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Testing of the European Union exposure-response relationships and annoyance equivalents model for annoyance due to transportation noises: The need of revised exposure-response relationships and annoyance equivalents model

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ABSTRACT

An *in situ* survey was performed in 8 French cities in 2012 to study the annoyance due to combined transportation noises. As the European Commission recommends to use the exposure–response relationships suggested by Miedema and Oudshoorn [Environmental Health Perspective, 2001] to predict annoyance due to single transportation noise, these exposure–response relationships were tested using the annoyance due to each transportation noise measured during the French survey. These relationships only enabled a good prediction in terms of the percentages of people highly annoyed by road traffic noise. For the percentages of people annoyed and a little annoyed by road traffic noise, the quality of prediction is weak. For aircraft and railway noises, prediction of annoyance is not satisfactory either. As a consequence, the annoyance equivalents model of Miedema [The Journal of the Acoustical Society of America, 2004], based on these exposure-response relationships did not enable a good prediction of annoyance due to combined transportation noises. Local exposure-response relationships were derived, following the whole computation suggested by Miedema and Oudshoorn [Environmental Health Perspective, 2001]. They led to a better calculation of annoyance due to each transportation noise in the French cities. A new version of the annoyance equivalents model was proposed using these new exposure-response relationships. This model enabled a better prediction of the total annoyance due to the combined transportation noises. These results encourage therefore to improve the annoyance prediction for noise in isolation with local or revised exposure-response relationships, which will also contribute to improve annoyance modeling for combined noises. With this aim in mind, a methodology is proposed to consider noise sensitivity in exposure-response relationships and in the annoyance equivalents model. The results showed that taking into account such variable did not enable to enhance both exposure-response relationships and the annoyance equivalents model.

1. Introduction

Environmental noise exposure is a major source of concern for European inhabitants (*e.g.* IFOP, 2014) due to urbanization and to the economic and the traffic intensity growth. In order to manage the environmental noise, the European Directive 2002/49/EC (Parlement Européen Et Conseil Européen, 2002) requires the European cities with more than 100,000 inhabitants to produce strategic noise maps for the transportation noises and the industrial sites. These maps characterize noise exposure using the energy-based index L_{den} — the day-evening-night level.

The European Commission (2002) recommends to use Miedema and Oudshoorn's exposure-response relationships (Miedema and Oudshoorn, 2001) to estimate annoyance due to transportation noises. These relationships link the percentages of highly annoyed, annoyed and a little annoyed people to the L_{den} noise index. Furthermore, the World Health Organization WHO (2011) used these exposure-response relationships and the strategic noise maps to estimate the number of Disability-Adjusted Life Years (DALYs) due to noise annoyance. In urban population of western European countries, it was thus estimated that 0.5 million DALYs are lost yearly due to the occurrence of noise annoyance (World Health Organization, 2011).

However, several studies showed that the European Union (E.U.) exposure-response relationships, suggested by Miedema and Oudshoorn (2001), did not enable a good prediction of annoyance

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measured during newer noise annoyance surveys: for example, Klæboe et al. (2004), for road traffic, Lim et al. (2006), for railway, and Lim et al. (2007), for aircraft, found that the E.U. exposure-response relationships underestimated the percentages of people highly annoyed measured through their surveys. On the contrary, for road traffic, Phan et al. (2010) and Birk et al. (2011) found that the E.U. exposure-response relationships overestimated the percentages of people highly annoyed measured through their surveys. Taking into account the fact that annoyance seems to increase over the years (*e.g.* for aircraft noise Janssen et al., 2011), it would be therefore a benefit to consider local or revised exposure-response relationships for the estimation of the number of lost DALYs.

Furthermore, because of the increasing densities of both population and of transportation networks in urban areas, numerous European citizens are exposed to combined noises. Noise annoyance due to combined noises yet remains difficult to characterize and to predict: some interaction effects occur, such as synergy effect (total noise annoyance due to combined noise exposure is higher than the maximum noise annoyance due to the single noises), resulting from a difficult characterization and a difficult prediction of total annoyance due to combined noises. Considering these difficulties, there is no consensus for a total annoyance model within the scientific community, leading to a regulatory gap for combined exposure management. For example, the strategic noise maps are established for each noise source but no noise maps are planned by the Directive 2002/49/EC to account for combined noise exposure.

Using the exposure-response relationships of Miedema and Oudshoorn (2001), Miedema (2004) suggested the annoyance equivalents model, which hence enables the estimation of total annoyance due to combined noise exposures, in terms of percentages of highly annoyed, annoyed and a little annoyed people. It would be interesting to test this model with total annoyance measured within a survey, as this total annoyance model is based on the exposure-response relationships which are recommended by the European Commission (2002) and used by the WHO (2011).

Considering this lack of knowledge for the prediction of annoyance due to combined transportation noises, the French Ministry of Ecology funded in 2012 an *in situ* socio-acoustic survey to study the annoyance due to combined noise exposures (Ecotière et al., 2014). Both annoyance due to noises in isolation and annoyance due to combined noises were measured. After Section 2 dedicated to the presentation of the survey methodology, the survey data are used in Section 3 to study the annoyance due to the transportation noises separately. The computation of the exposure-response relationships of Miedema and Oudshoorn (2001) is presented (Section 3.1). Then, the percentages predicted by these relationships are compared with the measured data and second, new exposure-response relationships are derived using the measured data and by following the computation suggested by Miedema and Oudshoorn (2001). In Section 4, the combined exposures are studied. The annoyance equivalents model is presented (Section 4.1). Then, the annoyance equivalents model is tested (Section 4.2), first using the exposure-response relationships of Miedema and Oudshoorn (2001), second using the new exposure-response relationships, established in Section 3.

2. Survey methodology

In 2012, a socio-acoustic survey was funded by the French Ministry of Ecology in order to study the annoyance due to combined transportation noise (*i.e.* road traffic noise combined with railway traffic noise, road traffic noise combined with aircraft noise, railway traffic noise combined with aircraft noise, road traffic noise combined with both railway traffic and aircraft noises).

The survey carried out by Ecotière et al. (2014) was performed in 8 French cities. Only people aged between 18 and 80 years old and living permanently in the dwelling since at least one year were face-to-face interviewed. The questions were in French language.

The questionnaire (Ecotière et al., 2014) was composed of questions concerning:

- the neighborhood, the living environment, the habitation;
- the global environment;
- the noise from the different studied noise sources, considered separately (*i.e.* road traffic, railway traffic and aircraft noises, depending on the cities the respondent lived in);
- the overall noise resulting from the combined sources (*i.e.* road traffic noise combined with railway traffic noise, road traffic noise combined with aircraft noise, railway traffic noise combined with aircraft noise, road traffic noise combined with both railway traffic and aircraft noises);
- and the non-acoustical factors related to the respondent (*e.g.* the noise sensitivity on a continuous scale from 0 to 10 with two labels at both ends ("not at all" and "extremely")).

The questions the noise annoyance complied with the recommendations provided by the ISO 15666 standard (ISO, 2003). Respondents were asked to give an annoyance rating on a continuous scale from "0" to "10", with 11 evenly spaced numerical labels and two verbal labels at both ends ("*not at all*" and "*extremely*"). The question and the scale concerning the noise sensitivity were built on the same format, as the ones used for annoyance.

The exposure of each respondent was determined using the strategic noise maps, available in 2012 for the studied cities. The strategic noise maps were calculated by technical services under contract with the French government, following the guidelines given by the European Directive 2002/49/CE (European Commission, 2002). In particular, the noise maps are established for each noise source in isolation and may display the noise exposure in terms of the L_{den} index, that is to say, for an average day. The database containing the survey responses and the L_{den} index gathered from the strategic noise maps of each transportation noise source enabled the data of 823 respondents to be used in the current study.

3. Exposure-response relationships for each transportation noise source in isolation

In this section, the exposure-response relationships for annoyance due to each transportation noise source will be studied. First, the computation performed by Miedema and Oudshoorn (2001) to suggest exposure-response relationships for each transportation noise source is presented, for its application to the French survey data. Then, the relationships suggested by Miedema and Oudshoorn (2001) and recommended by the European Commission are tested in terms of percentages of highly annoyed (%HA), annoyed (%A) and a little annoyed (%LA) people using measured annoyance. Finally, new exposure-response relationships are computed following Miedema and Oudshoorn's computation (Miedema and Oudshoorn, 2001) and using the survey data: these new relationships are then compared with the measured %HA, %A and %LA people.

3.1. Computation of exposure-response relationships according to Miedema and Oudshoorn (2001)

The computation suggested by Miedema and Oudshoorn (2001) as applied to our survey is presented, in order to use it to compute new exposure-response relationships using the data of the survey.

Annoyance is modeled using a multilevel regression model. The respondent *i* lived in the city *j*. The first level of the multilevel regression