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Work stress, worries, and pain interact synergistically with modeled traffic noise on cross-sectional associations with self-reported sleep problems

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Abstract

Objectives. To examine the risk of sleep problems associated with work stress (job strain, job demands, and decision authority), worries and pain, and to investigate the synergistic interaction between these factors and traffic noise.

Methods. Sleep problems and predictor variables were assessed in a cross-sectional public health survey with 12,093 respondents. Traffic noise levels were assessed using modeled A-weighted energy equivalent traffic sound levels at the residence. The risk of sleep problems were modeled using multiple logistic regression analysis.

Results. With regard to sleep problems not attributed to any external source (general sleep problems) independent main effects were found for traffic noise (women), decision authority (women), job strain, job demands, suffering from pain or other afflictions, worries about losing the job, experiencing bullying at work, having troubles paying the bills, and having a sick, disabled or old relative to take care of (women). Significant synergistic effects were found for traffic noise and experiencing bullying at work in women. With regard to sleep problems attributed to traffic noise strong synergistic interactions were found between traffic noise and, respectively, job demands (men), having pain or other afflictions, taking care of a sick, old, or disabled relative, and having troubles paying the bills. Main effects were found for worries about losing the job, experiencing bullying at work, job strain (men) and decision authority (men). Synergistic interactions could potentially contribute with 10-20% of the sleep problems attributed to traffic noise in the population.

Conclusions. Work stress, pain and different worries were independently associated with general sleep problems and showed in general no synergistic interaction with traffic noise. In contrast, synergistic effects between traffic noise and psychological factors were found with

regard to sleep problems attributed to traffic noise. The synergy may contribute significantly to sleep problems attributed to traffic noise in the population.

Key words: Noise, transportation; psychological stress; life stress; occupational exposure

Introduction

Sleep is essential for mental and physical reconstitution (Åkerstedt and Nilsson, 2003;Meerlo et al., 2008). Sleep deprivation and/or disturbed sleep is associated with fatigue (Åkerstedt et al., 2004), impaired cognitive functioning (Harrison and Horne, 1999), reduced quality of life (Kyle et al., 2010), and increased physiological stress (Meerlo et al., 2008). Chronic disturbance of normal sleep patterns is a risk factor for cardiovascular disease (Schwartz et al., 1999;Nilsson et al., 2001;Leineweber et al., 2003), diabetes (Nilsson et al., 2004), obesity (Gangwisch et al., 2005), depression (Chang et al., 1997) and musculoskeletal pain (Canivet et al., 2008). Both the seriousness and the wide range of health problems that have been linked to poor sleep are alarming in their own right but perhaps even more so since sleep problems are relatively prevalent in the society. For example, in a recent population survey 26.8% of the adults in Sweden reported sleep problems (Statistics Sweden, 2008). Similar high proportions of subjects with sleep problems have been found in other countries as well (Klink and Quan, 1997;Arber et al., 2009;Niedhammer et al., 2009). Thus, increasing the knowledge of how various factors at home and at work may contribute to poor sleep appears to be an important task that in the end may facilitate the development of effective countermeasures.

Psychological stress is an important determinant of poor sleep quality. The subjective experience of psychological stress is one of alertness that is linked to negative evaluations of the situation and may therefore be manifested in feelings of nervousness, tension, anxiety, and upsetting thoughts (Russell, 1980;Posner et al., 2005). As such psychological stress may be viewed as a result from an adaptive challenge in a specific situation (Nesse and Ellsworth, 2009). Indeed, psychosocial factors that have been shown to have a strong association with sleep problems are, among others, work stress (Kalimo et al., 2000;Åkerstedt et al., 2002;Linton, 2004;Ota et al., 2005;Fahlén et al., 2006;Rugulies et al., 2009), workplace

bullying (Niedhammer et al., 2009), chronic emotional stress (Vgontzas et al., 2008), and worries (Urponen et al., 1988;Middelkoop et al., 1996). Other psychosocial factors, such as negative social interactions and low rating of well-being is also associated with sleep problems (Steptoe et al., 2008). It must be acknowledged however, that poor sleep also can lead to lower well-being, and the relationship between psychological measures of well-being and sleep is therefore in general bidirectional.

A different determinant for sleep quality that has attracted increasing interest is environmental noise. Evidence from both laboratory and field studies suggests that traffic noise is a significant cause of disturbed sleep (Öhrström, 2000;Björk et al., 2006;Griefahn et al., 2006). In addition, a recent study that integrated data from 24 field studies demonstrated that the prevalence of reported of sleep problems increases with sound levels from traffic noise, and that the degree of disturbance increases in the order of railway noise, road traffic noise, and aircraft noise (Miedema and Vos, 2007).

In spite of the apparent differences between psychological distress factors and traffic noise they may in fact interfere with sleep through the same biological mechanisms. Specifically, the system that governs wakefulness includes the ascending reticular activating system and posterior hypothalamus which extends its neural projections to the thalamus and the cortex (Lin, 2000;Jones, 2003). This “arousal system” (Halász et al., 2004) is relatively quiescent during normal sleep, but activity in the system increases in response to various stimuli (Siegel, 2004;Saper et al., 2005). Thus, strongly activating emotions (Chrousos, 2007;Chrousos, 2009), as well as sounds (Raschke, 2004;Basner et al., 2008), pain (Lavigne et al., 2000) and increased upper airway resistance (Guilleminault and Davé, 2003) can activate the arousal system and thereby potentially cause awakening and difficulties falling asleep. Interestingly, it has recently been proposed that chronic insomnia should be characterized as a disorder of hyperarousal (Basta et al., 2007).

The common biological mechanism suggests the possibility of biological interactions between, for example, traffic noise and other stimuli such as psychological stress or pain. It is remarkable that no study, to the best of our knowledge, has investigated the interactions between these factors in relation to sleep quality. To extend the existing knowledgebase and improve the possibilities for giving advice regarding traffic noise, work stress and sleep, we decided to examine this in an already existing database that contained information obtained from the general occupationally active population in the Scania Region of southern Sweden. The information gathered in this survey includes general sleep problems as well as sleep problems that the persons attribute to various specific causes, including traffic noise at the residence. This investigation therefore focused on the following questions. Firstly, are the "profile" of risk factors similar for both general sleep problems and sleep problems attributed to traffic noise? Secondly, does a combination of high levels of traffic noise and high levels of psychological distress or pain result in more sleep problems than predicted by high levels of these determinants alone?

Methods

Population

The identification of participants was based on a population-based public health survey from 2004, encompassing 47 621 persons 18 to 80 years old in Scania, Sweden (Rosvall et al., 2005). The total response rate was 59% (n=27 879). From this initial survey, 14 189 subjects not employed or occupationally active were excluded leaving 13 131 subjects. As sleep medication may affect the reporting of sleep problems, and sleep medication may be taken for a number of reasons unrelated to the factors under investigation in this study (for example, shift-work, chronic or acute disease, etc.), the 482 subjects reporting the use of sleep

medication in the last 3 months as well as 556 non-responders to the question on sleep medication were excluded, leaving 12 093 for the analysis.

Outcome measures

General sleep problems were measured with two questions that assessed disturbed sleep without asking about attribution to external sources of disturbance (Table 1). Since the responses to these questions were highly correlated (Spearman $r=0.73$, $p<0.001$), the responses were combined into a single dichotomous variable for general sleep problems as described in Table 1. If nothing is else is stated, results are reported for the sleep problem outcome where the high level includes both intensely and moderately troubled persons. To test the sensitivity of the risk estimates to the response categories that is used to define sleep problems an alternative outcome for general sleep problems was defined as reporting the highest degree of trouble in response to one of the questions (that is, "To a very high degree" to the first question, or "Yes, very troubled" to the second question).

Disturbed sleep attributed to traffic was measured with two items (Table 1). Responses to these two items were significantly correlated (Spearman $r=0.63$), and the items were therefore combined to a single measure of the traffic-attributed sleep disturbance as described in Table 1.

Work stress

The Swedish version of the Job Content Questionnaire (JCQ) was used to assess how the participants perceived the work environment in terms of psychological job demands and decision latitude (Karasek et al., 1998). We chose to focus on decision authority because the items of this subdimension in our opinion reflect the relevant psychological stress better than skill discretion items. Psychological job demands was measured with 9 items and decision

authority measured with 3 items. Both decision authority and job demand items are formulated as statements and responded to on a 4-point scale: 1="I agree completely", 2="I agree", 3="I disagree" and 4="I completely disagree". Assignment of subjects to low, medium and high psychological job demands, respectively decision authority, were based on the mean scores with scales reversed where appropriate as shown in Table 1. Job strain groups expressing the balance between demands and decision authority were formed as illustrated in Figure 1. This is a new way of combining demand and decision authority scores, but in our opinion it is a less arbitrary way to express job strain than the traditional job strain metric based on, for example, tertiles of demands and decision authority scores.

Other psychological stress factors and pain

Worries about losing the job, the distress of experiencing or witnessing bullying at work, troubles paying bills, the distress of taking care of a sick, old or disabled relative, and distressing experience of pain and other afflictions were measured by single items as presented in Table 1, where also the response categories used in this study are defined.

Modeled traffic noise exposure

We assessed individual exposure with high resolution, using Geographical Information Systems (GIS) as a tool to link the individual geocoded residential addresses at the end of year 2003 with available exposure data attributed this address (geocoded, or grid data) as previously described (Ardö, 2005;Björk et al., 2006;Persson et al., 2007). In brief, the simplified Nordic prediction method for road traffic noise was used to estimate the A-weighted energy equivalent continous sound pressure level during a full day (24 hr, $L_{Aeq,24}$) (Bendtsen, 1999). The prediction method includes only noise reductions due to distance and due to ground type (soft or hard), but excludes reduction due to noise barriers. We have no

data on the floor of the apartment building on which the residences were located, and the noise level was therefore estimated for the ground floor for all residences. The residential traffic noise exposure was expressed as a categorical variable with levels *Low* ($L_{Aeq,24} < 50$ dBA), *Medium* (51-54 dBA) and *High* (≥55 dBA).

Confounders

Several demographic, socioeconomic and lifestyle factors have been shown to be associated with sleep quality, and therefore have the potential to confound the relation between sleep problems and traffic noise or distress. We considered the following variables in the study: Gender, age (18-34 yr; 35-44 yr; 45-54 yr; 55-64 yr; 65-80 yr), BMI (≤25 kg/m^2; 25-35 kg/m^2; >35 kg/m^2), marital status (co-habiting; single) and type of residence (house; rental apartment or other type of residence). The dimensions most often used to describe socioeconomic status are income, education and occupation. We included a categorical variable for the highest completed education (primary or lower secondary education which is 7 years or less; upper secondary education; or higher than upper secondary education). Lastly, we considered the following lifestyle factors in the statistical analysis: Alcohol intake (< 1 beverage/month; 2-4 per month; 2-3 per week; ≥4 per week), tobacco smoking (current smoker; non-smoker), and leisure time physical activity level (regular exercising; moderate regular exercising; no leisure time physical activity). All of the above-mentioned potential confounder variables, except gender, were included in all statistical analyses.

Strategy for the analyses

Statistical analysis of interaction effects in the combined group of men and women was preferred whenever possible in order to include the maximal number of cases in the analysis. However, differences between men and women in responsiveness to sleep disturbance factors

can potentially hide interaction effects in the statistical analyses. Stratification by sex was therefore used for the initial analyses of main effects. If a sleep disturbing factor did not show marked differences between men and women in this analysis, the analysis of the interaction effect with this factor was done for men and women combined.

Age may also interact with worries and stress, for example, it has been shown that sleep in middle-aged men is more sensitive to the arousing effect of corticotropin-releasing hormone than sleep in young men (Vgontzas et al., 2001). We investigated possible interaction effects, but for the same reasons as above all age groups were analyzed in one group unless the analyses showed differential effects of sleep disturbing factors in different age groups. Of course, as a potential confounder age was still entered in all statistical models.

Due to the problems of interpreting self-reports of sleep problems in subjects using sleep medication, the main analyses were restricted to occupationally active subjects not having used sleep medication the last 3 months. However, as the intake of sleep medication indeed is an indicator of sleep problems, a separate analysis of the distribution of sleep disturbing factors was conducted in the group of 482 occupationally active subjects reporting use of sleep medication.

Statistical analysis

Bivariate associations between variables were investigated using Spearman correlation coefficients. Odds ratios (OR) of sleep problems were estimated by multiple logistic regression analysis adjusted for age, marital status, educational qualifications, BMI, leisure time exercise, smoking status, and alcohol intake. Because of high collinearity, job strain and job demands and decision authority were analyzed in separate models. Interaction between traffic noise and the other determinants of sleep problems was evaluated using departure from additivity as criterion. The amount of interaction was quantified by the attributable proportion

(AP) (Kalilani and Atashili, 2006) which is related to the relative excess risk due to interaction (RERI) (also known as the interaction contrast ratio) (Greenland et al., 2008):

$$AP = RERI/RR_{11} = (RR_{11} - RR_{01} - RR_{10} + 1)/RR_{11}$$

RR_{11} is the relative risk associated with both factors at high level, while RR_{01} (RR_{10}) symbolizes the relative risk of one factor at high level and the other at low level. When interaction is absent the expected value of AP is 0, while AP>0 indicates a synergistic additive interaction between risk factors. AP's and their 95% confidence intervals were calculated as described by Hosmer and Lemeshow (1992). As AP is derived for two dichotomous variables the calculations of APs involving trichotomous variables (traffic noise, job strain, job demands and decision authority) were carried out for the highest and lowest levels of these variables. This method was preferred over combining the medium level with one of the extreme levels because eventual interaction probably would be easier to discern with stronger contrasts.

In order to estimate the impact of interaction from a pair of sleep disturbing factors in terms of the additional number of sleep problems it may cause, we calculated attributable fractions. The attributable fraction expresses the reduction in sleep problem cases that would happen if the exposure is removed (Greenland, 2008). Specifically, we calculated the attributable fraction for a pair of sleep disturbing factors under two conditions, which were that interaction was present and absent, respectively. The impact of the interaction was expressed as the difference between the two attributable fractions and termed the excess attributable fraction among exposed subjects due to interaction, EAFE. It was calculated as:

$$EAFE = AP/(1\text{-}AP) \times 1/RR_{11}$$

The derivation of the expression for EAFE is presented in the appendix. The excess number of among the exposed due to interaction was calculated by multiplying EAFE with the number of cases with both variables at high levels. Statistical computations were made with the SPSS computer software, version 17.0. P-values below 0.05 were considered statistically significant.

Results

Distribution of sleep problems and determinants of sleep problems

Table 2 presents the crude distribution of sleep problems together with distributions of determinants of sleep problems in occupationally active men and women that have not used sleep medication the last 3 monthts, as well as in the subgroup of occupationally active subjects that have used sleep medication.

With regard to the first group, a significantly higher proportion of women compared to men reported sleep problems the last 14 days (20.6% versus 14.1%, P<0.001) and sleep problems attributed to traffic noise (5.8% versus 4.7%, P=0.008). Determinants of sleep problems were typically distributed differently between men and women, with the proportion of women reporting the presence of the sleep disturbing factor significantly higher than the proportion of men. The exceptions are the traffic noise at the residence ($L_{Aeq,24}$), psychological job demands, and bullying at work, which did not differ significantly between men and women.

The proportion of subjects with self-reported sleep problems was much higher among the 482 persons that had used sleep medication the last 3 months compared to the 12.093 subjects that had not (Table 2). For example, in the sleep medication group 77% of the women and

72% of the men reported sleep problems the last 14 days while the corresponding figures for men and women in the group that had not used sleep medication was 21% and 14%, respectively. The presence of pain and other afflictions was overrepresented in the group using sleep medication (76% and 65 in men and women, compared to 51% and 44%, respectively, in the group not using sleep medication, P<0.001). Other determinants of sleep disturbance were also more common in the group using sleep medication, but mostly in women. However, GIS-estimated exposure to traffic noise at the residential address did not differ between sleep medication groups (Table 2). Despite the similar traffic noise exposure levels, the different distributions of self-reported sleep problems and sleep disturbing factors in the two sleep medication groups suggest that the underlying causes for sleep problems are different in these groups. Accordingly, it does not seem advisable to pool data. In the remaining part of the article the analyses were performed only on the group not having used sleep medication the last 3 months.

Univariate associations between sleep problems and determinants of sleep problems

General sleep problems and sleep problems attributed to traffic noise were both significantly correlated with the other variables in Table 2. Numerical values of Spearman correlation coefficients ranged from 0.051 to 0.285 (P<0.001 for all coefficients) for sleep problems the last 14 days, and from 0.041 to 0.080 (P<0.001 for all coefficients) for sleep problems attributed to traffic noise (results not shown). Traffic noise ($L_{A,eq\ 24}$) was significantly correlated with sleep problems attributed to traffic noise (Spearman rho = 0.106, P<0.001), but only marginally with general sleep problems (Spearman rho = 0.018, P=0.052) (results not shown). There was also a significant correlation between general sleep problems and sleep problems attributed to traffic noise (Spearman r=0.123, P<0.001). Nevertheless, the majority

(63%) of persons with sleep problems attributed to traffic noise did not have general sleep problems according to the above classification.

The psychological stress variables were also significantly correlated to each other. However, with the exception of job strain, job demands and decision authority the correlations were rather modest (all Spearman $r<0.15$). Spearman $r>0.1$ was observed only for correlations of job strain with, respectively, pain or other afflictions, experiencing bullying at work and worries of losing the job, as well as for the correlations of worries of losing the job with, respectively, decision authority and troubles paying the bills.

Determinants of general sleep problems

Estimates of OR of sleep problems associated with the sleep disturbance factors in Table 2 were estimated in multiple logistic regression analyses. Two models were investigated with work stress expressed as either job strain or job demands and decision authority. With the exception of job demands and decision authority the results concern the model with job strain. The results are summarized Table 3 for general sleep problems and in Table 4 for sleep problems attributed to traffic noise.

With regard to general sleep problems (Table 3) all sleep disturbance factors listed in Table 2 were significant risk factors of sleep problems with the exception in men of decision authority, taking care of a relative and traffic noise. In women decision authority was significantly associated with sleep problems at the medium level (OR=1.21, 95% CI 1.03-1.43, P=0.023) but not at the low level.

Dichotomizing the analysis according to age 45 years (Vgontzas et al., 2001), did not alter the general picture of significant risk factors seen in Table 3 (results not shown). This suggests that all age groups can be pooled for the analyses of general sleep problems.

To see how the above results were affected by the fact that the sleep problem cases include subjects that were only moderately or little troubled by sleep problems, the analyses were repeated with a more restrictive definition of general sleep problems, where cases are very troubled by sleep problems. Generally, the risks were similar although with larger confidence intervals. Thus, in the female group residential traffic noise exposure, taking care of a sick, disabled or old relative, and bullying at work was no longer significant, and job strain was no longer significant in men (results not shown).

Determinants of sleep problems attributed to traffic noise

With regard to sleep problems attributed to traffic noise all factors in Table 2 were associated with a significant risk, except the work stress variables in women (Table 4). Experiencing bullying at work was borderline significant in women (OR=1.86, 95% CI 0.99-3.14, P=0.054). In men, medium level decision authority was significantly associated with sleep problems relative to high level decision authority (OR=1.42, 95% CI 1.05-1.93).

The above conclusions were not influenced by limiting the analysis to subjects either above or below 45 years. The psychological variables remained strong risk factors of sleep problems attributed to traffic noise, but did not differ markedly in magnitude compared to those in Table 4 (results not shown). This suggests that all age groups can be pooled for the analyses of sleep problems attributed to traffic noise.

Interaction between traffic noise and other predictors of sleep problems

The results presented in Table 3 and 4 indicate that the risk associated with most sleep disturbing factors were similar in men and women. However, there were some exceptions. With regard to general sleep problems traffic noise was a significant risk factor in women but not in men. Consequently, for this outcome the analyses of interaction effects between traffic

noise and other sleep disturbing factors were carried out separately for men and women. With regard to sleep problems attributed to traffic noise men and women differed with respect to the effects of work stress. In this case analyses of interaction effects between work stress and traffic noise was therefore made separately for men and women, while interaction effects between traffic noise and the other stress-related factors were analyzed in men and women combined.

With regard to general sleep problems none of the AP estimates deviated significantly from 0, with the exception of AP associated with the interaction between traffic noise and experiencing bullying at work in women. This result is presented in Figure 2.

For sleep problems attributed to traffic noise the results of the analyses of interaction effects are presented in Table 5. Significant interaction effects were found between GIS modeled traffic noise and, respectively, job demands in men, taking care of a sick, disabled or old relative, troubles paying bills, and suffering from pain or other afflictions. Moreover, the interaction between experiencing bullying at work and traffic noise was borderline significant (AP=0.37, 95% CI -0.05-0.79), and in men the interaction between job strain and traffic noise was also borderline significant (AP=0.30, 95% CI -0.01-0.61).

These findings remained when the analyses were stratified according to age. Also the estimated AP remained similar in both groups defined as below or above 45 years of age (results not shown).

In Table 5 are also presented estimates of the excess fraction and excess number of sleep problems associated with significant interaction effects. The sum of the excess number of cases is 114, corresponding to 18% of the total number of 633 persons (Table 2) with self-reported sleep problems attributed to traffic noise. These estimates of the impact of interaction effects in terms of the number of cases should only be considered a rough estimate as neither the exposure for medium levels of traffic noise or work stress nor co-exposure to other stress

factors are considered. Nevertheless, the data in Table 5 suggest that 10-20% of the sleep problems that persons attribute to traffic noise can be attributed the interaction between high levels of traffic noise and high levels of psychological stress. Job demands in men contribute most to this excess attributable fraction, but this result should be interpreted with some caution because of the relative large uncertainty on the estimated AP for this interaction (Table 5).

Discussion

The main findings of the present study are, firstly, that work-related as well as non-work-related psychological stress factors are independent risk factors of general sleep problems in both men and women. This finding is in accordance with those obtained in other studies, which have focused on either work stress or non-work related distress as sleep disturbing factors (Middelkoop et al., 1996;Steptoe et al., 2008;Rugulies et al., 2009). Secondly, these factors were also strongly associated with sleep problems attributed to traffic noise in analyses disregarding interaction effects. This is somewhat surprising, as a reasonable *a priori* expectation would have been that factors unrelated to traffic noise would have a weaker effect on sleep problems attributed to traffic noise than on general sleep problems that are not attributed to external causes. This conundrum is at least partly resolved by our third main finding in the study, namely the observation of strong interaction between psychological factors and traffic noise with regard to sleep problems attributed to traffic noise. The analyses showed that many of the psychological factors were strong risk factor of sleep problems at high traffic noise levels only, but not at low levels.

The interaction effects exhibited a relatively consistent pattern. We found that high levels of traffic noise at the residence in combination with a high level of one of the other sleep disturbing factors showed a more than additive risk of sleep problems attributed to traffic

noise for 4 of the 8 combinations of the factors that were tested, and experiencing bullying at work as well as job strain in men was of borderline significance. The two variables that did not interact synergistically with traffic noise were decision authority and worries of losing the job. While it is clear that decision authority had no clear effect on sleep problems attributed to traffic noise at all and therefore interaction effects should not be expected, it is not obvious why worries about loosing the job showed should deviate from the otherwise consistent pattern of interactions.

The attributable proportion was in the order of 31-86% for the factors showing significant interaction with traffic noise. Since high traffic noise levels ($L_{Aeq,24}$ >55 dBA) at the residence and several other risk factors are widespread among the adult working population (Table 2), the interaction effect between traffic noise and other sleep disturbing factors have the potential to contribute significantly to sleep problem attributed to traffic noise in the society. Our rough estimation indicates that as much as 10-20% of the sleep problems attributed to traffic noise might be attributed to the interaction between traffic noise and other risk factors.

One implication of the results is that work-related psychological stress may have considerable impact on sleep problems attributed to traffic noise (which is not usually considered as a consequence of work stress). Another implication is that since living close to heavily trafficked roads may be considered an indicator of socio-economic status (Hoffman et al., 2003), it may be speculated if the interaction between traffic noise and psychological factors contributes significantly to lower life quality and poorer health associated with low socio-economic status via the impact on sleep problems.

With regard to general sleep problems only one significant interaction was found among the 8 that were investigated, namely, the moderating effect of traffic noise on the effect of experiencing bullying at work in women. Thus, the absence of a moderating effect of traffic

noise on psychological stress on this outcome is a relatively consistent pattern, which may be explained by the low strength of association between traffic noise and general sleep problems. The correlation between traffic noise and general sleep problems was just of borderline significance, and when adjusting for several confounders it was a weak but nevertheless significant risk factor in women only.

Considering that GIS modelled traffic noise is a strong risk factor of sleep problems attributed to traffic noise it may be asked why traffic noise is such a weak risk factor of general sleep problems. The reason might be that the underlying view, that sleep problems attributed to traffic noise is a subclass of general sleep problems, is too naïve. Actually, our analyses also showed that the majority of subjects with sleep problems attributed to traffic noise did not suffer from general sleep problems. Thus, sleep problems attributed to traffic noise is not generally perceived as a having "sleep difficulties" (the words used in the questionnaire to address general sleep problems) by the respondents. Therefore questions on sleep problems that mention traffic noise as the source of disturbance may be more accurate when assessing the effect of traffic noise. This seems to be recognized in studies of traffic noise effects as in most of these studies sleep problems are addressed as sleep problems attributed to specific traffic-related sources (Miedema and Vos, 2007) and not as "general sleep problems" in the sense used in this study.

Sleep problems were more prevalent among women, which is in accordance the findings in many previous studies (Chen et al., 2005;Arber et al., 2009;Niedhammer et al., 2009). This was not caused by the risk factors being stronger in women than in men as our analyses showed no marked differences between men and women in this respect. There were a few exceptions, however. For example, taking care of a sick, disabled, or old relative was a significant predictor of sleep problems in women, but not in men. This might reflect different social responsibilities of men and women, with fewer men having or taking this

responsibility. Job strain and job demands were strong risk factors of sleep problems attributed to traffic noise in men, but not in women. It may be speculated that since men and women in general hold different jobs, job strain and job demands means something different in men and women.

A number of strengths and limitations of the study should be mentioned. Among the strengths is the large number of subjects which confers sufficient statistical power to detect interaction effects. Secondly, traffic noise levels were estimated with GIS and therefore independent of the self-reported sleep problem measures which should reduce response bias. Thirdly, the study is based on a population survey which does allow some generalization of the findings. There are also several limitations however. Firstly, although the survey aimed at being representative, the participation rate was higher among women, the elderly, individuals born in Sweden and among individuals with high education and income (Rosvall et al., 2005). However, this is of minor importance for our main findings, as the associations investigated in this study are not dependent on strict representativity, and furthermore were adjusted for the influence of gender, age and other potential confounders. Secondly, the design of this study is cross-sectional and therefore does not allow us to infer the direction of causality between the predictors and sleep problems. Sleep problems can cause physiological stress (Meerlo et al., 2008) and musculoskeletal problems (Canivet et al., 2008) which may reduce ones capability to function at work and at home. This may in turn lead to increased levels of psychological stress. On the other hand there are also prospective studies which have demonstrated that psychological stress can precede sleep problems (Linton, 2004;Rugulies et al., 2009). Thirdly, it can not be excluded that the observed associations in part are caused by an underlying personality disposition. It has, for example, previously been demonstrated that trait anxiety scores are positively correlated with ratings of annoyance to factors in the home environment (Persson et al., 2007). It is also conceivable that other dispositions such as denial or the need

for approval have affected responses. However, the fact that the distribution and occurrence of various sources of psychological stress (e.g. pain or afflictions, job strain, bullying, worrying about loosing the job) differs quite markedly as well as the rather modest correlations between psychological stress variables suggest that the participants have been able to make a differential judgments and that it is meaningful to interpret them as indicators in their own right. Fourthly, the simplified modelling of road noise may in some cases yield uncertain exposure values with a bias towards too high exposure. This is due to the assumptions that all residents live on the ground floor, and that noise barriers and topography was not taken into account. Lastly, there were some factors of relevance for sleep problems that we were not able to include in this investigation because of the lack of information, such as shift work, if the bedroom was facing the main source of the traffic noise or not, and whether the bedroom window was open or closed during the night. It is our opinion that these shortcomings have not biased our findings but they might have reduced the strength of the statistical associations.

In conclusion, job strain, job demands, pain and different worries were independently associated with general sleep problems in both men and women. With regard to sleep problems attributed to traffic noise, job strain and job demands were significant risk factors in men only, while different worries and pain were significant risk factors in both sexes. Lastly, with regard to the risk factors of sleep problems attributed to traffic noise significant synergistic interactions were found between traffic noise and different worries and pain in both sexes, as well as between traffic noise and job demands in men.

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Conflicts of interests: The authors declare that they have no conflict of interest.

Appendix

Calculation of excess attributable fraction

Consider two interacting variables as a single variable with level low (both variables at low level) and high (both high), and RR is the relative risk of sleep problems at the high level. The attributable fraction of sleep problem cases among the exposed, AFE, is then:

AFE = (RR-1)/RR (Greenland, 2008).

Likewise, assume that RR* would be the relative risk if there was no interaction between the variables, and the corresponding attributable fraction, is AFE* = (RR*-1)/RR*. We define the excess attributable fraction of sleep problem cases among the exposed, EAFE, as the difference between these two attributable fractions:

EAFE = AFE – AFE* = (RR-1)/RR – (RR*-1)/RR*.

RR and RR* are related through AP. Thus

$$AP = (RR_{11} - RR_{10} - RR_{01} + 1)/RR_{11} = (RR_{11} - RR^*_{11})/RR_{11}$$

where $RR^*_{11} = RR_{10} + RR_{01} - 1$. Rearranging this expression for AP one reaches the relation $RR^*_{11} = RR_{11} \times (1\text{-}AP)$. Inserting this in the expression for EAFE (and making use of the

identities $RR = RR_{11}$ and $RR^* = RR^*_{11}$) we arrive to the expression for EAFE used in this study:

$$EAFE = AP/(1\text{-}AP) \times 1/RR_{11}.$$

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Table 1. Items used to measure sleep problems and sleep problem predictors in the study.

Items	Response categories and value labels
Sleep problems:	
Have you the last 14 days been troubled by sleep difficulties?	1=*To a very high degree; Somewhat*, 2=*A little; Not at all*
Have you during the last 14 days been troubled by sleeping difficulties or sleep problems and if this is the case how troubled have you felt?	1=*Yes, very troubled; Yes, a little troubled* 2=*No*
General sleep problems	1=*Yes* (response=1 to one of the above questions) 0=*No* (response=2 to both questions above)
Does traffic noise (road, train or airplane) lead to some of the following disturbances in your home:	
a) Difficult to sleep?	1=*Yes, at least once per day once per week; Yes, at least once per week* 2=*Yes, more rarely*, *No*
b) Awakening?	1=*Yes, at least once per day; Yes, at least once per week* 2=*Yes, more rarely; No*
Sleep problems attributed to traffic noise	1=*Yes* (response=1 to one of the above questions) 0=*No* (response=2 to both questions above)
Worries about losing the job	
Are you worried that you might lose your job within the next year?	1=*Not at all; Not particular worried* 0=*Somewhat worried; Very worried*
Bullying at work	
How often does bullying or persecutions occur at your work?	1=*Every day;Some days per week* 0=*More rarely; Never*
Troubles paying bills	
How often during the last 12 months do you have had problems paying your bills?	1=*Every month; About half of the months; Sometimes* 0=*Never*
Taking care of a relative	
Do you have an old, sick or disabled relative that you have to help in their everyday routines, look after or take care of?	1=*No* 0 =*Yes*
Pain	
Indicate the statement that best describes your present state of health: a) Pain/afflictions	1=*I have some pain or afflictions*; *I have strong pain or afflictions* 0=*I have no pain or afflictions;*
Work stress	
Job demands	Job demands score 1-1.99 = *Low* Job demands score 2-2.99 = *Medium* Job demands score 3-4 = *High*
Decision authority	Decision authority score 1-1.99 = *Low* Decision authority score 2-2.99 = *Medium* Decision authority score 3-4 = *High*
Job strain	*See Figure 1*.

Table 2. Crude distribution of sleep problems, and potentially sleep disturbing factors in occupationally active subjects that have not used sleep medication the last 3 months and in subjects that have used sleep medication. Statistical test of the difference in distributions between sleep medication groups of same gender (chi-square test): [a] P<0.05; [b] P<0.01; [c] P<0.001.

	Not using sleep medication					Using sleep medication				
	Women		Men		Men vs. women (P-value)	Women		Men		Men vs. women (P-value)
	n	%	n	%		n	%	n	%	
All	6396		5697			313		169		
Sleep problems in the last 14 days					P<0.001					0.204
No	4922	79.4%	4749	85.9%		70	22.9%[c]	47	28.1%[c]	
Yes	1279	20.6%	778	14.1%		236	77.1%[c]	120	71.9%[c]	
Very troubled by sleep problems in the last 14 days (alternative outcome)					P<0.001					0.386
No	5658	91.3%	5258	95.1%		143	89.1%[c]	85	50.9%[c]	
Yes	540	8.7%	269	4.9%		163	53.3%[c]	82	49.1%[c]	
Sleep problems attributed to traffic noise					P=0.008					0.608
No	5995	94.2%	5400	95.3%		277	89.1%[c]	147	87.4%[c]	
Yes	367	5.8%	266	4.7%		34	10.9%[c]	21	12.6%[c]	
Traffic noise at residence ($L_{Aeq.24}$)					0.124					0.850
<50 dBA	2489	38.9%	2152	37.8%		116	37.1%	67	39.6%	
50-54 dBA	1471	23.0%	1300	22.8%		72	23.0%	38	22.5%	
≥55 dBA	2436	38.1%	2245	39.4%		125	39.9%	64	37.9%	
Pain or afflictions?					<0.001					0.024
None	3040	48.9%	3121	56.1%		68	24.1%[c]	54	35.1%[c]	
Yes	3183	51.1%	2440	43.9%		214	75.9%[c]	104	64.9%[c]	
Job strain					<0.001					0.046

Low	2945	48.2%	3030	55.4%		117	39.4%[b]	77	48.4%	
Medium	2507	41.0%	2053	37.5%		132	44.4%[b]	68	42.8%	
High	659	10.7%	387	7.1%		48	16.2%[b]	14	8.8%	
Psychological job demands					0.121					0.307
Low	327	5.3%	285	5.2%		16	5.4%[c]	10	6.2%	
Medium	4585	74.8%	4186	76.4%		195	65.4%[c]	114	71.3%	
High	1215	19.8%	1008	18.4%		87	29.2%[c]	36	22.5%	
Job decision authority					<0.001					0.060
Low	221	3.5%	151	2.7%		15	5.0%	4	2.4%	
Medium	2425	38.9%	1704	30.8%		131	43.2%	57	35.0%	
High	3588	57.6%	3681	66.5%		157	51.8%	102	62.6%	
Experiencing bullying at work?					0.380					0.784
Rarely	4904	96.7%	4903	97.0%		206	96.7%	125	96.2%	
Daily or weekly	168	3.3%	152	3.0%		7	3.3%	5	3.8%	
Worried about loosing the job?					0.030					0.980
No	5725	89.7%	5172	90.8%		272	86.5%	147	87.0%	
Yes	659	10.3%	521	9.2%		41	13.5%	22	13.0%	
Troubles paying bills?					0.006					0.499
Never	4727	74.7%	4334	76.8%		212	69.1%[a]	121	72.0%	
Sometimes or often	1602	25.3%	1307	23.2%		95	30.9%[a]	47	28.0%	
Taking care of a relative?					<0.001					0.120
No	5526	87.0%	5138	90.9%		257	82.9%[a]	149	88.2%	
Yes	825	13.0%	515	9.1%		53	17.1%[a]	20	11.8%	

Table 3: Odds ratio (OR) and 95% confidence intervals (CI) of sleep problems in the last 14 days estimated in multiple logistic regression analysis. Job strain was replaced by job demands and decision authority in regression models of the two latter variables. All risk estimates are adjusted for age, marital status, educational level, BMI, leisure time exercise, smoking status, and alcohol intake.

		Women			Men		
Variable	Level	OR		95% CI	OR		95% CI
Work stress: Job demands	Low (reference)	1			1		
	Medium	0.99	NS	0.66-1.49	1.06	NS	0.66-1.71
	High	1.70		1.11-2.61	1.82		1.10-2.99
Work stress: Decision authority	High (reference)	1			1		
	Medium	1.21		1.03-1.43	1.03	NS	0.84-1.26
	Low	1.38	NS	0.92-2.07	0.99	NS	0.58-1.70
Work stress: Job strain	Low (reference)	1			1		
	Medium	1.40		1.18-1.66	1.13	NS	0.93-1.37
	High	1.96		1.54-2.49	1.89		1.39-2.57
Residential traffic noise[e] ($L_{Aeq,24}$)	<50 dBA (reference)	1			1		
	50-54 dBA	0.97	NS	0.79-1.20	1.14	NS	0.90-1.43
	>=55 dBA	1.25		1.04-1.50	0.92	NS	0.75-1.14
Pain or afflictions?	None (reference)	1			1		
	Yes	2.33		1.97-2.76	2.35		1.94-2.85
Taking care of a relative?	No (reference)	1			1		
	Yes	1.30		1.04-1.63	1.10	NS	0.81-1.49
Worried about loosing the job?	No (reference)	1			1		
	Yes	1.48		1.16-1.90	2.18		1.67-2.84
Experiencing bullying at work?	Rarely (reference)	1			1		
	Daily or weekly	1.75		1.20-2.56	1.60		1.03-2.49
Troubles paying bills?	Never (reference)	1			1		
	Sometimes or often	1.23		1.02-1.49	1.41		1.14-1.73

Table 4: Odds ratio (OR) and 95% confidence intervals (CI) of sleep problems attributed to traffic noise estimated in multiple logistic regression analysis. Job strain was replaced by job demands and decision authority in regression models of the two latter variables. All risk estimates are adjusted for age, marital status, educational level, BMI, leisure time exercise, smoking status, and alcohol intake.

		Women			Men		
Variable	Level	OR		95% CI	OR		95% CI
Work stress: Job demands	Low (reference)	1			1		
	Medium	0.75	NS	0.42-1.34	2.74	NS	0.98-7.65
	High	0.88	NS	0.47-1.64	4.07		1.43-7.65
Work stress: Decision authority	High (reference)	1			1		
	Medium	1.07	NS	0.81-1.40	1.42		1.05-1.93
	Low	0.94	NS	0.46-1.90	1.42	NS	0.67-3.02
Work stress: Job strain	Low (reference)	1			1		
	Medium	1.08	NS	0.82-1.44	1.43		1.05-1.96
	High	1.05	NS	0.69-1.61	2.30		1.46-3.63
Residential traffic noise ($L_{Aeq,24}$)	<50 dBA (reference)	1			1		
	50-54 dBA	1.83		1.22-2.73	1.31	NS	0.83-2.07
	>=55 dBA	2.86		2.02-4.04	2.75		1.91-3.97
Pain or afflictions?	None (reference)	1			1		
	Yes	1.42		1.08-1.88	1.44		1.06-1.95
Taking care of a relative?	No (reference)	1			1		
	Yes	1.44		1.00-2.07	1.85		1.20-2.85
Worried about loosing the job?	No (reference)	1			1		
	Yes	1.86		1.29-2.67	1.53		1.00-2.35
Experiencing bullying at work?	Rarely (reference)	1			1		
	Daily or weekly	1.76	NS	0.99-3.14	1.92		1.07-3.45
Troubles paying bills?	Never (reference)	1			1		
	Sometimes or often	1.51		1.12-2.04	1.79		1.30-2.46

Table 5. Analysis of additive interaction between traffic noise and various predictors of sleep problems attributed to traffic noise (EAFE: Excess attributable fraction among those exposed to both factors at high level).

		Sleep problems attributed to traffic noise					Excess number of cases among the exposed due to interactions	
		Low traffic noise (<50 dBA)		High traffic noise (≥55 dBA)		Signifi-cance test		
		OR	95% CI	OR	95% CI		EAFE	n
Job demands (men)	Low	1		0.33	(0.03-3.89)			
	High	1.45	(0.31-6.92)	5.55	(1.23-24.9)			
AP				0.86	(0.53-1.00)	P<0.001	1.00	51
Job demands (women)	Low	1		2.21	(0.61-7.98)			
	High	0.45	(0.13-1.61)	2.10	(0.69-6.34)			
AP				0.21	(-0.78-1.00)	NS	-	-
Decision authority (men)	High	1		2.59	(1.61-4.18)			
	Low	0.90	(0.11-7.41)	3.72	(1.34-10.3)			
AP				0.33	(-0.49-1.00)	NS	-	-
Decision authority (women)	High	1		2.97	(1.85-4.78)			
	Low	0.65	(0.13-1.61)	2.40	(0.87-6.58)			
AP				-0.09	(-1.21-1.00)	NS	-	-
Job strain (men)	Low	1		2.05	(1.19-3.55)			
	High	2.15	(0.86-5.41)	5.41	(2.69-10.88)			
AP				0.41	(-0.05-0.86)	P=0.079	(0.128)	(7)
Job strain (women)	Low	1		2.39	(1.43-3.99)			
	High	0.60	(0.20-1.83)	2.84	(1.46-5.50)			
AP				0.30	(-0.19-0.79)	NS	-	-
Taking care of a relative?	No	1		2.48	(1.90-3.25)			
	Yes	0.95	(0.48-1.85)	4.81	(3.23-7.16)			
AP				0.50	(0.27-0.72)	P<0.001	0.205	14
Worried about loosing the job?	No	1		2.93	(2.22-3.86)			
	Yes	2.30	(1.34-3.96)	4.57	(3.02-6.92)			
AP				0.07	(-0.33-0.48)	NS	-	-
Troubles paying bills?	No	1		2.46	(1.81-3.33)			
	Yes	1.41	(0.89-2.23)	4.77	(3.37-6.77)			
AP				0.40	(0.21-0.59)	P<0.001	0.140	21
Experiencing bullying at work?	No	1		2.70	(2.09-3.51)			
	Yes	1.42	(0.55-3.66)	4.96	(2.82-8.72)			
AP				0.37	(-0.05-0.79)	P=0.087	(0.118)	(3)
Pain or other afflictions?	No	1		2.27	(1.57-3.29)			
	Yes	1.08	(0.71-1.65)	3.42	(2.39-4.91)			
AP				0.31	(0.10-0.53)	P=0.004	0.131	28

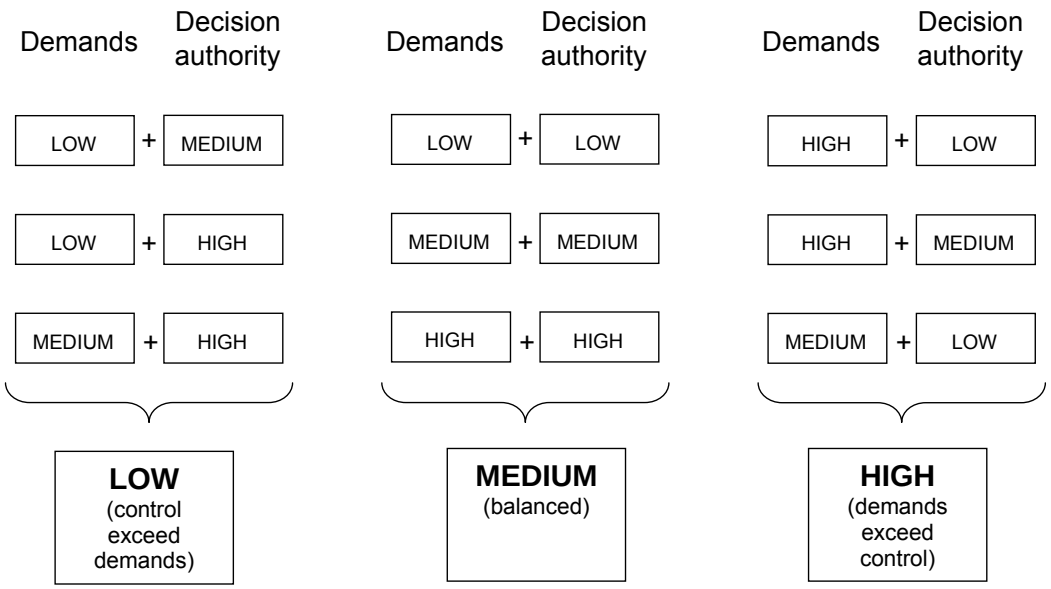

Figure 1. Construction of Low, Medium and High job strain categories based on the balance between job demands and decision authority categories.

Figure 2. Estimated OR (with 95% CI) demonstrating the interaction between traffic noise ($L_{Aeq,24}$) and experiencing bullying at work on the risk of self-reported general sleep problems in women. OR different from 1, **P<0.01. AP: Attributable proportion due to interaction (±95% CI).