Influence of temporal structure of the sonic environment on annoyance

A. Bockstael[1], B. De Coensel[1], P. Lercher[2], D. Botteldooren[1]

[1] Ghent University, Department of Information technology, Acoustics Research Group, Gent, Belgium. {annelies.bockstael, bert.decoensel, dick.botteldooren}@intec.ugent.be

[2] Medical University of Innsbruck, Department of Hygiene, Microbiology & Social Medicine, Division of Social Medicine, Innsbruck, Austria. Peter.Lercher@i-med.ac.at

INTRODUCTION

The relationship between environmental noise exposure and annoyance has been well-investigated and well-documented, insofar that the European Commission includes estimated annoyance as an evaluation measure for the impact of noise exposure (2002-49-EC). Although exposure-effect relationships for different sources have been generally accepted, the uncertainty in these models remains substantial (Marquis-Favre et al. 2005; Fields et al. 2000) for example have calculated that the response between communities differs on average by the equivalent of about 7 dB in noise exposure. One major issue here is the contribution of non-acoustical factors (Fields 1993) and another the uncertainty of the exposure modeling method (Lercher et al. 2008b).

In addition, current exposure indicators are overall, average measures like L_{den}. Nevertheless, sound perception does not only depend on overall sound pressure levels, but also on the temporal structure of the sound and on subject's attention (Botteldooren et al. 2008; De Coensel et al. 2009). Because annoyance is related to perception, including those temporal aspects might improve noise annoyance models. It could be hypothesized that the established source dependence of reported annoyance (Miedema & Oudshoorn 2001) might be (partially) explained by differences in noise variation over time. In addition, people's activity patterns do not only introduce fluctuation in attention and—connected with this—noise perception, being at home or not also directly determines the A-weighted equivalent noise level people are exposed to in their home environment. In this, the negative effects of sleep-disturbance have been well-established (Miedema & Vos 2007), but noise exposure during awake periods could be equally important as it interferes with behavior (like communication and concentrated activity) or a desired state (like relaxation) (Miedema 2007).

Two major research topics are currently investigated, namely the possibility to capture the influence of the traffic noise source on annoyance by taking into account the temporal structure of the sound and the subject's attention, and possible model improvement by accounting for activity and time spend at home. Annoyance data are collected from a large-scale questionnaire conducted in North and South Tyrol. For each participant's dwelling, noise data are calculated using noise mapping and detailed traffic models. Additionally, the previously developed notice-event model (De Coensel et al. 2009) is applied, taking into account activity patterns from Austrian inhabitants and simulated sound pressure level time series.

MATERIAL AND METHODS

Reported annoyance

In 2004, a face-to-face survey was carried out in the framework of the BBT (Brenner Base Tunnel) study conducted in North and South Tyrol for 2,070 volunteers. More details about data collections can be found in Lercher et al. (2008a). Noise annoyance was measured on an 11-point scale (compliant with ICBEN and ISO standards) by asking (in German) 'How much are you annoyed/disturbed during the past 12 months in your home or on your property' separately for highway, main road and railway.

Noise exposure

Estimating the time-varying sound level at the dwelling façade of each survey participant caused by transportation noise, ideally involves simulating the dynamic behavior of all vehicles/trains on the surrounding roads/tracks, coupled with a detailed modeling of sound propagation (De Coensel et al. 2005). For a large number of survey locations, this approach becomes unfeasible because of computational complexity. Instead, a simplified two-stage estimation procedure is followed here. Firstly, time series of values caused by each source at each survey location are simulated, taking into account the *closest* highway, major road and railway only. Simplifications are used for pass-by distributions, source strength and sound propagation (see De Coensel et al. 2009) for more details on this proceeding. Secondly, the simulated time series are calibrated such that the L_{den} corresponds to that obtained from a noise map, taking into account the particular alpine propagation conditions of the study area (Heimann et al. 2007). In essence, the first stage makes sure that the temporal structure of the simulated level time series is realistic given the distance of the survey point to the roads/tracks, while the second stage fixes the overall level. Finally, percentile levels were calculated for the total sound exposure, as well as for the exposure caused by all combinations of sources, based on the calculated time series of values for each source.

From the percentiles, *'fluctuation'* and *'emergence'* can be calculated per source. The fluctuation is the difference between the source event (L_1 for highway, L_5 for main roads, L_{10} for railway) and the source background level (L_{90} for highway, L_{99} for main roads, L_{90} for railway). Emergence on the other hand is the difference between the source event (L_{10} for highway, L_5 for main roads, L_{10} for railway) and the overall background level consisting of the sound of all natural and traffic sources except the source under study (L_{90} for highway, L_{99} for main roads, L_{90} for railway). For the three sources, particular percentile levels are selected to establish minimal correlation between fluctuation, emergences another noise measures, an important issue for statistical modeling later on.

Notice event model

The simulated sound level time series serve as input to the notice-event model (De Coensel et al. 2009). This psychoacoustic model is used to estimate (on a statistical basis), for each dwelling in the survey, the time periods that a person, living at that dwelling, would pay attention to the sound of each of the considered sources. For this, a 'virtual' individual is modeled for each participant in the survey. Next to the temporal pattern of the signal-to-noise ratio of the sound of each source as compared to the other sources, the notice-event model takes into account effects of habituation to sound sources over time, and focusing of attention after sudden changes in levels. More details can be found in De Coensel et al. (2009). Essential is that the sound produced by each modeled individual itself (through its activity, such as cooking or watching television) has to be taken into account, including the location of the activity and the corresponding sound insulation of the dwelling. This is necessary since activity-related sounds may mask intruding transportation noise. In order to construct activity patterns for each survey participant, a number of personal variables are used, such as the age category, the type of employment, or whether the person works in shifts or works at night. Representative 14-day activity patterns for each combination of variables are extracted from the ALPNAP database of activity diaries collected from people living in an adjacent study area, in combination with the Austrian Time Use Survey of 2008-2009. Subsequently, an activity-related sound level time series was constructed for each activity pattern, based on sound level ranges found in literature (Diaz & Pedrero 2006). Finally, results of the notice-event model are only considered for those time periods for which the person is at home and not sleeping. A first outcome of the notice-event model is the (indoor) exposure L_{Aeq} calculated over these 'home-and-awake' periods for each source. A second outcome is the estimate of the total duration of attention paid to each sound source, the notice time. Inspired by the hypothesis that only consciously noticed sounds contribute to annoyance, a third outcome is the notice SEL of the sound of each source during those periods that it is paid attention to. Additionally, assuming that the contribution of an event to annoyance is proportional to its audibility above the background, a fourth outcome is the noticed sound exposure level above the notice-threshold, noted as notice SELthr.

Statistical analysis

Logistic regression is carried out with statistical software R to investigate probability of high annoyance in terms of noise exposure. For the outcome variable, noise annoyance questions for the three sources are grouped into one variable *annoyance* which is rated 'high' for answers between 8 and 10.

Not purely acoustical independent variables are the *noise source* (levels 'highway', 'main road' or 'railway') and the *distance* to that particular source. For the acoustical indicators per source, L_{den}, *fluctuation, emergence,* L_{Aeq} *during home and awake periods, notice time, notice SEL* and *notice SELthr* are selected as candidate independent parameters. Per observation in the data set, reported annoyance is linked to noise from the particular source the question was referring to.

Candidate independent variables are introduced in the different models through a manual stepwise procedure. Conclusions on variables' contribution to the model are based on the statistical significance of their coefficients (α=0.05) and changes in model deviance and AIC (Akaike Information Criterion)—measures of a model's goodness-of-fit—when this variable is added. Finally, the goodness-of-fit is addressed with the le Cessie–van Houwelingen normal test statistics (p>0.05) and typical measures for the model's predictive power are calculated like C index– corresponding to the area under the ROC curve–, Somer's D_{xy}, Goodmann-Kruskal gamma, Kendall τ, Nagelkerke's R^2 and Brier score (Harrell 2001).

RESULTS

Sound source and time pattern

First, probability of high annoyance is modeled as a function of L_{den} and sound source to set a benchmark. As expected, Figure 1 reveals that the probability of high annoyance increases with increasing L_{den} ($p<0.001$). In this model, probability of high annoyance appears lower for railway noise than for road traffic noise ($p<0.001$), which is in accordance with previous studies investigating high annoyance as a function of source specific day-night levels (DNL) (Miedema & Vos 1998).

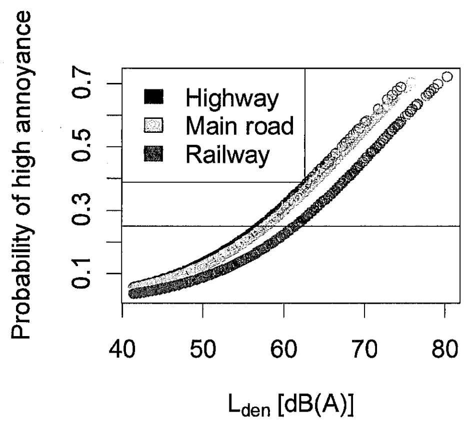

Figure 1: Probability of high annoyance from traffic noise as a function of L_{den} and noise source. As a reference, 0.25 probability of high annoyance is indicated.

Secondly, high annoyance is investigated in relationship to L_{den} and notice-event parameters *notice time, notice SEL* and/or *notice SELthr*, so without the noise source as such. This leads to the following expression for probability of high annoyance P(HA)

$$P(HA) = \frac{1}{1 + \exp(-X\beta)} \quad (1)$$

$$X\beta = -5.8 + 0.06\,\mathbf{Lden} + \mathbf{7.4 \cdot 10^{-6}}\,\tau + \mathbf{0.01}\,\varsigma \quad (2)$$

with τ notice time and ς notice SEL.

The new expression consumes 3 degrees of freedom like the previous model with the variable noise source, but it has a more favorable AIC (4,622.5 versus 4,653.1). In addition, the new model scores (slightly) better on predictive power although for both expressions the goodness-of-fit is less convincing ($p<0.001$). Nevertheless, this suggests that notice-event parameters are better in predicting annoyance for different sound sources than naming the source. An increase in L_{den} has the strongest influence on increasing probability of high annoyance ($p<0.001$), followed by notice SEL ($p<0.001$) and notice time ($p<0.001$).

In Equation 2 *notice SEL* could be replaced by *notice SELthr* and although the latter variable contributes statistically significantly, the AIC is slightly worse (4633.2). Due to their extreme correlation (Pearson ρ =0.98), both variables could not be combined in one model.

Finally, adding the variable sound source to Equation 2 reveals that the sound source as such still has a statistical significant influence ($p<0.001$) similar to the baseline model, stronger than notice time but less important than L_{den} and notice SEL. Hence, the time pattern of a particular noise source appears clearly important in the general appreciation of a source, but it cannot explain everything.

An alternative parameter for L_{den}

Because the questionnaire addresses explicitly noise annoyance at home, indoor L_{Aeq} during periods that people are actually at home an awake is put forward as an alternative exposure indicator. Statistically modeling the probability of high annoyance as a function of L_{Aeq} during home and awake periods (see Figure 2) reveals that this model has a better AIC then the model with only L_{den} (4,575.9 versus 4,676.3). Moreover, its predictive power appears better and the goodness-of-fit is satisfying ($p > 0.05$) whereas it is not the case for the expression with L_{den} ($p<0.001$).

Comparing Figure 1 and Figure 2 reveals that 0.25 probability of high annoyance corresponds to exposure levels around 60 dBA for L_{den} whereas the level is substantially lower for L_{Aeq} during home and awake periods (less than 50 dBA).

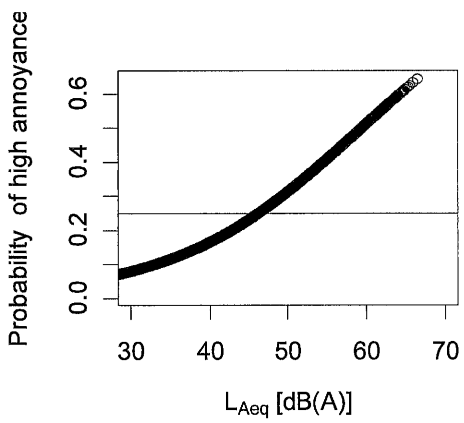

Figure 2: Probability of high annoyance from traffic noise as a function of L_{Aeq} during home and awake periods. As a reference, 0.25 probability of high annoyance is indicated.

Optimized model

The findings described in the two previous sections are combined into one model, analyzing the probability of high annoyance as a function of L_{Aeq} during home and awake periods, notice time τ and notice SEL ς. This leads to the following expression for $X\beta$ in the general equation 1

$$X\beta = -4.7 + 0.07\,\mathbf{LAeq} + \mathbf{8.3} \cdot \mathbf{10^{-6}}\,\tau + \mathbf{0.005}\,\varsigma. \quad (3)$$

Figure 3 illustrates that 0.25 probability of high annoyance for this model lies around the same level of L_{Aeq} during home and awake when only that variable is taken into account (see Figure 2).

Similar to the model with L_{den} (Equation 2), all independent variables contribute statistically significantly and L_{Aeq} during home and awake periods appears the most influential parameter ($p<0.001$). However, notice time ($p<0.01$) is now slightly more important than notice SEL ($p<0.01$) and the AIC of the current model is better (4,574.5). This suggests that for the annoyance questions asked in this study, people base their response more on the noise they are exposed to when fully awake, and not on for instance possible sleep disturbance at night.

Furthermore, the performance of the current model is compared to a conceptually more elementary approach where the probability of high annoyance is assessed as a function of L_{den}, the sound source and the logarithm of the distance to the source. Comparing the AIC of both models confirms that taking into account notice-events and people's activity pattern really has an added value (4,574.5 versus 4,596.0). Moreover, its predictive power appears better and the goodness-of-fit is satisfying ($p > 0.05$) as opposed to the expression with distance and sound source ($p<0.001$). In addition, replacing in the current model the notice-event parameters by the noise source increase the AIC to 4,588.5, showing again the benefits of this new approach.

Finally, the possibility to improve the model in Equation 3 is further investigated by adding the variable *emergence, fluctuation* and *sound source* separately. Fluctuation has no statistically significant influence in this model, possibly because this variable is very strongly correlated to L_{den} (Pearson ρ =0.93). Similar, introducing emergence has only a limited effect ($0.05 < p < 0.1$) due to the high correlation with L_{den} (Pearson ρ =0.86) Third, the contribution of sound source is also marginally significant ($0.05 < p < 0.1$). Although no longer very pronounced, it should be noted that here railway noise has a higher probability of high annoyance (0.105) than main roads (0.09) and only slightly smaller than highways (0.112).

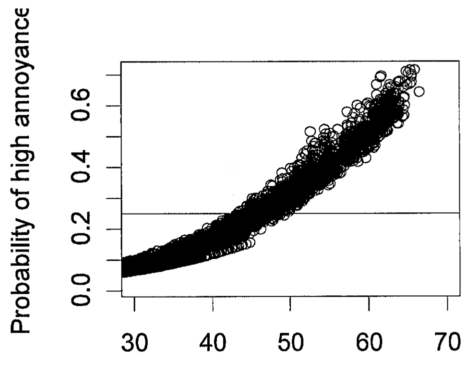

Figure 3: Probability of high annoyance from traffic noise as a function of L_{Aeq} during home and awake periods, taking into account notice time and notice SEL. As a reference, 0.25 probability of high annoyance is indicated.

DISCUSSION

Noise annoyance due to traffic noise is an important issue, especially given the increase in population density and mobility. In this regard, refined exposure-effect models might provide further insight and facilitate annoyance abatement.

L_{den} is widely used as noise exposure indicator. This measure penalizes noise levels in the evening and at night because exposure is believed to be especially adverse when interfering with so-called restoration periods. However, in this analysis, noise annoyance can be predicted more precisely if L_{Aeq} during home and awake periods is used instead of L_{den}, suggesting that nighttime noise exposure— when most people are asleep—determines less the reported annoyance. Naturally, this does not mean that noise-induced sleep disturbance could be regarded as less important, rather it might imply that people refer more to the actual disturbance during fully awake periods when answering the question on noise annoyance. A plausible explanation is that people adapt to nighttime noise exposure, decreasing subjective awakening (Passchier-Vermeer & Passchier 2000).

Another issue in noise exposure are the apparent differences between noise sources. This could be due to the temporal fluctuation of the particular sources, people's attitudes and believes towards them or, most likely, a combination of both (Miedema & Vos 1998). Current analysis suggests that the ability to notice sounds (operationalized by the the notice-event model) accounts to some extent for the difference in perceived annoyance between sources—at least more than entering only the noise source into the model. All three calculated parameters (notice time, notice SEL and notice SELthr) contribute significantly to the probability of high annoyance, but notice SELthr seems somewhat less capable of capturing the observed variance. A possible factor is the applied 'notice threshold' used to calculate notice SELthr. An improved estimation might increase the strength of the latter variable in estimating the probability of high annoyance.

All this underlines the importance of notice-ability, but this study does not allow to pronounce on a causal relationship between annoyance and temporal fluctuation. Moreover, the current analyses are not designed to make a strong point on the mutual relation of highway, main roads and railway with respect to (higher) risks of noise annoyance, all the more because highway and railway are tied closely together geographically in the data under study.

Further research should investigate the acoustical and non-acoustical variables that could be added to improve prediction of high annoyance. Here, (logistic) regression makes it sometimes difficult to assess the influence of candidate independent parameters because they are often more or less correlated. When non-acoustical parameters are further added to these notice event models it may be even more difficult to separate the various determinants of annoyance. More advanced modeling techniques might therefore be necessary in such extended models, also because they could provide more insight into the underlying mechanisms determining people's reaction to noise exposure.

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REFERENCES

2002-49-EC (2003). Directive 2003-10-EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Brussels: European Parliament and Council.

Botteldooren D, De Coensel B, Berglund B et al. (2008). Modeling the role of attention in the assessment of environmental noise annoyance. In: Proceedings of the 9th Congress of the International Commission on the Biological Effects of Noise (ICBEN 2008), p 617.

De Coensel B, De Muer T, Yperman I et al. (2005). The influence of traffic flow dynamics on urban soundscapes. Appl Acoust 66: 175–194.

De Coensel B, Botteldooren D, De Muer T et al. (2009). A model for the perception of environmental sound based on notice-events. J Acoust Soc Am 126: 656–665.

Diaz C, Pedrero A (2006). Sound exposure during daily activities. Appl Acoust 67: 271–283.

Fields J (1993). Effect of personal and situational variables on noise annoyance in residential areas. J Acoust Soc Am 93: 2753.

Fields J, Ehrlich G, Zador P (2000). Theory and design tools for studies of reactions to abrupt changes in noise exposure. Technical Report NAS 1.26210280. Langley Research Center.

Harrell F (2001). Regression modeling strategies: with application to linear models, logistic regression and survival analysis. New York: Springer-Verlag.

Heimann D, De Franceschi M, Emeis S et al. (2007). Air pollution, traffic noise and related health effects in the alpine space– a guide for authorities and consulters. ALPNAP comprehensive report Universita degli Studi di Trento, Dipartimento di Ingegneria Civile e Ambientale, Trento, Italy 335.

Lercher P, De Greve B, Botteldooren D et al. (2008a). A comparison of regional noise-annoyance-curves in alpine areas with the European standard curves. In: Proceedings of the 9th Congress of the International Commission on the Biological Effects of Noise (ICBEN 2008), p 562.

Lercher P, De Greve B, Botteldooren D et al. (2008b). The effect on annoyance estimation of noise modeling procedures. In: Proceedings of the 9th Congress of the International Commission on the Biological Effects of Noise (ICBEN 2008), p 670.

Marquis-Favre C, Premat E, Aubree D (2005). Noise and its effects: a review on qualitative aspects of sound. Part II: Noise and annoyance. Acta Acust Acustica 91: 626–642.

Miedema H (2007). Annoyance caused by environmental noise: Elements for evidence-based noise policies. J Soc Issues 63: 41–57.

Miedema H, Oudshoorn C (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect 109: 409.

Miedema H, Vos H (1998). Exposure-response relationships for transportation noise. J Acoust Soc Am 104: 3432–3445.

Miedema H, Vos H (2007). Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behav Sleep Med 5: 1–20.

Passchier-Vermeer W, Passchier W (2000). Noise exposure and public health. Environ Health Perspect 108(Suppl 1): 123.

Variation of evaluation of signal sound in the public place with several kinds of noise

T. Akita

Department of Architecture, School of Science and Technology for Future Life, Tokyo Denki University, 2-2 Kanda-Nishiki-cho Chiyoda-ku, Tokyo 1018457 Japan, akita@cck.dendai.ac.jp

INTRODUCTION

Signal sound is used as a mark that indicates emergency or something important in the public place. It is expected that the signal can be easily heard and draw one's attention successfully. However, loud signal sound can cause annoyance. Therefore, signal sound in the public place should be planned appropriately. In the present research, one experiment is carried out to investigate the effects of frequency and sound pressure level with several kinds of noise on psychological evaluation of signal sound from the viewpoint of efficiency of drawing attention and annoyance.

MEHODS

Ten persons (male = 9, female = 1) participated in the experiment. Pure tones of three frequencies (300; 800; 1,300 Hz) are used as signal sounds. Recorded noises at five kinds of sound environment and pink noise are used as back ground noise. L_{Aeq} of recorded noises and pink noise are shown in Table 1.

Table 1: L_{Aeq} of recorded noises and pink noise

Noise No.	L_{Aeq} [dB)]	kind of noise	included sound
1	77	inside a train	railway track noise, A/C noise, announcement, talking
2	50	pink noise	pink noise
3	64	shopping mall	talking, footsteps, A/C noise, BGM
4	74	street crossing	talking, footsteps, BGM, road traffic noise, cell phone, honker sound
5	74	station concourse	talking, footsteps, guide signal, road traffic noise, honker sound, ticket vender, cell phone
6	79	station platform	railway track noise, announcement, ringing bell, talking, footsteps

Signal sound has time length of one second, and there are 4.5 seconds between one signal and the next. Three signal sounds constitute of one set of signal. Each signal sound that has two conditions of sound pressure level (64, 84 dBA) is added to each noise. In this way, 36 experimental sounds are created. Each subject experiences all of the experimental sounds through headphone.

Evaluation method

After listening each experimental sound, subjects are asked about three types of questionnaire. Firstly, they are asked whether they can hear the signal sounds or not. Secondly, they are asked about impression of signal sound comparing to noise by five steps. Finally, they are asked about impression of whole sound environment that consists of signal and noise. Evaluation items are shown in Table 2 and 3.