Number of aircraft noise events and motility during sleep

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ABSTRACT

Both the WHO and the EC advise on the use of L_{night} as the primary indicator for sleep disturbance. Still, a key question for noise policy is whether from a public health point of view it may be advantageous to use number of events in addition to L_{night}. For some effects, it may be more effective to reduce the number of events above a certain threshold than to lower the overall exposure level of events. Based on data of a field study among 418 people, the current paper investigates the association between objectively measured sleep disturbance and the number of aircraft noise events. The data from this study are well suited for this purpose, since for every subject both the number and the level of events were available. The analysis focuses on mean motility during the sleep period, and addresses the question whether this motility can be predicted more accurately taking the number of passages into account. The results suggest that an increase in the average sound exposure level of events contributes more to motility than an increase in the number of events. However, it was also found that the influence of number of events increases with increasing levels of the events. Thus, to reduce motility as a proxy for restless sleep, it may be better to prevent the occurrence of events with high maximum levels than to reduce the overall number or level of events.

INTRODUCTION

Sleep disturbance due to night time noise is a health impact of noise of increasing importance for policy. The recently published WHO Night Noise Guidelines for Europe (WHO 2009) primarily refer to relationships between health and the equivalent noise exposure during the night (L_{night}). Both the WHO and the EC (2004) advise on the use of L_{night} as the primary indicator for sleep disturbance. L_{night} can be linked to subjective measures but also to the number of additional awakenings due to nighttime noise (Basner et al. 2010) and motility (Passchier-Vermeer et al. 2002, 2007). However, there are indications that some aspects of sleep disturbance are also dependent on the number, character and distribution of individual noise events over the night (e.g. Basner et al. 2010). A key question for policy is whether equivalent sound limit levels offer sufficient protection against sleep disturbance. In order to answer these questions more insight is needed into the influence of number of events during the night on the degree of sleep disturbance at a given equivalent sound level. Previous analysis on survey data around Schiphol Airport (Miedema et al. 2000) showed that an increase in the number of flights was adequately reflected in the equivalent sound levels as far as annoyance was concerned. However, for sleep disturbance this could be different. Theoretically, given a certain equivalent level, the maximum level of disturbance should take place at L_{Amax} or SEL levels close to the threshold level for a specific indicator of sleep disturbance (EC 2004).

While an association between L_{Aeq} or L_{night} has been established for subjective sleep disturbance, mean motility and number of awakenings, L_{Amax} and *SEL* of individual events may be more predictive of instantaneous and short term effects such as (onset of) motility, awakening, cardiovascular responses and sleep stage changes (WHO 2009). Therefore, in principle the prediction of effects such as mean motility and number of awakenings may be improved by additional information on the number (combined with levels) of individual events. Based on a field study among 418 people, Passchier-Vermeer et al. (2002) presented relationships between night-time aircraft noise exposure and motility for three time scales (instantaneous levels, sleep period and long term). Both *SEL* and L_{Amax} of aircraft noise events as measured inside the bedroom were found to be related to instantaneous (onset of) motility (measured by actimetry), and behavioral awakening (button push). Also, mean motility over a sleep period as measured by actimetry was shown to be associated with L_{Aeq}, while long term mean motility was associated with L_{night}. Furthermore, mean motility (both per night and over longer periods) was positively associated with indicators of subjective sleep quality and/or perceived awakenings, health complaints and adverse sleep effects.

Taking these findings as a point of departure this paper investigates the association between objectively measured aspects of sleep disturbance and the number of the individual noise events, based on the available data from the field study of Passchier-Vermeer et al. (2002). The data from this study are well suited for the present purpose, since for every subject aircraft noise exposure was measured inside the bedroom for several nights, on the basis of which both the number and the level of events could be derived. Furthermore, both subjective and objective measures of sleep disturbance were collected. The analysis focuses on mean motility during the sleep period, and addresses the question whether this motility can be predicted more accurately taking the number of passages into account.

METHODS

Data

As part of the health impact assessment around Schiphol airport commissioned by the Netherlands Ministry of Housing, Spatial Planning and the Environment and in close collaboration with the Netherlands Institute for Public Health and the Environment (RIVM), a study was performed among 418 adults residing at various distances from Schiphol airport. The objective of the total study was to derive dose response relationships for night time noise effects and to estimate the prevalence of noise related sleeping disorders at a population level.

Respondents

Candidates for participation in the study were recruited by mail. The request to participate and a leaflet with information about the study were sent to 3,000 addresses. About 540 candidates showed interest in participating, 440 of which were selected for an intake visit and further consultation, and 418 subjects decided to take part in the study. All 418 subjects that actually started participation completed the study, for which they received a small remuneration. Subjects participated from a Monday evening until a Friday morning 11 days later. During this period, they wore an actimeter (CNT, type AW4, weight about 50 grams) monitoring body movements continuously, with the exception of periods of bathing and swimming. In addition, they filled out an extensive questionnaire at the start of the study, they filled out a morning and evening diary, as well as a sleepiness scale during day and evening (five times). The subjects in this study were exposed to usual night-time aircraft noise in their bedroom. Ages varied between 18 and 81 years, 50 % of the subjects were male, 6 % lived less than 1 year in the present neighborhood, 44 % were over 15 years and the remaining 50 % between 1 and 15 years.

Locations

The study was carried out successively at 15 locations within a distance of 20 km from Schiphol, selected mainly on the basis of modeled nighttime (23h-06h) aircraft noise exposure. Other selection criteria pertained to road and railway noise, degree of urbanization and type of dwelling. Two locations were selected because of their presumed absence of nighttime aircraft noise. The other locations had various degrees of nighttime aircraft noise exposure, from relatively few aircraft at night up to the highest exposure in residential areas close to Schiphol Airport. At each location, data were collected during two subsequent intervals of 11 nights. Valid data are available for 414 respondents, with a maximum of 11 nights. In total, exposure measures and sleep characteristics were collected during 4,048 respondent-nights.

Sleep disturbance measures

Motility is the term used for accelerations of the body or body parts during movements. It is measured with actimeters, usually worn on the wrist in field research, detecting whether movement has or has not taken place during a specified interval (in this study, the sample rate was 15 s). Actimetry has been used in the last decade to monitor sleep disturbance in large field studies with subjects sleeping at home exposed to the usual aircraft, road traffic or railway noise (Ollerhead et al. 1992; Horne et al. 1994; Fidell et al. 1995, 1998; Griefahn et al. 1999; Passchier-Vermeer et al. 2002). For this particular analysis, the mean probability of motility was derived based on all 15 s intervals within one sleep period time. In addition, self-reported sleep quality was used, measured with a question in the morning diary. The wording of the question was: 'How well did you sleep last night?', with extreme answering categories labeled: 0=very bad, 10=very well. This 11-point scale was recoded into a 0-100 scale where 0 means good and 100 means bad sleep quality.

Noise exposure measures

To assess night-time aircraft noise exposure of subjects, noise measurements were performed from 22-9h with indoor noise monitors in the bedroom of each subject and with one outdoor noise monitor. For each second, the noise monitors stored the equivalent sound level. Aircraft noise events were identified by comparing the noise and time data stored in the indoor and outdoor noise monitors with information obtained from the aircraft identification system at Schiphol (FANOMOS).

Statistical analyses

Although the method previously described and used by Miedema et al. (2000) is in principle very appropriate to quantify the trade-off between number of events and sound level, this analysis did not give reliable estimates for the trade-off parameters, because the relationship between exposure level during the sleep period and mean motility was not strong enough for a stable optimization of the parameters. Therefore, following earlier studies (Fields 1984; Vogt 2005), the relative impact of the noise level L of events and the number N of its average daily occurrence on the variable of interest (Y) was expressed as the ratio of regression coefficients BN/BL taken from:

$$Y = B_0 + B_L L + B_N \log N + B_t \log(\Delta t / T) + B_i X_i$$

where Δt is the average duration of the noise events for a night and T the total sleep time for a night. B_0 and B_L are the regression coefficients for number and sound exposure level (SEL) of a noise event, respectively. The ratio between the two ($k = B_N / B_L$) indicates the relative importance of number compared to level, and is called the decibel-equivalent number effect. It equals 10 in the equal-energy indices (e.g. Leq), because a tenfold increase in number corresponds to a 10 dB increase in level. $B_i X_i$ are additional variables of interest.

To predict mean motility during a sleep period time, linear regression models were built in a stepwise manner, starting from the overall mean to a final model predicting motility from the average sound exposure level as well as the number of aircraft passages, controlling for sleep time, average duration of events, age and gender. Sleep time was included in the model to adjust for the fact that a longer sleep period may be associated with increased mean motility, regardless of the number of aircraft passages. The other control variables were chosen on the basis of earlier studies, indicating that effects of age (Passchier-Vermeer et al. 2002) and gender (Reyner et al. 1995) are to be expected. To account for highly correlated observations within persons, respondent ID was treated as a random factor in the model.

RESULTS

Motility during the sleep period proved to be positively related to both indoor sound exposure levels and to the number of events, although number of events no longer contributed significantly when controlling for age and gender of the subject. Age had a curvilinear effect, with the lowest motility for respondents aged between 40 and 50, while gender had no effect on motility. Furthermore, a decrease in subjective sleep quality was found to be positively associated with indoor sound exposure levels, but not significantly with the number of events, and females overall proved to have decreased subjective sleep quality as compared to males. The equivalent rise in sound exposure levels to the hypothetical case of a tenfold increase in the number of passages was estimated by the decibel-equivalent number effect *k*, defined as the ratio between the estimates for the number and for the level effect. This proved to be around 5 for the prediction of motility in the unadjusted model, meaning that doubling the number of aircraft passages is equivalent to a 1.50 dB increase in average sound exposure level. For the prediction of bad subjective sleep quality, *k* was found to be 3.5 in the unadjusted model, meaning that doubling of number of aircraft passages is equivalent to a 1.07 dB increase in average sound exposure level.

CONCLUSIONS

The present results suggest that, over the whole range of exposure in the present dataset, an increase in the average sound exposure level of events contributes more to motility and to subjective sleep quality than an increase in the number of events. However, in a posthoc descriptive analysis indications were also found that, given a certain L_{Aeq} level, the number of events has relatively little influence when all events are taken into account, but that the influence of number of events increases with increasing levels of the events. Thus, to reduce motility as a proxy for restless sleep, it may be better to prevent the occurrence of events with high maximum levels than to reduce the overall number or level of events.

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