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Combined road traffic, railway and aircraft noise sources: total noise annoyance model appraisal from field data

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Abstract

Appraisal of environmental noise effects on health considers single noise exposure. In large cities, noise exposure is frequently due to multiple sources. Their combination, interaction or successive presence is known to affect people's health. The prediction of their effects has been little studied and needs more investigation to address the problem. Studies dealing with annoyance due to combined noise sources proposed different total annoyance models. They were very rarely assessed using field annoyance data. The current work aims to assess them using data of annoyance due to different urban situations of two, and even three, combined transportation noise sources. The considered noises were from road, railway and aircraft traffic. Assessment of ten classical total annoyance models highlighted relevant existing models to account for combined transportation noise annoyance in cities. Perceptual total annoyance models, based on annoyance due to each transportation noise source, better performed total annoyance calculation than psychophysical total annoyance models based on the L_{den} index. As the dominant source effect mainly explained total annoyance responses from the residents, the strongest component model led to a good calculation of mean total annoyance ratings. But perceptual models with an interaction term, such as the vector summation and mixed models, better explained total annoyance judgments from residents as they account for the contribution of each combined noise source and their interaction. The perceptual linear regression model was also interesting as it accounted for the contribution of each combined noise source, and might be used for more than two combined noise sources. Those perceptual models accounted well for the resident feeling towards the different combined noise sources. These results might contribute to the endeavor aiming at filling the lack of consensus among the scientific community and the corresponding lack of regulations.

Keywords: Total noise annoyance; combined transportation noises

1. Introduction

Noise exposure is a great environmental and health concern in industrial countries. Noise levels increase (World Health Organization, 2018) due to urbanization and traffic growth. For environmental noise management, the European Directive 2002/49/EC (European commission, 2002a) makes it mandatory for European cities with more than

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45 100,000 inhabitants to produce strategic noise maps for each type of transportation
46 noises. These maps characterize noise exposure using the day-evening-night level, L_{den}
47 index. They are used to estimate the number of Disability-Adjusted Life Years
48 (DALYs) due to the impact of single environmental noise exposure on health (World
49 Health Organization, 2011). Both environmental health impact assessment and urban
50 planning only consider single noise exposure. But in large cities, combined noise
51 exposure is a frequent situation and few data are available about the number of
52 European citizens exposed to several noise sources (*cf.* Lercher *et al.*, 2017).
53 Simultaneous noise sources may interact. For example, Öhrström and her colleagues
54 (2007) reported a greater annoyance due to combined sound exposure from two equally
55 noisy sources than annoyance due to the same total sound exposure involving one
56 dominant source. It has also been highlighted that different noise sources successively
57 perceived over time period affect people (*e.g.* Pierrette *et al.*, 2012a for annoyance due
58 to road traffic noise combined with weak but permanent industrial noise; ENNAH,
59 2013 for child learning impairment due to combined aircraft and road traffic noises).
60 Thus, characterization and prediction of the effects of multiple noise source situations
61 need endeavor (*e.g.* Lercher *et al.*, 2017, Lechner *et al.*, 2019 and Gille *et al.*, 2019).
62

63 Annoyance due to combined noise exposures has been mainly studied for two
64 environmental noise sources (*e.g.* Lam *et al.*, 2009 for combined road traffic and
65 railway noises; Nguyen *et al.*, 2012 for combined aircraft and road traffic noises;
66 Wothge *et al.* 2017 for combined aircraft and road traffic noises and combined aircraft
67 and railway noises). Very few field studies investigated annoyance due to three
68 combined transportation noise sources (*e.g.* Ragletti *et al.*, 2015 in Canada; Gille *et al.*,
69 2016 in France; Lercher *et al.*, 2017 in the Alpine valley; Lechner *et al.*, 2019 in
70 Innsbrück). Among field studies dealing with annoyance due to combined
71 transportation noise sources, few of them investigated classical total annoyance models
72 from the literature in order to highlight relevant ones (*e.g.* Nguyen *et al.*, 2012). The
73 very limited number of studies dealing with total annoyance model appraisal using field
74 data leads to a lack of consensus among the scientific community, and results in a
75 corresponding lack of national regulations. Thus, more studies are needed to test total
76 annoyance models, and to point out whether existing total annoyance models might be
77 relevant for combined transportation noise exposure situations, when people are
78 exposed to two, or even three noise sources. Close to large cities, such combined
79 transportation noise exposure situations are frequent.
80

81 In 2012, a French socio-acoustic survey (Ecotière *et al.*, 2014) was conducted for
82 the Ministry of Ecology in order to study annoyance due to combined transportation
83 noise sources in France. Different combinations of two transportation noise sources
84 were considered (*i.e.* road traffic noise combined with railway noise, road traffic noise
85 combined with aircraft noise, and railway noise combined with aircraft noise).
86 Furthermore, a combination of three transportation noise sources was also under study
87 (road traffic noise combined with railway and aircraft noises). These field data were
88 analyzed using structural equation modeling to highlight various potentially influencing
89 factors on total annoyance (Gille *et al.*, 2017). The analysis of transportation noise
90 source contributions showed that aircraft noise has a higher influence on total
91 annoyance than road traffic noise, and that in turn road traffic noise has a higher

92 influence on total annoyance than railway noise. These field data were used to test the
93 exposure-effect relationships (Gille *et al.*, 2016) recommended by the European
94 Commission (2002b) to predict annoyance due to single transportation noise exposure.
95 They were also used to test Miedema's model (2004), which was proposed to predict
96 annoyance due to combined transportation noise sources and was based on the
97 previously mentioned exposure-effect relationships (*cf.* Gille *et al.*, 2016). The testing
98 results showed that the different exposure-effect relationships and Miedema's model
99 generally fail to provide a good prediction of both partial annoyance (*i.e.* annoyance
100 due to a noise source heard in presence of another source) and total annoyance (*i.e.* due
101 to combined noise sources), (*cf.* Gille *et al.*, 2016). Thus, assessment of more total
102 annoyance models using field data has to be considered as a better characterization of
103 total annoyance is needed.

104 The current work will focus on total annoyance due to combined transportation
105 noise sources to point out 1) perceptual mechanisms which might govern total
106 annoyance, and 2) relevant total annoyance models among the main ones proposed in
107 the literature. Annoyance ratings gathered during the French socio-acoustic survey
108 (Ecotière *et al.*, 2014) will be used for such purposes. Frequent combined transportation
109 noise source situations in large cities will be considered: i) road traffic combined with
110 aircraft noise, and ii) road traffic combined with railway noise. Furthermore, the less
111 studied combined transportation noise exposure in the literature will be also under
112 consideration in the current paper: road traffic noise combined with both railway and aircraft
113 noise sources.

114

115 **2. The socio-acoustic survey**

116

117 The survey was conducted in 2012 by Ecotiere *et al.* (2014) in 8 French cities
118 exposed to various combined transportation noise sources (*i.e.* road traffic and railway;
119 road traffic and aircraft; railway and aircraft; road traffic, railway and aircraft noises).
120 The respondents were interviewed face-to-face through a questionnaire. In this section, the
121 main characteristics of the survey are briefly summed up from published articles (Gille
122 *et al.*, 2016 and Gille *et al.*, 2017).

123

124 *2.1 The questionnaire*

125 The 30-minute questionnaire in French (*cf.* Ecotière *et al.*, 2014) was organized with
126 questions dealing with:

- 127 - housing description and assessment;
- 128 - neighborhood description and assessment
- 129 - global outdoor sound environment: description and assessment;
- 130 - noise from the different sources under study, considered separately: description and
131 assessment of annoyance when the noise source is heard in presence of another
132 transportation noise source depending on the city of residence (hereafter denoted
133 by partial annoyance);
- 134 - overall noise resulting from the combined exposure under study (*i.e.* road traffic
135 and railway; road traffic and aircraft; railway and aircraft; as well as road traffic,

136 rail and aircraft noise sources): description about the different noise sources within
 137 the combination using items such as “road traffic noise alone would be bearable”;
 138 - annoyance due to these combined noise sources (hereafter denoted by total
 139 annoyance);
 140 - non-acoustical factors related to the respondent (*e.g.* self-estimated noise
 141 sensitivity).

142
 143 The questions concerning partial and total noise annoyances complied with
 144 ISO/TS 15666 technical specification recommendations for French language (*e.g.*
 145 “Thinking about the last 12 months, when you are here at home, how much does noise
 146 from road traffic annoy you?”; “Thinking about the last 12 months, when you are here
 147 at home, how much do noise from road traffic and noise from railway together annoy
 148 you?”). Respondents were asked to give an annoyance rating to the specified noise
 149 source(s) on a continuous scale ranging from “0” to “10”, comprised of 11 evenly
 150 spaced numerical labels and two verbal labels at both ends (“not at all” and
 151 “extremely”). The self-estimated noise sensitivity in general was assessed on a
 152 continuous scale from “0” to “10”, built on the same format (Ecotièrre *et al.*, 2014).

153

154 2.2 Study population

155 A total of 823 people were successfully interviewed face-to-face. The respondents
 156 were aged between 18 and 80, and had been living permanently in their dwelling for at
 157 least one year (*cf.* Gille *et al.*, 2017). Their socio-demographic characteristics are
 158 presented in Table 1.

159

160 **Table 1.** Socio-demographic characteristics of the studied population (*cf.* Gille *et*
 161 *al.*, 2017).

	N(%)	Mean ±SD(Min-Max)
Gender		
Male	48.5%	
Female	51.5%	
Age		46 ±16.9 (18-80)
Length of residence		13.4±14.1(1-77)
Occupation		
Working	55.9%	
Non-working	44.1%	
Retired	22.7%	
Student	4.9%	
Unemployed	7.4%	
Housewife	6.7%	
Disabled	1.2%	
Other	1.2%	

162

163 From the normally distributed noise sensitivity ratings, it appeared that about
 164 70.5% of respondents reported themselves to be sensitive or highly sensitive to noise in
 165 general.

166

167 2.3. Combined noise exposures under study

168 Noise exposure in terms of the L_{den} index was known thanks to strategic noise maps
 169 available in 2012 for each city from the survey. The maps were drawn by technical services
 170 under contract with the French government, using European Directive 2002/49/CE
 171 guidelines. The noise maps were established for each single transportation noise exposure.

172 Table 2 gives the combined noise exposures for 6 cities studied during the socio-
 173 acoustic survey, and studied in the current work. The corresponding combined transportation
 174 noise exposures were respectively combined road traffic and railway noise sources,
 175 combined road traffic and aircraft noise sources, and finally combined road traffic, railway
 176 and aircraft noise sources. The combined railway and aircraft noise source situations (*i.e.*
 177 without road traffic noise), studied during the socio-acoustic survey in two French cities, will
 178 not be analyzed in the current work as it corresponds to a less common combined exposure
 179 for inhabitants of cities. This type of exposure - not studied here - concerned 121
 180 respondents from the socio-acoustic survey (*cf.* Gille *et al.*, 2017).

181 Table 2 summarizes for the combined exposures studied in the current paper, sample
 182 size and noise exposure in terms of L_{den} range (*cf.* Gille *et al.*, 2017).

183
 184 **Table 2.** Noise exposure expressed in L_{den} (dB(A)) per noise source and sample
 185 size of areas in 6 cities of the survey (Ecotièrre *et al.*, 2014; Gille *et al.*, 2017).
 186 Road: Road traffic; Rail: Railway; Air: Aircraft; ¹: city exposed to Orly airport
 187 noise; ²: city exposed to Roissy-Charles-de-Gaulle airport noise.
 188

Exposure (Total sample size)	City (sample size)	Lden Road Traffic dB(A)	Lden Railway dB(A)	Lden Aircraft dB(A)
Road and Rail (301)	Bourg Les Valence (82) Caluire (79) Lyon 6 (140)	58.0 to 80.8 55.6 to 78.0 48.4 to 74.2	58.1 to 77.4 45.6 to 82.2 40.6 to 83.6	no exposure
Road and Air (212)	Paray-Vieille-Poste ¹ (153) Saint Brice-sous-Forêt ² (59)	49.9 to 77.9 53.7 to 67.5	no exposure	42.0 52.0 to 54.0
Road, Rail and Air (189)	Villeneuve-Saint-Georges ¹ (189)	42.3 to 79.3	43.2 to 80.8	44.7 to 62.8

3. Perceptual mechanisms linked to total annoyance judgments

Annoyance ratings collected during the socio-acoustic survey were first analyzed to understand the main perceptual mechanisms which might govern total annoyance judgments.

For the different combined transportation noise exposures, the analysis was helped by means of the representation proposed by Vos (1992). For each combined noise exposure, the representation displays mean partial and total annoyance ratings versus L_{den} when only one noise within the combination varies in L_{den} values and the other(s) is(are) at a fixed L_{den} value. For each noise exposure, L_{den} values are displayed per 5 dB(A) interval as it is done for noise maps in European countries. The representation highlights the main perceptual mechanisms between mean partial annoyance ratings and mean total annoyance ratings. Then t-test analyses were carried out to confirm or not, from a statistical point of view, the significance of the observed differences between partial and total annoyance ratings. T-test analyses may highlight if total annoyance is greater than, equal to or lower than the maximum partial annoyance.

When total annoyance is equal to the maximum partial annoyance, total annoyance is governed by the most annoying noise source; such source is the strongest component within the combination. This was observed in different studies of combined noise sources (*e.g.* Berglund *et al.*, 1981; Morel *et al.*, 2012; Wothge *et al.*, 2017). This is explained by energy masking effects (*e.g.* Hellmann, 1982). The most annoying source is often the dominant source in global sound pressure level or in loudness (*e.g.* Berglund *et al.*, 1981). For that reason, the effect is denoted in the literature by the dominant source effect. But a non-dominant source in global sound pressure level can be the most annoying source within the combination (*e.g.* Wothge *et al.*, 2017). The phenomenon might be explained by partial energy masking between the noise sources (*e.g.* high energy masking at low frequencies as highlighted in Morel *et al.*, 2012).

When total annoyance is greater than the maximum partial annoyance, the phenomenon is called the synergistic effect. This effect has been explained by interactions between the combined noise sources and has been observed when annoyances due to each noise source within the combination are close (*cf.* Ohrström *et al.*, 2007; Ota *et al.*, 2008). When total annoyance is lower than the maximum partial annoyance, this is named the paradox effect. This latter is explained in the literature as a possible consequence of the method used to assess annoyance (*e.g.* Lercher, 2011), or explained in some noise situations by cognitive effects due to the presence of natural noises which are known to decrease annoyance (Alayrac *et al.*, 2011; Klein *et al.*, 2017) and sound unpleasantness (Guastavino, 2006).

The analysis is hereafter presented per exposure: road traffic noise combined with aircraft noise, road traffic noise combined with railway noise, and finally road traffic noise combined with both railway noise and aircraft noise.

3.1 Road traffic noise combined with aircraft noise

The analysis carried out for the combined road traffic and aircraft noise sources showed that total annoyance ratings were not significantly different from the maximum partial annoyance ratings. The strongest component model from the literature (*cf.* section 4) should therefore allow a good calculation of total annoyance ratings.

As an example, figure 1 displays the representation proposed by Vos (1992), with mean annoyance ratings (for partial road traffic noise annoyance, partial aircraft noise annoyance and total annoyance) versus the variation of road traffic noise L_{den} per interval of 5 dB(A) when aircraft noise L_{den} is at a fixed value within the half-open interval [40; 45dB(A)].

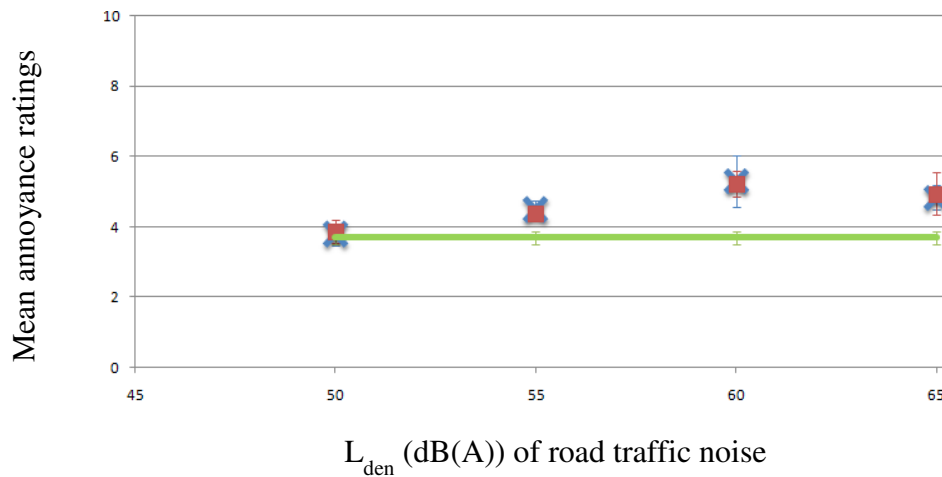


Figure 1: Mean annoyance ratings with standard errors versus the variation of L_{den} of road traffic noise per 5 dB(A) interval and when aircraft noise L_{den} is at a fixed value within the interval [40; 45 dB(A)].

■: partial road traffic noise annoyance; —: partial aircraft noise annoyance; ×: total annoyance due to combined road traffic and aircraft noises.

3.2 Road traffic noise combined with railway noise

When L_{den} of road traffic noise was identical to L_{den} of railway noise, no significant differences were observed between the two mean partial annoyance ratings. The results indicated thus no railway bonus.

For most of the studied situations of the combined road traffic and railway noise sources, total annoyance ratings were not significantly different from the maximum partial annoyance ratings. Among the different situations under study, only one case of synergistic effect was identified when road traffic noise ranged between 70 and 75 dB(A) and the railway noise level between 60 and 65 dB(A). Therefore, it can be expected that the strongest component model will allow in general a good calculation of total annoyance due to combined road traffic and railway noises.

3.3 Road traffic noise combined with both railway noise and aircraft noise

For this combination of three transportation noise sources, total annoyance was equal to the maximum partial annoyance. Actually, t-test analyses showed that total annoyance ratings were not significantly different from the maximum partial annoyance ratings. The strongest component model from the literature should thus allow a good calculation of total annoyance ratings.

4. Main total annoyance models from the literature

Total annoyance models are usually grouped into two categories: psychophysical models and perceptual models. Psychophysical models link total annoyance ratings to one or several noise metrics, and perceptual models link total annoyance ratings to perceptual data, such as partial annoyance ratings (Berglund and Nilsson, 1997).

265

266 4.1 Presentation of total annoyance models from the literature

267 In the current study, 10 main total annoyance models from the literature (6 psychophysical ones and
268 4 perceptual ones) are considered. They are briefly described below using the following notations:

269 A_{Total} : total annoyance,

270 A_i : partial annoyance due to noise source i heard within the combination or its specific annoyance when
271 noise source i is heard in isolation (when the other noise sources of the combination do not emit any
272 noise),

273 L_{Total} : total noise level for the combined noises,

274 L_i : noise level for noise source i .

275

276 **Psychophysical models**

277 As these models are based on mean sound pressure levels, these variables have to explain a
278 significant part of annoyance ratings in order to make the models meaningful. This is not always the
279 case in socio-acoustic surveys dealing with noise annoyance assessment (e.g. Pierrette *et al.*, 2012a and
280 2012b).

281

282 **The energy summation model**

283 This model links total annoyance to total noise level:

$$284 A_{Total} = a L_{Total} + b \quad (1)$$

285 This equation leads to the same mathematical expression of annoyance due to each noise source,
286 whatever the noise sources considered, *i.e.* different noise sources cause the same annoyance at the same
287 noise level L . Such a result has not been validated in various field studies. For example, Miedema and
288 Oudshoorn (2001) showed that, for the same L_{den} , annoyance ratings due to road traffic, aircraft and
289 railway noises do not lead to the same relationships.

290

291 **The independent effect model**

292 This model expresses total annoyance as a function of the sound pressure level of each combined
293 noise source:

$$294 A_{Total} = \sum_{i=1}^n a_i L_i \quad (2)$$

295 Compared to the energy summation model, this model allows that changes due to one noise source
296 could influence total annoyance ratings as this model allows different noise sources to have independent
297 contributions to total annoyance. As no potential interaction effect between the combined noise sources
298 is taken into account, phenomena such as the synergistic effect will be neglected by the model.

299

300 **The energy difference model**

301 This model, established for two combined noise sources, expresses total annoyance as a function of
302 the total sound pressure level and the difference in sound pressure levels of both noise sources.

303

$$304 A_{Total} = a L_{Total} + b/L_1 - L_2 + c \quad (3)$$

305 The application of this model is thus limited to combinations of two noise sources. This model
306 proposed by Taylor (1982) corresponds to a modification of the energy summation model. The

307 difference between the two sound pressure levels has been introduced to take into account potential
 308 interaction effects between the combined noise sources. But this model leads to the same relationships
 309 between each noise source in isolation and their respective annoyance, which is not true (e.g. Miedema
 310 and Oudshoorn, 2001 for transportation noise sources).

312 **The mixed model**

313 Morel *et al.* (2012) proposed a model of total annoyance as a function of the sound pressure level of
 314 each source and the absolute value of the difference between these levels. The purpose is to take into
 315 account potential interaction effects between combined noise sources.

$$316 \quad A_{Total} = a_1 L_1 + a_2 L_2 + b|L_1 - L_2| + c \quad (4)$$

317 As for the previous model, the application of this model is limited to two combined noise sources.
 318 But contrary to the previous one, this model might lead to different relationships between each noise
 319 source and the corresponding annoyance.

321 **The quantitative model**

322 This model was proposed by Vos (1992). Annoyance depends on an overall noise index L_t . This
 323 index corresponds to the sum of a corrected sound pressure level from each source. The correction is
 324 applied in such a way that the corrected sound pressure level leads to the same annoyance due to a
 325 source of the combination chosen as a reference.

326 In the case of a combination of different noise sources, the annoyance A_i due to a source i is
 327 calculated from its sound pressure level L_i :

$$328 \quad A_i = a_i L_i + b_i \quad (5)$$

329 The annoyance due to the reference source at a sound pressure level L_{ref} is denoted by A_{ref} , and
 330 given by the following equation:

$$331 \quad A_{ref} = a_{ref} L_{ref} + b_{ref} \quad (6)$$

332 A penalty is added to the sound pressure level L_i of the source i to provide the sound pressure level
 333 of the equally annoying reference noise source. This penalty P_i , obtained by equalizing the two previous
 334 equations, is given by:

$$335 \quad P_i = \frac{b_i - b_{ref} + (a_i - a_{ref}) * L_i}{a_{ref}} \quad (7)$$

336 Such penalty P_i allows the noise from each source to be translated into the equally annoying sound
 337 pressure level of the reference source; the overall noise index L_t is then obtained by summing all sound
 338 pressure levels:

$$339 \quad L_t = k * \log \left(10^{\frac{L_{ref}}{k}} + \sum_{i=1}^n 10^{\frac{L_i + P_i}{k}} \right) \quad (8)$$

340 where k is a parameter to be adjusted, n is the number of noise sources combined with the reference
 341 source. Vos (1992) proposed to consider road traffic noise as the reference source, and found that a k
 342 value equal to 15 optimized the calculation.

344 **The annoyance equivalents model**

345

346 The annoyance equivalents model stemmed from Miedema's work (Miedema, 2004), which
 347 includes the generalization of the quantitative model.

348 From multi-level regressions applied on data from different surveys dealing with noise annoyance
 349 due to transportation noise sources, Miedema and Oudshoorn (2001) had proposed annoyance equations
 350 for each transportation noise source. These equations link the sound pressure level L (L_{den} , or L_{dn} the
 351 day-night level) of each noise source to each respondent's annoyance rating as follows:

$$352 \quad A_{ij} = \beta_0 + \beta_1 L + u_{0j} + \epsilon_{ij} \quad (9)$$

353 where i represents the respondent and j represents the survey. For survey j , the intercept is $\beta_0 + u_{0j}$. The
 354 terms u_{0j} and ϵ_{ij} are error terms which follow a normal distribution.

355 From these annoyance equations considered without the intercept term u_{0j} , Miedema (2004) set the
 356 following equations, based on L_{den} , for road traffic, railway and aircraft noises as indicated by the
 357 respective subscripts Road, Air and Rail:

$$359 \quad A_{Road} = -107,0 + 2,22 * L_{den,Road} \quad (10)$$

$$360 \quad A_{Air} = 2,17 * L_{den,Air} - 91,4 \quad (11)$$

$$361 \quad A_{Rail} = 2,10 * L_{den,Rail} - 110,1 \quad (12)$$

362 Miedema (2004) considered road traffic noise as a reference source and calculated a correction term
 363 to be applied to the sound pressure level of the other sources.

364 The railway noise level and the aircraft noise level are then corrected to simulate the level of road
 365 traffic noise that would generate the same annoyance rating:

$$366 \quad L'_{Rail} = \frac{(A_{Rail}+107,0)}{2,22} = \frac{(-3,1+2,10*L_{den,Rail})}{2,22} \quad (13)$$

$$367 \quad L'_{Air} = \frac{(A_{Air}+107,0)}{2,22} = \frac{(15,6+2,17*L_{den,Air})}{2,22} \quad (14)$$

368 The overall noise index of the annoyance equivalents model is then for road traffic noise combined
 369 with aircraft noise:

$$370 \quad L'_{Road+Air} = 10 * \log(10^{\frac{L_{den,Road}}{10}} + 10^{\frac{L'_{Air}}{10}}), \quad (15)$$

371 for road traffic noise combined with railway noise:

$$372 \quad L'_{Road+Rail} = 10 * \log(10^{\frac{L_{den,Road}}{10}} + 10^{\frac{L'_{Rail}}{10}}), \quad (16)$$

373 and for road traffic noise combined both with aircraft noise and railway noise:

$$374 \quad L'_{Road+Air+Rail} = 10 * \log(10^{\frac{L_{den,Road}}{10}} + 10^{\frac{L'_{Air}}{10}} + 10^{\frac{L'_{Rail}}{10}}). \quad (17)$$

376 Perceptual models

377 The strongest component model

378 This model considers that total annoyance due to combined noise sources is equal to the most
 379 annoying source within the combination of n noise sources (Berglund *et al.*, 1981):

$$380 \quad A_{Total} = \max_{i=1,n}(A_i) \quad (18)$$

381 This perceptual model is generally known to lead to a good calculation of total annoyance (*e.g.*
 382 Botteldooren and Verkeyn, 2002; Pierrette *et al.* 2012a and 2012b). But some studies reported a weak

383 quality (cf. Gille *et al.* 2019; Lechner *et al.* 2019). Due to its mathematical formulation, it is not able to
384 account for perceptual mechanisms such as synergistic effect.

385 Considering the perceptual mechanisms highlighted in the studied field data, we may expect a good
386 correlation between annoyance calculated from this model and the measured total annoyance.

388 **The linear regression model**

389 The total annoyance is expressed as a weighted sum of the annoyance due to each combined noise
390 source i :

$$391 \quad A_{Total} = \sum_i w_i A_i \quad (19)$$

392 where w_i is the weighting applied to the annoyance due to each source i . This model is a perceptual form
393 of the independent effect model previously presented. According to Berglund and Nilsson (2000), the
394 weighting w_i can be explained by the time of appearance of the source. However, (Botteldooren and
395 Verkeyn, 2002) pointed out that this explanation of the weighting by the duration of noise occurrence is
396 not valid for all sources. Botteldooren and Verkeyn (2002) found that this model was a less effective
397 predictor than the strongest component model.

398 However, the weighted coefficients of annoyance due to each noise source are interesting as the weights
399 can highlight the relative influence of each noise source to total annoyance. This can not be pointed out
400 by the strongest component model.

402 **The mixed model**

403 This model is limited to two combined noise source situations. It is based on the principle of the
404 previous model and considers in addition an interaction term:

$$405 \quad A_{Total} = a_1 A_1 + a_2 A_2 + b/A_1 - A_2 + c \quad (20)$$

406 This model is a perceptual form of the mixed model previously presented among the
407 psychophysical models. This perceptual model assumes that people are able to separately identify and
408 assess the different noise sources in their environment. Their assessment is adjusted according to which
409 noise source appears to be more annoying. As the linear regression model, the mixed model may allow
410 different contributions of annoyance due to each noise source to the total annoyance to be taken into
411 account. The potential theoretical improvement compared to the linear regression and the strongest
412 component models lies in the interaction term which may allow perceptual mechanisms to be accounted
413 for. Pierrette *et al.* (2012a and 2012b) showed a significant interaction term in a combined road traffic
414 and industrial noise exposure where mean total annoyance ratings were equal to mean road traffic noise
415 annoyance ratings (average over all respondents). The significant interaction term was explained by the
416 fact that nearly one third of the respondents judged the soft permanent industrial noise as annoying as
417 the loud intermittent road traffic noise. Contrary to the perceptual mixed model, the strongest
418 component model was not able to account for the point of view of one third of the respondents.

420 **The vector summation model**

421 As the previous one, this model is limited to the case of two combined noise sources. It is
422 calculated using annoyance due to each noise source within the combination, and an interaction term,
423 denoted by α_{12} :

$$424 \quad A_{Total} = \sqrt{A_1^2 + A_2^2 + 2 * A_1 * A_2 \cos(\alpha_{12})} \quad (21)$$

425 By iteration, Berglund *et al.* (1981) found that the model better predicted total annoyance when the
426 term α_{12} is 90° , i.e. when the interaction term is zero, despite a slight overestimation of annoyance by
427 the model (*cf.* Botteldooren and Verkeyn, 2002).

428 In order to determine the angle α_{12} which optimizes the calculation of total annoyance, Morel
429 (2012) proposed to calculate a value of α_o from each triplet of ratings of each respondent (A_1, A_2, A_{Total}),
430 and then to average all values of α_o over the respondents. The formula for α_o is as follows:

$$431 \quad \alpha_o = \cos^{-1}\left(\frac{A_{Total}^2 - (A_1^2 + A_2^2)}{2A_1A_2}\right) \quad (22)$$

432 Thus, the interaction term has to be determined for every new combined noise study, in order to
433 improve the performance of this model. However, given the absence of weightings for annoyance due to
434 each noise source, the model does not allow different contributions of each noise source to total
435 annoyance to be taken into account.

437 4.2 Relevance of total annoyance models

438 The relevance of the total noise annoyance models was investigated using data from the French
439 survey.

440 Linear regression analyses were carried out by fitting each model to the survey data. The regression
441 analyses used respondents' total annoyance ratings, L_{den} values defining their noise exposure or their
442 partial annoyance ratings from the French survey. Results of the different regression analyses are
443 displayed in the three following tables (Tables 3 to 5). In particular, results for the total noise annoyance
444 models considered for the combination of road traffic noise and aircraft noise are displayed in Table 3,
445 for the combination of road traffic noise combined with railway noise in Table 4, and for the
446 combination of the three transportation noise sources (road traffic, railway and aircraft noises) in Table
447 5.

448 The sample size of the survey data is not big enough to use the equations displayed in these tables
449 in further studies. The purpose of showing them is rather to highlight the fact that some coefficients of
450 the obtained regressions may be not statistically significant, and thus the corresponding variables appear
451 to be not relevant to be considered in total annoyance models. Such information is useful for further
452 research works.

453 In all three tables, significant regression coefficients ($p < 0.05$) are indicated using a superscript. The
454 adjusted coefficient of determination $R^2_{adjusted}$ resulting from the fit of each model to the measured data
455 is given. In addition, a correlation analysis between the total annoyance ratings calculated by each
456 model and the measured total annoyance ratings is also given, with the correlation coefficient, and the
457 intercept and slope of the corresponding regression line, for further indications on the model
458 performances: a perfect calculation by a model would lead to values of the intercept, slope, correlation
459 coefficient respectively equal to 0, 1 and 1, *i.e.* all the dots would be perfectly lined up on the bisector of
460 the plan. For the quantitative and annoyance equivalents models, the fitting was applied between the
461 overall noise index and the measured total annoyance ratings. This was carried out as an attempt of
462 improving the goodness-of-fit of these two models. For the vector summation model, the angle is
463 optimized according to the procedure described in (Morel, 2012). The obtained angle value is given in
464 each of the three tables.

465 For the different combined transportation noise situations under study, perceptual total annoyance
466 models lead to better results ($R^2_{adjusted}$ greater than 0.7 for two combined noise exposures, and greater
467 than 0.5 for the three combined transportation noise exposure) compared to psychophysical total
468 annoyance models ($R^2_{adjusted}$ generally below 0.1).

Table 3. Total annoyance models for combined road traffic and aircraft noises. A_{Road} : road traffic noise annoyance; A_{Air} : aircraft noise annoyance; A_{Total} : total annoyance. $L_{den, Total}$: total L_{den} ; $L_{den, Road}$: L_{den} for road traffic noise; $L_{den, Air}$: L_{den} for aircraft noise; $R^2_{adjusted}$: the adjusted determination coefficient; Intercept, slope and correlation coefficient linked to the regression between measured and calculated total annoyances; L_t : overall noise index for the quantitative and annoyance equivalents models; k : parameter in the quantitative model; α : angle in the vector summation model; a : $p < 0.05$.

<i>Psychophysical model</i>	<i>Equation</i>	$R^2_{adjusted}$	<i>Intercept</i>	<i>Slope</i>	<i>correlation</i>
Energy summation	$A_{Total} = 0,097^a * L_{den, Total} - 0,883$	0,028 ^a	4,648 ^a	0,032 ^a	0,180 ^a
Independent effects	$A_{Total} = 0,047 * L_{den, Road} + 0,139^a * L_{den, Air} - 4,121$	0,085 ^a	4,404 ^a	0,094 ^a	0,307 ^a
Energy difference	$A_{Total} = 0,184^a * L_{den, Total} - 0,126^a * L_{den, Road} - L_{den, Air} - 4,260$	0,090 ^a	4,368 ^a	0,099 ^a	0,315 ^a
Mixed	$A_{Total} = 0,047 * L_{den, Road} + 0,139^a * L_{den, Air} - 4,121 + 0,001 * L_{den, Road} - L_{den, Air} $	0,085 ^a	4,404 ^a	0,094 ^a	0,307 ^a
Quantitative	$A_{Road} = 0,111^a * L_{den, Road} - 2,012$; $R^2_{adjusted} = 0,043^a$	$A_{Air} = 0,209^a * L_{den, Air} - 5,098^a$; $R^2_{adjusted} = 0,152^a$			
	$k=15: A_{Total} = 0,117^a * L_t - 2,620$	0,095 ^a	4,318 ^a	0,099 ^a	0,315 ^a
	$k=10: A_{Total} = 0,113^a * L_t - 2,236$	0,097 ^a	4,320 ^a	0,101 ^a	0,318 ^a
Annoyance equivalents	$A_{Total} = 0,123^a * L_t - 2,475$	0,045 ^a	4,595 ^a	0,050 ^a	0,223 ^a
<i>Perceptual model</i>	<i>Equation</i>	$R^2_{adjusted}$	<i>Intercept</i>	<i>Slope</i>	<i>correlation</i>
Strongest component	$A_{Total} = 0.840^a * \max(A_{Road}; A_{Air}) + 1.194^a$	0,754 ^a	0,194 ^a	0,840 ^a	0,869 ^a
Linear regression	$A_{Total} = 0,521^a * A_{Road} + 0,482^a * A_{Air} + 0,412^a$	0,760 ^a	1,145 ^a	0,762 ^a	0,873 ^a
Mixed	$A_{Total} = 0,491^a * A_{Road} + 0,497^a * A_{Air} + 0,220^a * A_{Road} - A_{Air} + 0,105$	0,784 ^a	1,025 ^a	0,787 ^a	0,887 ^a
Vector summation	$A_{Total} = \sqrt{A_{Road}^2 + A_{Air}^2 + 2 * A_{Road} * A_{Air} * \cos(\alpha)}$ $\alpha = 115,3^\circ$	0,775 ^a	1,091 ^a	0,835 ^a	0,881 ^a

Table 4. Total annoyance model for combined road traffic and railway noises. A_{Road} : road traffic noise annoyance; A_{Rail} : railway noise annoyance; A_{Total} : total annoyance. $L_{den, Total}$: total L_{den} ; $L_{den, Road}$: L_{den} for road traffic noise; $L_{den, Rail}$: L_{den} for railway noise; $R^2_{adjusted}$: the adjusted determination coefficient; Intercept, slope and correlation coefficient linked to the regression between measured and calculated total annoyances; L_t : overall noise index; k : parameter; α : angle; a : $p < 0.05$.

<i>Psychophysical model</i>	<i>Equation</i>	$R^2_{adjusted}$	<i>Intercept</i>	<i>Slope</i>	<i>correlation</i>
Energy summation	$A_{Total} = 0,147^a * L_{den, Total} - 5,162^a$	0,062 ^a	5,005 ^a	0,065 ^a	0,256 ^a
Independent effects	$A_{Total} = 0,134^a * L_{den, Road} + 0,017 * L_{den, Rail} - 5,042^a$	0,065 ^a	4,979 ^a	0,071 ^a	0,267 ^a
Energy difference	$A_{Total} = 0,143^a * L_{den, Total} + 0,032 * L_{den, Road} - L_{den, Rail} - 5,123^a$	0,065 ^a	4,970 ^a	0,071 ^a	0,267 ^a
Mixed	$A_{Total} = 0,086^a * L_{den, Road} + 0,072^a * L_{den, Rail} + 0,082^a * L_{den, Road} - L_{den, Rail} - 5,881^a$	0,076 ^a	4,849 ^a	0,084 ^a	0,291 ^a
Quantitative	$A_{Road} = 0,155^a * L_{den, Road} - 5,933^a$; $R^2_{adjusted} = 0,088^a$	$A_{Rail} = 0,119^a * L_{den, Rail} - 3,455^a$; $R^2_{adjusted} = 0,089^a$			
	$k=15: A_{Total} = 0,199^a * L_t - 9,307^a$	0,105 ^a	4,788 ^a	0,108 ^a	0,329 ^a
	$k=10: A_{Total} = 0,198^a * L_t - 8,927^a$	0,105 ^a	4,803 ^a	0,108 ^a	0,328 ^a
Annoyance equivalents	$A_{Total} = 0,156^a * L_t - 5,598^a$	0,070 ^a	4,997 ^a	0,074 ^a	0,271 ^a
<i>Perceptual model</i>	<i>Equation</i>	$R^2_{adjusted}$	<i>Intercept</i>	<i>Slope</i>	<i>correlation</i>
Strongest component	$A_{Total} = 0,884^a * \max(A_{Road}; A_{Rail}) + 0,769^a$	0,843 ^a	0,769 ^a	0,885 ^a	0,918 ^a
Linear regression	$A_{Total} = 0,562^a * A_{Road} + 0,422^a * A_{Rail} + 0,923^a$	0,736 ^a	1,405 ^a	0,738 ^a	0,859 ^a
Mixed	$A_{Total} = 0,455^a * A_{Road} + 0,513^a * A_{Rail} + 0,436^a * A_{Road} - A_{Rail} + 0,152$	0,844 ^a	0,829 ^a	0,846 ^a	0,919 ^a
Vector summation	$A_{Total} = \sqrt{A_{Road}^2 + A_{Rail}^2 + 2 * A_{Road} * A_{Rail} * \cos(\alpha)}$ $\alpha = 112,8^\circ$	0,842 ^a	0,743 ^a	0,891 ^a	0,918 ^a

Table 5. Total annoyance model for combined road traffic, railway and aircraft noises. A_{Road} : road traffic noise annoyance; A_{Air} : aircraft noise annoyance; A_{Rail} : railway noise annoyance; A_{Total} : total annoyance. $L_{den, Total}$: total L_{den} ; $L_{den, Road}$: L_{den} for road traffic noise; $L_{den, Air}$: L_{den} for aircraft noise; ; $L_{den, Rail}$: L_{den} for railway noise ; $R^2_{adjusted}$: the adjusted determination coefficient; Intercept, slope and correlation coefficient linked to the regression between measured and the calculated total annoyances; L_t : overall noise index for the quantitative and annoyance equivalents models; k : parameter in the quantitative model; α : angle in the vector summation model; a : $p < 0.05$.

<i>Psychophysical model</i>	<i>Equation</i>	$R^2_{adjusted}$	<i>Intercept</i>	<i>Slope</i>	<i>correlation</i>
Energy summation	$A_{Total} = 0,003 * L_{den, Total} + 6,389^a$	<0,001	6,581 ^a	<0,001	0,008
Independent effects	$A_{Total} = 0,017 * L_{den, Road} + 0,112^a * L_{den, Air} - 0,045 * L_{den, Rail} + 1,736$	0,085 ^a	5,878 ^a	0,100 ^a	0,315 ^a
Quantitative	$A_{Road} = 0,057^a * L_{den, Road} + 1,867 ; R^2_{adjusted} = 0,041^a$				
	$A_{Rail} = 0,067^a * L_{den, Rail} + 0,246 ; R^2_{adjusted} = 0,039^a$	$A_{Air} = 0,109^a * L_{den, Air} + 0,446 ; R^2_{adjusted} = 0,067^a$			
	$k=10: A_{Total} = 0,061 * L_t + 1,523$	<0,001	6,589 ^a	<0,001	0,021
	$k=15: A_{Total} = 0,062 * L_t + 1,396$	<0,001	6,584 ^a	<0,001	0,029
Annoyance equivalents	$A_{Total} = 0,056 * L_t + 2,876$	0,017	6,447 ^a	0,018	0,133
<i>Perceptual model</i>	<i>Equation</i>	$R^2_{adjusted}$	<i>Intercept</i>	<i>Slope</i>	<i>correlation</i>
Strongest component	$A_{Total} = 0,860^a * \max(A_{Road} ; A_{Air} ; A_{Rail}) + 0,487$	0,594 ^a	2,533 ^a	0,691 ^a	0,771 ^a
Linear regression	$A_{Total} = 0,594^a * A_{Air} + 0,275^a * A_{Road} - 0,006 * A_{Rail} + 1,241^a$	0,566 ^a	2,808 ^a	0,573 ^a	0,757 ^a

469 Looking into the details in each of these 3 tables, it appears that energy summation is
470 the worst of the psychophysical models. The annoyance equivalents model has no
471 significant coefficients to describe total annoyance due to three combined transportation
472 noise exposure.

473 As expected from the analysis on perceptual mechanisms associated with total
474 annoyance judgments (*cf.* section 3), the strongest component model provided a good
475 calculation of total annoyance for all the studied combined transportation noise exposures.
476 This model generally accounts well for total annoyance felt by people. This is in agreement
477 with t-tests analyses carried out in section 3 between total annoyance ratings and the
478 maximum partial annoyance ratings.

479 All the variables of the perceptual linear regression and mixed models were comprised
480 between 0 and 10. Their associated coefficients thus allowed contributions of each variable
481 to total annoyance to be considered. These two perceptual models gave interesting
482 information on the contribution of each partial annoyance to total annoyance for the
483 combined transportation noise exposures studied.

484 In the case of combined road traffic and aircraft noise exposure, partial road traffic
485 noise annoyance and partial aircraft noise annoyance nearly equally contributed to total
486 annoyance within the perceptual linear and mixed models. The mixed model indicated a
487 significant interaction term between the two partial annoyances. This term moderately
488 contributed to total annoyance compared to each partial annoyance. The relevance of this
489 interaction term is also observed in the vector summation model with an optimized angle
490 different from 90°. Thus the strongest component model highlighted the main trend: total
491 annoyance equalized the maximum partial annoyance which might be road traffic noise
492 annoyance or aircraft noise annoyance depending on the noise exposure level of the noise
493 sources. The linear regression and mixed models highlighted in details contributions of each
494 partial annoyance to total annoyance. The relative contributions of each partial annoyance
495 and the interaction term might be explained by the fact that the 212 respondents exposed to
496 aircraft and road traffic noises had different feelings regarding each noise source within the
497 combined exposure: 55% of them quite agreed or agreed with the item “road traffic noise
498 alone would be bearable” and 40% of them quite agreed or agreed with the item “aircraft
499 noise alone would be bearable”. Thus with a good adjustment quality of model (*e.g.*
500 adjusted determination coefficient values), the linear regression and the mixed models are
501 able to give more information compared to the strongest component model.

502 In the case of the combined road traffic and railway noise exposure, the interaction term
503 of the mixed model between partial road traffic noise annoyance and partial railway noise
504 annoyance was significant and nearly equally contributed to total annoyance in comparison
505 with partial annoyances. The relevance of the interaction term was also observed within the
506 vector summation model with an optimized angle different from 90°. These close
507 contributions of variables indicated by the linear regression and mixed models might be
508 explained by the fact that among the 301 respondents 43% of them quite agreed or agreed
509 with the item “road traffic noise alone would be bearable” and 53% of them quite agreed or
510 agreed with the item “railway noise alone would be bearable”.

511 In the case of the exposure to the three combined transportation noises under study,
512 partial railway noise annoyance did not contribute to total annoyance within the perceptual
513 linear regression model as its coefficient was non-significant. Partial aircraft noise
514 annoyance appeared to contribute more than partial road traffic noise annoyance to total
515 annoyance. These respective contributions of partial annoyances to total annoyance might
516 be explained by feelings expressed by the 189 respondents: 63% of them quite agreed or
517 agreed with the item “railway noise alone would be bearable”, 60% of them quite agreed or
518 agreed with the item “road traffic noise alone would be bearable”, and only 22% of them
519 quite agreed or agreed with the item “aircraft noise alone would be bearable”.

520 5. Discussion

521
522 The analysis of potential perceptual mechanisms related to total annoyance judgments
523 revealed that total annoyance ratings did not in general differ from the maximum partial
524 annoyance ratings. This was mainly observed for the different combined transportation
525 noise source situations under study during the French socio-acoustic survey. This result is in
526 agreement with literature findings dealing with combined transportation noise sources (*e.g.*
527 Wothge *et al.*, 2017). Due to this effect, the strongest component model led to a good
528 calculation of total annoyance.

529 For all the studied combined transportation noise exposures in the current work, the
530 studied psychophysical total annoyance models based on L_{den} led to poor adjustment quality
531 of total annoyance. The perceptual total annoyance models led to a better calculation of total
532 annoyance. Such results agreed with literature findings on psychophysical total annoyance
533 model assessment, for example Nguyen *et al.* (2012) for combined road traffic and aircraft
534 noise exposure in Ho Chi Minh City and Hanoi, and Pierrette *et al.* (2012a and 2012b) for
535 combined road traffic and industrial noise exposure in Lyon suburbs. Their respective
536 findings showed that the strongest component model better calculated total annoyance.
537 Lechner *et al.* (2019) obtained comparable results between 55 and 65 dB in the Alpine
538 valleys. This range corresponded to the highest category of sound pressure level for the
539 three combined transportation noise source situations they studied in Innsbrück. By
540 considering the whole range of noise exposure in Innsbrück (from 35 up to 65dB), they
541 highlighted an annoyance equivalents model, based on quadratic functions rather than linear
542 regressions, with better results than the strongest component model. These different results
543 highlighted the difficulty of defining a unique total annoyance model, and the need for more
544 studies dealing with various combined noise situations and comparisons of existing total
545 annoyance models.

546 In the current study, the other perceptual models, such as the linear regression, mixed
547 and vector summation models, which consider partial annoyances and even potential
548 interaction term as variables, gave an equally good or better calculation of total annoyance
549 than the strongest component model. Specifically, the perceptual mixed model gave good
550 results with interesting information on the relative contributions of partial annoyances and
551 interaction term to total annoyance. The highlighted contributions were explained by
552 feelings expressed by respondents about each noise source within the combination. This is

553 in agreement with Pierrette *et al.* (2012a and 2012b) dealing with road traffic noise
554 combined with a permanent industrial noise. They pointed out the good quality of the
555 strongest component model to account for the dominant source effect due to road traffic
556 noise.

557 Moreover, the perceptual mixed model enables a good calculation of total annoyance
558 and highlights contributions of each partial annoyance and of the interaction term. This term
559 accounts for the fact that one third of respondents found the soft industrial noise as annoying
560 as the dominant road traffic noise because the permanent industrial noise was still present
561 when the road traffic was low.

562 A specific attention to the combined road traffic and railway noise source situations
563 highlighted no significant differences between the two partial annoyance ratings when the
564 two transportation noise exposures were at identical L_{den} values. This result thus indicated
565 no railway bonus, such as the bonus of 5 dB which has been applied to railway noise in
566 various European Union countries (*e.g.* France, Germany, Switzerland). This result
567 contradicts the railway bonus identified in previous studies (*e.g.* Miedema and Oudshoorn,
568 2001), and corroborates more recent findings from the literature showing no rail bonus in
569 some European countries and Asian countries (*e.g.* Öhrström *et al.*, 2007; Lam *et al.*, 2009;
570 Lechner *et al.*, 2019; Brink *et al.*, 2019). For example in a Swiss survey, Brink *et al.* (2019)
571 highlighted no railway bonus effect on the percentage of highly annoyed (%HA) Swiss
572 people when L_{den} from railway traffic was above 45 dB(A) despite the well-known railway-
573 friendliness in Switzerland.

574 For the situation where all three combined transportation noise sources were studied,
575 people expressed more negative feelings towards aircraft noise exposure close to Orly
576 airport than towards higher sound pressure levels from railway and road traffic noises. Total
577 annoyance was better calculated by perceptual models, the strongest component model and
578 linear model. This latter highlighted a stronger contribution of aircraft noise annoyance to
579 total annoyance than road traffic noise annoyance, and no contribution of railway noise
580 annoyance. Such results for combined transportation noise sources were also observed in the
581 vicinity of the Frankfurt airport by Wothge *et al.* (2017) who noticed the main contribution
582 of aircraft noise and a minor contribution of the second transportation noise source (road
583 traffic or railway noise) within the combination.

584 The current study has shown that perceptual total annoyance models better performed
585 than psychophysical ones to estimate total annoyance. In particular, the linear regression
586 model and the mixed model fitted well to the feelings expressed by people towards each
587 noise source within the combination. Such results were obtained for the different combined
588 transportation noise source situations in French cities (combined road traffic and aircraft
589 noises, combined road traffic and railway noises, road traffic noise combined with both
590 aircraft and railway noises). Klein *et al.* (2017), from laboratory data of combined road
591 traffic and tramway noises, and also Gille and Marquis-Favre (2019), from field data of
592 combined aircraft and road traffic noises, have shown that applying such perceptual models
593 on predicted partial annoyances rather than measured partial annoyances allowed total
594 annoyance to be better predicted in comparison with psychophysical models based on L_{den} .
595 This constitutes highly interesting perspectives.

596 Furthermore, the current study highlighted that 70% of the survey respondents declared
597 themselves to be sensitive or very sensitive to noise. This was in agreement with Lechner
598 and Schnaiter's results obtained from a sample of 545 inhabitants of the Alpine valleys
599 (Lechner and Schnaiter, 2019). This was also in agreement with the structural equation
600 analysis carried out on the data of this French survey; the analysis highlighted the great
601 contribution of noise sensitivity to annoyance models (e.g. Gille *et al.*, 2017).

602 Relevant perspectives would be to consider the benefit of taking into account noise
603 sensitivity both in predicted partial annoyance models, and in predicted perceptual total
604 annoyance models using predicted partial annoyance values as variables (cf. Gille and
605 Marquis-Favre, 2019). Actually, it would be interesting in further works to test, for different
606 population samples and combined noise situations, perceptual total annoyance models based
607 on partial annoyance values predicted from models using noise sensitivity. If such testing
608 confirms enhancement of total annoyance prediction for different combined noise situations,
609 it might have interesting perspectives for regulatory applications.

610 **6. Conclusion**

611 Total annoyance prediction is still a complex scientific problem to be addressed. As a
612 consequence, there is a lack of national regulations. More endeavors on this topic are thus
613 needed. Although different total annoyance models exist in the literature, they were very
614 rarely assessed using field annoyance data. The current work aims to compare them using
615 data of annoyance due to different French urban situations of two, or three, combined
616 transportation noise sources. The noises under consideration were road traffic, railway and
617 aircraft noises. Appraisal of main total annoyance models highlighted those able to account
618 for combined transportation noise annoyance in cities. Perceptual total annoyance models,
619 based on annoyance due to each transportation noise source, better performed total
620 annoyance estimation than psychophysical total annoyance models based on the L_{den} index.
621 The dominant source effect mainly explained total annoyance judgments from French
622 people exposed to combined noises. For that reason, the strongest component model led to a
623 good calculation of mean total annoyance ratings. But perceptual models, such as the linear
624 regression and mixed models, better explained total annoyance judgments from residents as
625 they account well for the feeling expressed by people towards each combined noise source.
626 More investigations are needed, in particular to assess whether applying such perceptual
627 models on predicted partial annoyances rather than measured partial annoyances might be
628 successful, as it has been highlighted in the literature for some combined noise situations.

629

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