $\eta^2 = 1\%$ ], respectively.

#### 157 **IV. DISCUSSION**

158 Regarding the results of the three one-factorial RM-ANOVAs carried out on  $A_N$  (collected  
159 during sessions A and D),  $A_V$  (collected during sessions B and D) and  $A_T$  (collected during  
160 sessions C and D) with factor *SESSION*, it seems that the factor session (*i.e.* the method)  
161 had no influence on the partial and total annoyance responses. However, the method of  
162 collecting the annoyance responses seems to have had a small effect on task difficulty.

163 The results of the six two-factorial RM-ANOVAs conducted with the factors *NOISE* and  
164 *VIBRATION* levels suggest that the presence of vibration did not have any influence on  
165 the  $A_N$  responses. This finding is in agreement with the conclusions of previous laboratory  
166 studies (e.g. [10]). However, other research works conducted in the laboratory and *in situ*  
167 (e.g. [13]) showed that this influence may exist and therefore contradict this conclusion.  
168 In a laboratory experiment, Paulsen and Kastka [11] showed that noise annoyance tends to  
169 increase with vibration magnitude only for low to moderate noise levels. However, the noise  
170 levels used in their experiment were quite low compared to those used in other studies (e.g.  
171 [10] and the current study). This difference in the noise levels could explain the differences  
172 between the results of these studies.

173 The noise level seems to have had an influence on the  $A_V$  collected during session B. Although  
174 this result is consistent with other studies ([10],[11],[13]), this influence was not found when  
175 the  $A_V$  were collected during session D. Although the proportion of variance  $\eta^2$  explained  
176 by the noise level during session B was very small (less than 1%). Therefore the effect of  
177 the noise level highlighted on  $A_V$  was very weak.

178 Both noise and vibration levels influenced  $A_T$ . According to the proportions of variance  
179 explained by the two factors,  $A_T$  is mainly influenced by noise. This result is in agreement  
180 with several laboratory and *in situ* studies ([10],[11],[13]).

## 181 V. CONCLUSION

182 The purpose of this study was to compare two methods of collecting annoyance responses  
183 in laboratory conditions: their collection during the same session or during separate sessions.  
184 Four sessions with 16 combined noise and vibration stimuli were designed to achieve this  
185 goal. During the first session (A), the task was to evaluate partial noise annoyance. During  
186 another session (B), the task was to evaluate partial vibration annoyance. The task in the  
187 third session (C) was to evaluate total annoyance. Finally during the fourth session (D), the  
188 task was to evaluate all three annoyances after each stimulus.

189 The results indicated that no differences existed between the partial and total annoyance  
190 responses collected during the same session and during separate sessions. Session D appeared  
191 as rather more difficult for participants. Lastly, session D was suitable as a reduced number  
192 of stimuli can lead to as many results as the cumulative sessions A, B and C.

193 Therefore, this laboratory method may be adopted in further experiments in which a larger  
194 number of stimuli are used.

## 195 ACKNOWLEDGMENTS

196 The vibration measurements on site were made possible by Acouphen ([www.acouphen.fr](http://www.acouphen.fr)).  
197 This work was supported by the LabEX CeLyA (“Centre Lyonnais d’Acoustique”) of Uni-  
198 versité de Lyon (ANR-10-LABX-60/ ANR-11-IDEX-007).

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