

Nighttime transportation noise annoyance in Germany: Personal and regional differences in the German National Cohort Study

Kathrin Wolf¹, Ute Kraus¹, Mihovil Džolan^{1,2}, Gabriele Bolte³, Tobia Lakes⁴, Tamara Schikowski⁵, Karin Halina Greiser^{6,7}, Oliver Kuss⁸, Wolfgang Ahrens^{9,10}, Fabian Bamberg¹¹, Heiko Becher¹², Klaus Berger¹³, Hermann Brenner¹⁴, Stefanie Castell¹⁵, Antje Damms-Machado⁶, Beate Fischer¹⁶, Claus-Werner Franzke¹⁷, Sylvia Gastell¹⁸, Kathrin Günther⁹, Bernd Holleczek¹⁹, Lina Jaeschke²⁰, Rudolf Kaaks⁶, Thomas Keil^{21,22,23}, Yvonne Kemmling¹⁵, Lilian Krist²¹, Nicole Legath¹³, Michael Leitzmann¹⁶, Wolfgang Lieb²⁴, Markus Loeffler^{25,26}, Claudia Meinke-Franze²⁷, Karin B. Michels¹⁷, Rafael Mikolajczyk⁷, Susanne Moebus²⁸, Ulrich Mueller²⁹, Nadia Obi¹², Tobias Pischon^{20,30,31,32}, Wolfgang Rathmann⁸, Sabine Schipf²⁷, Borge Schmidt²⁸, Matthias Schulze³³, Inke Thiele¹, Sigrid Thierry^{1,34}, Sabina Waniek²⁴, Claudia Wigmann⁵, Kerstin Wirkner^{25,26}, Johannes Zschocke^{7,35}, Annette Peters^{*,1,36}, Alexandra Schneider^{*,1}

¹ Helmholtz Zentrum München - German Research Center for Environmental Health (GmbH), Institute of Epidemiology, Neuherberg, Germany

² Technical University of Munich, Department of Sport and Health Sciences, München, Germany

³ University of Bremen, Institute of Public Health and Nursing Research, Department of Social Epidemiology, Bremen, Germany

⁴ Humboldt-Universität zu Berlin, Geography Department, Berlin, Germany

⁵ IUF-Leibniz Research Institute for Environmental Medicine, Düsseldorf, Germany

⁶ German Cancer Research Center (DKFZ), Division of Cancer Epidemiology, Heidelberg, Germany

⁷ Institute of Medical Epidemiology, Biostatistics, and Informatics, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany

⁸ German Diabetes Center, Leibniz Institute for Diabetes Research at Heinrich Heine University, Institute for Biometrics and Epidemiology, Düsseldorf, Germany

⁹ Leibniz Institute for Prevention Research and Epidemiology - BIPS, Bremen, Germany

¹⁰ Faculty of Mathematics/Computer Science, Institute of Statistics, University of Bremen, Bremen, Germany

¹¹ Department of Diagnostic and Interventional Radiology, Medical Center – University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany

¹² Institute of Medical Biometry and Epidemiology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany

¹³ Institute of Epidemiology and Social Medicine, University of Münster, Münster, Germany

¹⁴ German Cancer Research Center (DKFZ), Division of Clinical Epidemiology and Aging Research, Heidelberg, Germany

¹⁵ Department for Epidemiology, Helmholtz Centre for Infection Research (HZI), Braunschweig, Germany

¹⁶ Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany

¹⁷ Institute for Prevention and Cancer Epidemiology, Faculty of Medicine and Medical Center, University of Freiburg, Freiburg, Germany

¹⁸ German Institute of Human Nutrition Potsdam-Rehbrücke, NAKO Study Center, Nuthetal, Germany

¹⁹ Saarland Cancer Registry, Saarbrücken, Germany

²⁰ Molecular Epidemiology Group, Max Delbrück Center for Molecular Medicine in the Helmholtz Association (MDC), Berlin, Germany

²¹ Institute for Social Medicine, Epidemiology and Health Economics, Charité-Universitätsmedizin Berlin, Germany

²² Institute for Clinical Epidemiology and Biometry, University of Würzburg, Würzburg, Germany

²³ State Institute of Health, Bavarian Health and Food Safety Authority, Bad Kissingen, Germany

²⁴ Institute of Epidemiology, Kiel University, Kiel, Germany

²⁵ LIFE - Leipzig Research Center of Civilization Diseases, University of Leipzig, Leipzig, Germany

²⁶ Institute for Medical Informatics, Statistics, and Epidemiology, University of Leipzig, Leipzig, Germany

²⁷ Institute for Community Medicine, University Medicine Greifswald, Greifswald, Germany

²⁸ Institute for Medical Informatics, Biometry and Epidemiology, University of Duisburg-Essen, Essen, Germany

²⁹ Federal Institute for Population Research, Wiesbaden, Germany

³⁰ Charité – Universitätsmedizin Berlin, Berlin, Germany

³¹ German Center for Cardiovascular Research (DZHK), partner site Berlin, Berlin, Germany

³² MDC/BIH Biobank, Max Delbrück Center for Molecular Medicine in the Helmholtz Association (MDC) and Berlin Institute of Health (BIH), Berlin, Germany

³³ German Institute of Human Nutrition Potsdam-Rehbrücke, Nuthetal, Germany

³⁴ NAKO Study Center, Universitätsklinikum Augsburg, Augsburg, Germany

³⁵ Institute of Physics, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany

³⁶ Institute for Medical Information Processing, Biometry and Epidemiology, Ludwig-Maximilians-Universität München, München, Germany

* Shared last authorship

Correspondence address

Kathrin Wolf

Institute of Epidemiology – Research Group “Environmental Risks”

Helmholtz Zentrum München - German Research Center for Environmental Health (GmbH)

Ingolstädter Landstr. 1

85764 Neuherberg

kathrin.wolf@helmholtz-muenchen.de

Abstract

Background: Noise annoyance is associated with adverse health-related conditions and reduced wellbeing. Thereby, subjective noise annoyance depends on the objective noise exposure and is modified by personal and regional factors.

Objective: How many participants of the German National Cohort Study (GNC; NAKO Gesundheitsstudie) were annoyed by transportation noise during nighttime and what factors were associated with noise annoyance?

Materials and methods: This cross-sectional analysis included 86,080 participants from 18 study centers, examined from 2014 to 2017. We used multinomial logistic regression to investigate associations of personal and regional factors to noise annoyance (slightly/moderately or strongly/extremely annoyed vs. not annoyed) mutually adjusting for all factors in the model.

Results: Two thirds of participants were not annoyed by transportation noise during nighttime and one in ten reported strong/extreme annoyance with highest percentages for the study centers Berlin-Mitte and Leipzig. The strongest associations were seen for factors related to the individual housing situation like the bedroom being positioned towards a major road [OR of being slightly/moderately annoyed: 4.26 (95% CI: 4.01; 4.52); OR of being strongly/extremely annoyed: 13.36 (95% CI: 12.47; 14.32)] compared to a garden/inner courtyard. Participants aged 40–60 years and those in low and medium income groups reported greater noise annoyance compared to younger or older ones and those in the high income group.

Conclusion: In this study from Germany, transportation noise annoyance during nighttime varied by personal and regional factors.

Keywords

Noise annoyance, noise exposure, personal factors, urban environment, GNC study

INTRODUCTION

According to the World Health Organization (WHO), noise is the second largest environmental health threat in Europe after air pollution [1, 2]. Humans are exposed to noise mainly in built-up areas, but also increasingly outside urban areas, with road traffic, air traffic, rail traffic, industrial activities, and neighborhoods being the main noise sources. The European Environment Agency estimated that 6.7 million people in Germany are exposed to harmful noise from road traffic during the day and 4.3 million people at night [3]. A variety of epidemiologic studies has reported adverse impacts of environmental noise on human health and well-being [4, 5, 6, 7]. Overall, the WHO assessed that more than one million disability adjusted life years, i.e. the number of years lost due to ill-health, disability or early death, in Western Europe each year are due to diseases caused by traffic noise [1, 2].

Noise annoyance is generally understood to be a psychological reaction to noise exposure [8] and is considered an environmental health burden. The WHO stated that noise annoyance is the second largest health outcome of environmental noise exposure after sleep disturbances [1] and is itself in turn associated with cardiovascular diseases and mental health [9, 10, 11, 12, 13, 14, 7]. In particular, noise annoyance was linked with an increased risk of arterial hypertension [13], atrial fibrillation [15], depression, and anxiety [9]. Noise during night is an evident source of sleep disturbance and noise annoyance, and adverse effects on health were shown to be more pronounced for nighttime noise annoyance compared to daytime noise annoyance [15, 5].

Three recent surveys among the Germany population, conducted between 2013 and 2016, reported 37% to 76% of the study participants to be at least slightly annoyed by road traffic noise [16, 11, 17]. Moreover, the burden of environmental noise was recently quantified for Germany by estimating the years lost due to disability (YLD, the years people are living with an adverse health condition or its consequences) with 29,433 YLD for noise annoyance due to road traffic noise, 5,669 YLD due to aircraft noise, and 23,367 YLD due to railway noise [18]. In view of the high numbers of affected individuals, there is a strong public health interest in identifying and evaluating factors that determine noise annoyance in Germany since it can only partly be explained by objectively measured noise levels. In fact, the correlation between objective and subjective measures of noise exposure is only modest as the association might be modified by regional and personal factors [19, 11, 20, 14, 21, 22]. Several studies demonstrated associations of noise annoyance with regional factors such as residential areas, type of municipality, and deprived living areas [23, 22, 16]. Regarding personal factors, noise sensitivity and coping capacities may contribute to the variability of subjective annoyance in comparable proportions to the individual noise levels [24, 25]. Further personal factors that were related to noise annoyance included fear of harm [24], perceived noise control [21],

perception of greenery [26], but also age, sex, socio-economic status, and housing conditions [24, 27, 23, 16, 25, 11, 28, 22].

Noise annoyance and selected potentially influential factors have already been studied in the general German population in several surveys [29, 23, 16, 11]. The two population-based studies “Studie zur Gesundheit Erwachsener in Deutschland” (DEGS1) [16] conducted among 7,988 participants between 2008-2011, and the telephone health survey “Gesundheit in Deutschland Aktuell” (GEDA) conducted among 19,294 participants in 2012/13, both reported higher noise annoyance among persons with lower socio-economic status and poor housing conditions. Also, lower-income households were more likely to be located close to busy roads and, thus, more exposed to noise [16].

The main objective of this cross-sectional analysis using the midterm baseline dataset of the German National Cohort Study (GNC; NAKO Gesundheitsstudie; www.nako.de) [30] was to assess the amount of GNC participants being annoyed by nighttime transportation noise and whether these numbers are comparable to previous findings, especially from studies conducted in Germany. In addition, we aimed to identify personal (demographic, socio-economic and housing condition) and regional factors associated with noise annoyance.

METHODS

Study population

We used data from the midterm baseline dataset of participants of the GNC study [30] collected in 18 study centers (Augsburg, Berlin-Mitte, Berlin-Nord, Berlin-Süd, Bremen, Düsseldorf, Essen, Freiburg, Halle, Hamburg, Hannover, Kiel, Leipzig, Mannheim, Münster, Neubrandenburg, Regensburg and Saarbrücken) between 2014 and 2017 (see also the introductory article by Schipf and colleagues of this special issue). The GNC study aims to investigate the causes for the development of major chronic diseases using extensive personal interviews and self-administered questionnaires, a wide range of medical examinations, and the collection of various biological samples [30]. Participants aged 20 to 69 years with main residence in one of the recruitment regions in Germany were randomly selected from the general population. In total, 101,816 participants were included in the midterm baseline dataset. Of these, 86,080 participants provided information on noise annoyance, comprising the sample for this analysis. The study was conducted in accordance with the Declaration of Helsinki.

Assessment of noise annoyance

Participants were asked via a touch-screen based questionnaire to answer the following question: “How much are you disturbed during nighttime (10 p.m. - 6 a.m.) by traffic noise of cars, trucks, trains or airplanes in your bedroom when windows are tilted or completely open?” on a Likert scale

ranging from “1: not disturbed at all” to “5: extremely disturbed”. Since response frequencies for categories 2-5 were rather small, we combined categories 2 and 3 to “slightly/moderately disturbed” and 4 and 5 to “strongly/extremely disturbed” according to a previous study [16]. Even though the wording “disturbed” was used in the questionnaire, we interpret the question rather in the sense of annoyance as we did not ask about particular events at night such as waking up or falling asleep which is usually done when evaluating disturbances [31]. In addition, the words “disturbed” and “annoyed” are used synonymously in the German language [32]. Therefore, we will generally refer to noise annoyance in the following.

Personal and regional factors

We investigated several personal demographic and socio-economic factors including age, sex (females vs. males), nationality (German vs. other), marital status (married vs. not married including divorced and widowed), education (low: secondary school or no graduation, medium: high-school, high: higher education entrance qualification), household income per month (low: < 1,700€, medium: 1,700€ - 4,499€, high: ≥ 4,500€), employment status (employed vs. not employed including pupils and pensioners). In addition, we examined the following personal factors describing housing conditions: home ownership (rented apartment/house, own apartment/house, assisted living, senior citizens’ home, and nursing home), number of persons living in the household (one, two, three and more persons), floor position of the bedroom (basement/ground floor vs. upper floor) and position of bedroom (towards major road, minor road, or garden/inner courtyard). For subsequent analyses, information on home ownership was dichotomized into rented apartment/house (including assisted living, senior citizens’ home and nursing home) and own apartment/house. As regional factor, we used the study center to account for regional differences of the recruitment regions and heterogeneity among the respective study populations.

Statistical analyses

We used multinomial logistic regression to investigate relations of personal and regional factors to noise annoyance mutually adjusting for all factors in the model by comparing the slightly/moderately and strongly/extremely annoyed groups with the not annoyed group. For age, the only variable available on a continuous scale, we inspected natural cubic splines with 2, 3 and 4 degrees of freedom to investigate a potential non-linear association with noise annoyance. The study centers were included as fixed effects since we were specifically interested in differences between the study centers. As sensitivity analyses, we performed two separate binary logistic regression models comparing at least slightly annoyed vs. not annoyed and strongly/extremely annoyed vs. not/slightly/moderately annoyed. Regression results are presented as odds ratios (OR) with 95%

confidence intervals (CI). All analyses were performed with R, version 3.6.0 (<https://www.r-projects.org/>) using the “mgcv” and “VGAM” packages.

RESULTS

Participant characteristics

Our sample included slightly more women than men (Table 1). Most participants were between 45 and 65 years old, were of German nationality, were employed, and were married. More than three-quarters of participants reported that their bedroom was located in the upper floor and more than half indicated that it was positioned towards the garden/inner courtyard. Nearly two-thirds of participants were not annoyed at all by night transportation noise (62.3%), 27.3% were slightly/moderately annoyed, and 10.4% reported strong/extreme annoyance (Table 1). When we compared demographic characteristics of participants across levels of noise annoyance, we noted that male individuals tended to be less annoyed by noise than female participants. By comparison, participants in the low income group, unmarried participants, those living in a rented apartment/house, those whose bedroom was located in the upper floor, and those whose bedroom was positioned towards a major road were more strongly/extremely annoyed than their respective counterparts (Table 1 and Supplementary Figure Z1 for row percentages of selected variables). Since differences in levels of noise annoyance were most pronounced for income and housing conditions, we also examined the relation of housing conditions to income. Participants with low income were more likely to live in a rented apartment/house, to have their bedroom in the basement/ground floor, and to have their bedroom positioned towards a major road compared to participants with high income (Supplementary Figure Z2). When examining the data by study center, participants in Berlin-Mitte and Leipzig showed the highest percentages of strong/extreme noise annoyance (16.4 and 13.7%, respectively), whereas participants from Augsburg and Regensburg showed the lowest percentages (7.1 and 7.3%, respectively; Figure 1).

Association of noise annoyance with personal and regional risk factors

Of the 86,080 participants with information on noise annoyance, 80,828 provided complete information for all explanatory factors and thus, were included in our main analysis. The inclusion of age as natural spline with 2, 3 and 4 degrees of freedom resulted in similar shapes indicating a quadratic association with highest noise annoyance among participants aged 40-60 years compared to younger and older participants (Figure 2). We therefore included age as natural spline with 2 degrees of freedom in our main models.

All other personal factors were included as binary or categorical variables and results are depicted in Table 2 compared to the respective reference categories. Interestingly, women were less likely to be

slightly/moderately annoyed by noise [OR: 0.92 (0.89; 0.96)] but more likely to be strongly/extremely annoyed by noise [OR: 1.26 (95% CI: 1.20; 1.33)] compared to not annoyed than males. For all other variables, effect estimates for slightly/moderately annoyed or strongly/extremely annoyed vs. not annoyed pointed in the same direction. Participants with non-German nationality, individuals with high-school, secondary school or no graduation, and those with more than three persons in the household were less likely to be annoyed by noise than those with German nationality, those with a higher education entrance qualification, and those living in single households. By comparison, those in low or medium income groups, those not employed, those not married, those living in a rented apartment/house, and individuals with a bedroom in the upper floor or a bedroom positioned towards a major or minor road were all more likely to be annoyed by noise than individuals in the high income group, individuals who were employed, married, those with home ownership, those whose bedroom was located in the basement or ground floor, and those whose bedroom was facing a garden/inner courtyard. The most pronounced increments in the odds of being slightly/moderately annoyed or being strongly/extremely annoyed vs. not being annoyed by noise were observed for housing conditions, particularly for position of the bedroom towards a major road [OR of being slightly/moderately annoyed by noise: 4.26 (95% CI: 4.01; 4.52)]; OR of being strongly/extremely annoyed by noise: 13.37 (95% CI: 12.47; 14.33)].

In terms of study region, participants in Berlin-Mitte [OR of being slightly/moderately annoyed by noise: 1.46 (95% CI: 1.34; 1.59); OR of being strongly/extremely annoyed by noise: 2.49 (95% CI: 2.19; 2.82)] and Leipzig [1.60 (95% CI: 1.84; 1.73); 2.04 (95% CI: 1.80; 2.30), respectively] showed the highest levels of noise annoyance compared to the reference study center Augsburg (chosen by default), whereas Kiel was the only study center whose participants reported significantly less noise annoyance than those in Augsburg [0.83 (95% CI: 0.75; 0.92); 0.90 (95% CI: 0.76; 1.06), respectively] (Figure 3).

As sensitivity analysis, we fitted two separate binary logistic regression models comparing at least slightly annoyed vs. not annoyed and strongly/extremely annoyed vs. not/slightly/moderately annoyed and effect estimates showed a similar pattern for the personal factors (Supplementary Table 1) as well as the study centers (Supplementary Figure Z3) compared to the multinomial logistic regression.

DISCUSSION

Main findings

In this cross-sectional analysis of the midterm baseline dataset, nearly two-thirds of GNC participants were not annoyed at all by nighttime transportation noise. However, 27.3% were slightly/moderately annoyed and one in ten reported strong annoyance by noise. All investigated demographic and socio-

economic factors as well as all variables related to housing conditions showed an association in mutually adjusted analyses. Though we cannot directly compare the size of the effect estimates, the most pronounced association was seen for location of the bedroom, followed by education level, nationality, and monthly household income. However, differences in the perception of noise annoyance were not solely explained by personal factors or housing conditions, but were also seen between participating study centers, possibly reflecting differences in regional factors such as deprivation index, access to green spaces or composition of the study population.

Comparisons with previous studies

Noise annoyance came into focus of research as early as the 1960s and several reviews on personal and regional factors potentially causing noise annoyance from transportation but also from other sources have been published since [33, 24, 25, 34, 35, 36]. Most studies were based on data from Europe and North America. An overview on studies investigating the prevalence of noise annoyance in Germany can be found in Table 3. The German Federal Health Survey (Bundes-Gesundheitssurvey, BGS) examined data from a representative sample of 6,644 individuals aged 18-79 years gathered between 1997-1999, of whom 32.1% reported that they were at least slightly and 22.0% moderately or very strongly annoyed by road-traffic noise in their dwellings [29]. Between 2008 and 2011, 7,988 residents aged 18-79, consisting of former BGS participants complemented with a new sample, were investigated within the DEGS1 study. It was shown that 37.4% were at least slightly annoyed and 6.3% were strongly or extremely annoyed by residential road-traffic noise at home [16]. In GEDA, 19,294 residents aged 18 years and older were interviewed via telephone between February 2012 and March 2013 [11]. Road-traffic was identified as the major source of noise annoyance in the current dwelling, with 37.2% of females and 39.3% of males feeling at least slightly annoyed, and 5.4% of both, males and females feeling strongly or extremely strong annoyed. In the German Socio-Economic Panel (GSOEP) in 1999, 7,275 heads of households aged 17–98 years reported by questionnaire how strongly they felt affected by noise exposure in general in their neighborhood [23]. Of these, 75.8% felt not affected at all, 16.4% felt weakly to strongly affected and 7.8% reported that they felt very strongly affected by noise exposure from all sources in their neighborhood (Table 3). In addition to the aforementioned studies, the most recent examination was conducted by the German Environment Agency (UBA), but which indicated a much higher level of noise annoyance. Specifically, of 2,030 participants representative of the German population aged 14 and older, only 24% stated to be not annoyed at all, 76% were at least slightly annoyed, of whom 23 percentage points felt strongly or very strongly annoyed by road traffic noise [17]. The reason for this discrepancy might lie in the online form that was used. The authors of the report pointed out that the frequencies of the online surveys in 2014 and 2016 were much higher than the results from

personal interviews conducted in 2012 and 2014 [17], when 46% stated not to be annoyed at all and 54% to be at least slightly annoyed.

All these studies focused on noise annoyance during the whole day limiting comparability with our results. In addition, the assessment of noise annoyance was not consistent across studies (Table 3). Only UBA and DEGS1 used the ICBEN/ISO wording [37]. Overall, questions contained different reference points (the home in general, indoors in the apartment or the home environment without specifying indoors or outdoors), differences in the scales and the combination of categories as well as differences in the wording including being annoyed, disturbed and affected. Regarding the last point, we believe that it is justified to interpret all questions in the sense of evaluating noise annoyance. Though, strictly speaking, there are differences between disturbance and annoyance as disturbance rather implicates that an activity cannot be carried out as desired, whereas annoyance implies a negative evaluation of environmental conditions [8]. However, neither the previous studies nor the GNC study asked about particular events that indicate disturbances. For example, when investigating sleep disturbances, events like waking up or difficulties of falling asleep are explicitly queried [31]. Moreover, in the German language, the words annoyed, disturbed, bothered and affected can be used synonymously [32]. Therefore, we believe that the participants rather indicated their annoyance than an unvalued disturbance.

Since previous studies differed with regard to their definition of transportation noise annoyance, explanatory factors and statistical analysis approaches, the following comparison is only of qualitative nature. Housing conditions and especially the orientation of the bedroom showed the strongest association with noise annoyance in our analysis, confirming findings from BGS [29], DEGS1 [16] and two previous studies from Sweden [38] and Switzerland [39], though all investigations considered the home position in general. Findings are mixed regarding home ownership or type of dwelling, with studies reporting no difference in noise annoyance [38, 33], a higher prevalence of noise annoyance among home owners [25] but also a lower prevalence [36, 16]. In our study, similar to DEGS1, people who lived in self-owned accommodations were less likely to be annoyed by transportation noise. Furthermore, participants with high income were less likely to be annoyed by transportation noise and income was at the same time correlated with housing conditions, an observation also made in DEGS1 [16] and GSOEP [23]. However, for DEGS1 and GSOEP, no significant differences in noise annoyance were seen for educational or occupational status, whereas we observed a higher noise annoyance among people with a higher educational status, similar to a Swiss study [39]. In contrast, other studies observed only weak or no associations between income or education and noise annoyance [33, 19, 38, 25]. In GEDA, low socio-economic status based on education, occupational status, and income was associated with a stronger noise annoyance by

traffic [11]. Similarly, in BGS, people of lower socio-economic status more likely lived close to busy roads and more often felt annoyed by traffic noise than those with higher socio-economic status [29]. This is consistent with the UBA survey, which showed an increased proportion of noise annoyance among people with a low social status [17]. In a recent review on social inequalities in environmental noise exposure, Dreger and colleagues concluded that indicators representing material aspects, such as income or ownership of dwelling, are associated with where people can afford to live. For these material indicators, a low socio-economic position is related to a higher noise exposure or noise annoyance whereas evidence is mixed for education [22].

While we observed a higher proportion of transportation noise annoyance for participants with German nationality compared to non-Germans, GSOEP participants with non-German nationality were more often annoyed by noise in general [23]. Regarding age, several studies reported older people to be less annoyed by noise [39, 25], which is similar to our findings and may be due to higher rates of hearing loss in that subpopulation [40, 4]. Other studies including DEGS1, however, found no significant differences in traffic-related noise annoyance for different age groups [38, 33, 16], whereas the GSOEP reported perceived exposure to noise in general to be more pronounced in higher age groups [23]. We observed higher strong/extreme noise annoyance for females compared to males which was also reported by previous studies suggesting a higher awareness of environmental exposures for women than men [39, 41, 42]. However, women were also less likely to be slightly/moderately annoyed by noise in our analysis and DEGS1, GSOEP, and other studies detected no clear pattern regarding sex [25, 16, 23].

Further factors related to a higher rate of traffic noise annoyance in DEGS1 and perceived high exposure to general noise in GSOEP were living in East Germany or in large towns or industrial areas. A similar pattern was also apparent in our analysis, with study centers located in larger cities (Berlin-Mitte, Berlin-Nord, Bremen) and in East Germany (Leipzig, Halle) showing a higher proportion of participants with noise annoyance than centers in West Germany or smaller cities (Kiel). Interestingly, Neubrandenburg, a small city located in rural East Germany, also showed a high proportion of participants with noise annoyance. For this analysis, we could only use the study centers as crude approximation for regional factors. More precise factors describing the exact location and neighborhood of the participants' residences would be of high interest and are planned for future analyses.

Our results support findings from previous studies showing that indicators which represent material aspects are associated with the location people can afford to live and thus determine noise exposure

[22]. For example, lower-income households are more frequently located close to busy roads and thus, are more frequently exposed to transportation noise, and their occupants more frequently feel adversely affected by noise [29, 23, 16, 11]. In contrast, persons from higher-income households are better able to settle in neighborhoods with lower noise levels or to re-locate if noise levels increase [16, 23, 22]. Whether an unequal distribution of noise exposure across population subgroups defined by socio-economic status is associated with negative health impacts in socially disadvantaged groups requires further research.

Strengths and limitations

Major strengths of this study are the large sample size and the well-characterized study population, offering a valuable opportunity to assess noise annoyance in a comprehensive and standardized process. Furthermore, we used multiple regression analyses to investigate personal and regional factors while mutually adjusting for those variables, thus minimizing potential confounding by each other. However, this might also be seen as a limitation since some of the factors such as the socio-economic ones could be correlated potentially leading to multicollinearity issues within the models. Nevertheless, this first analysis was intended to give a broad overview and further in-depths analyses are needed to disentangle the interplay of these factors and identify the main drivers. Moreover, univariate correlation analyses indicated only low to moderate correlations between the considered factors.

A major limitation of our study is that we lacked data on objective noise measurements, traffic intensity, and additional regional factors such as population and building density or unemployment rate, which have also been found to affect noise annoyance [16, 35, 23]. However, we plan to link our cohort to such data sources in future analyses. In addition, we did not follow the ICBEN/ISO wording [37] for assessing noise annoyance and thus, comparability might be limited. Since we asked for all transportation noise simultaneously, we were not able to distinguish between the single sources. Furthermore, we could not account for noise sensitivity, an important personal factor that might influence noise annoyance, but is in turn independent from noise annoyance [35]. Moreover, we were unable to investigate health-related conditions of participants because such data are currently not yet available for analysis. Due to the cross-sectional nature of our analyses, causal inference is limited with regard to the directionality of the relations of demographic and socio-economic factors and housing situation to noise annoyance. A further potential limitation might be that due to the large sample size, also rather small and potentially irrelevant associations might indicate statistical significance. However, all observed associations seemed plausible. Last, it has to be noted that the GNC study is not representative of the German population.

CONCLUSIONS

This cross-sectional analysis of the GNC study identified noise annoyance as a still relevant public health topic since every third participant reported to be at least slightly/moderately annoyed by transportation noise at nighttime confirming previous studies from Germany. Furthermore, our study provides information on nighttime noise annoyance complementing results from previous analysis that only focused on noise annoyance during the whole day. Several demographic and socio-economic factors were associated with a high level of noise annoyance, in particular housing conditions and income-related factors. The study centers as regional indicators played a prominent role in our study, demanding further analyses with regard to the relation of regional factors to noise annoyance.

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INFORMATION ON COMPLIANCE WITH ETHICAL GUIDELINES

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national; approval number 13023) and with the Helsinki Declaration of 1975 (in its most recently amended version). Informed consent was obtained from all patients included in the study.

POTENTIAL CONFLICT OF INTEREST

The authors indicate that there is no conflict of interest.

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Figure 1. Distribution of transportation noise annoyance during nighttime by study center.

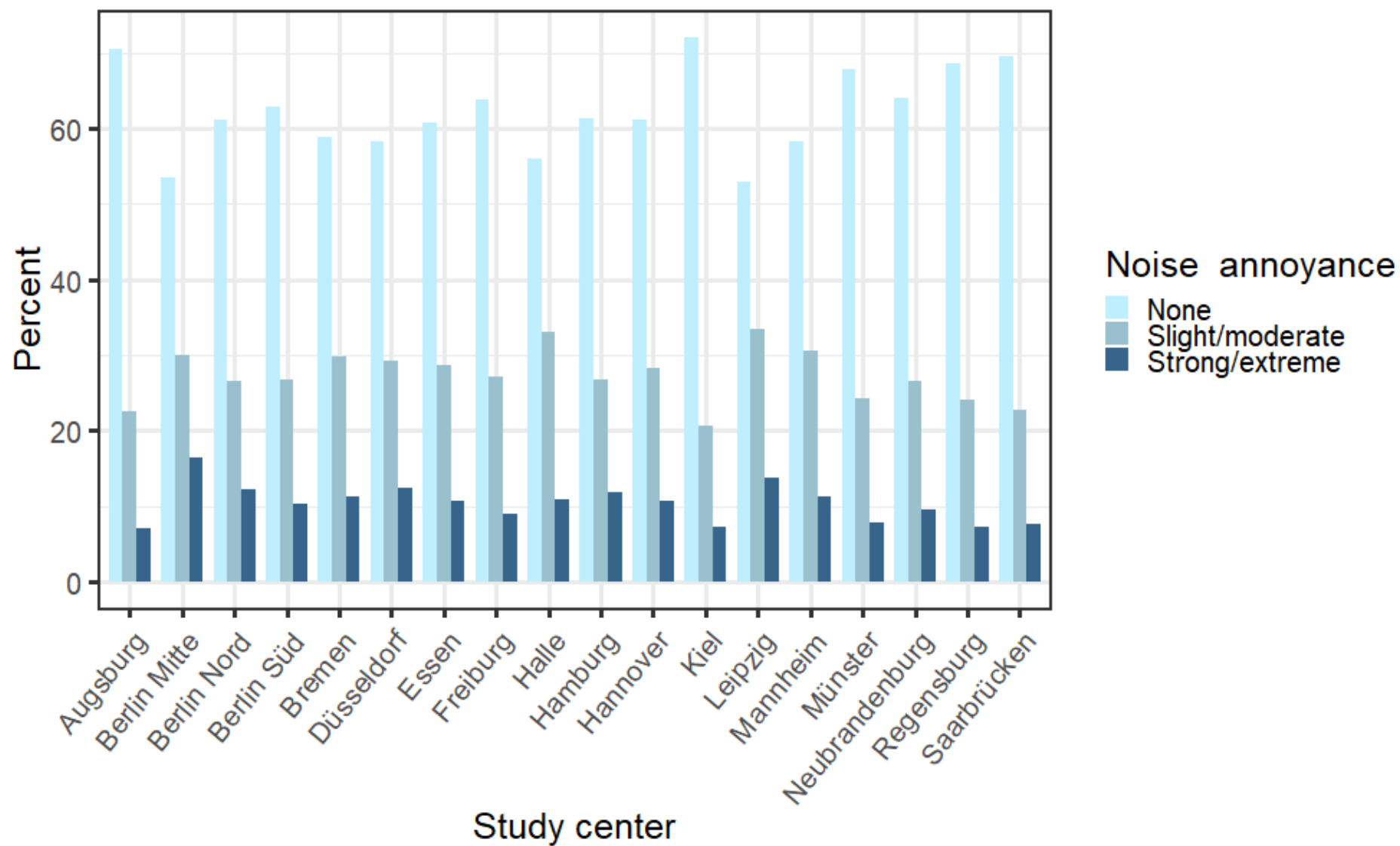


Figure 2. Non-linear association for age comparing slight/moderate (left panels) or strong/extreme (right panels) transportation noise annoyance during nighttime to the not annoyed group using natural cubic splines with 2 (top), 3 (center) and 4 (bottom) degrees of freedom in a multinomial logistic regression framework adjusting for all other covariates.

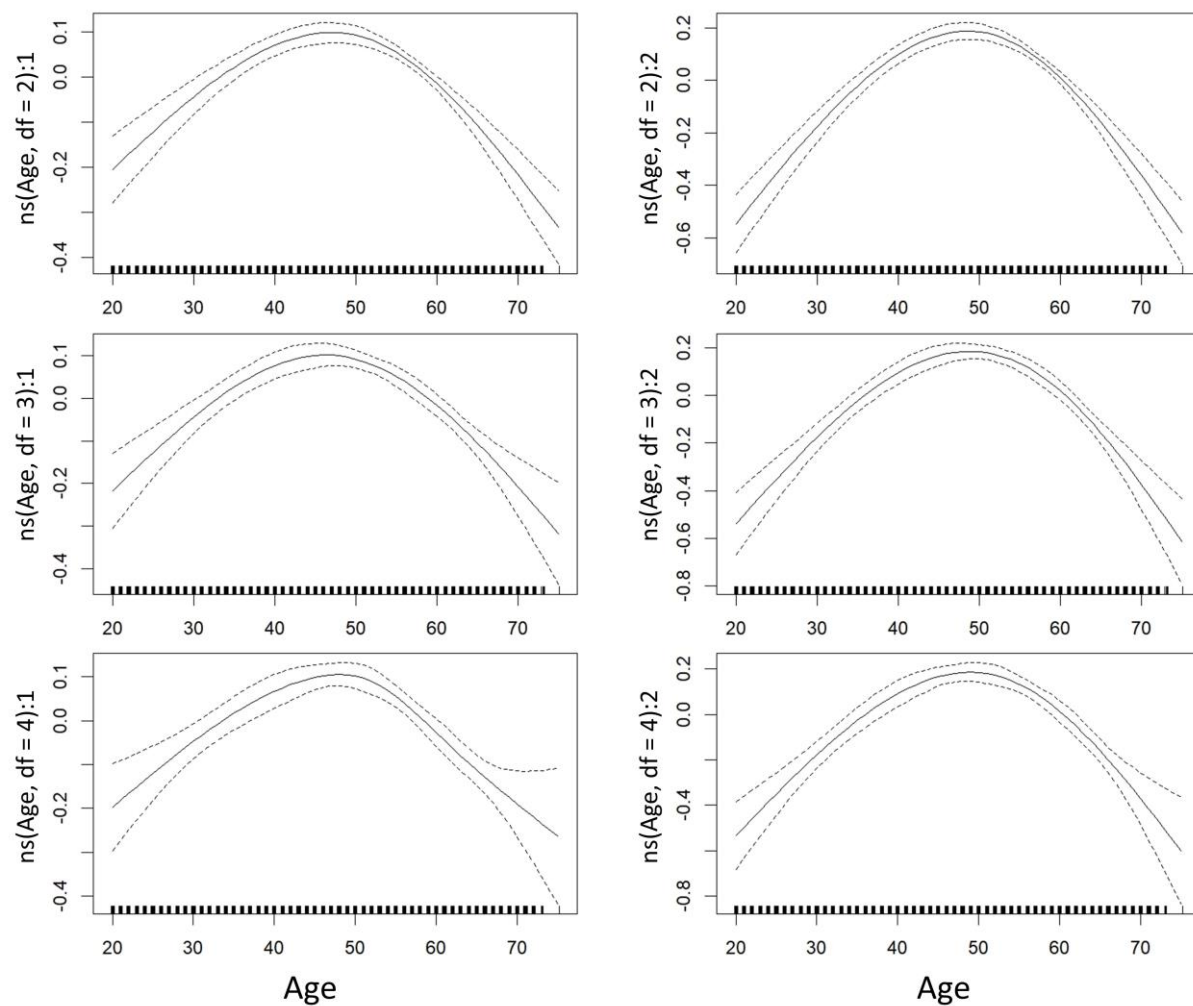
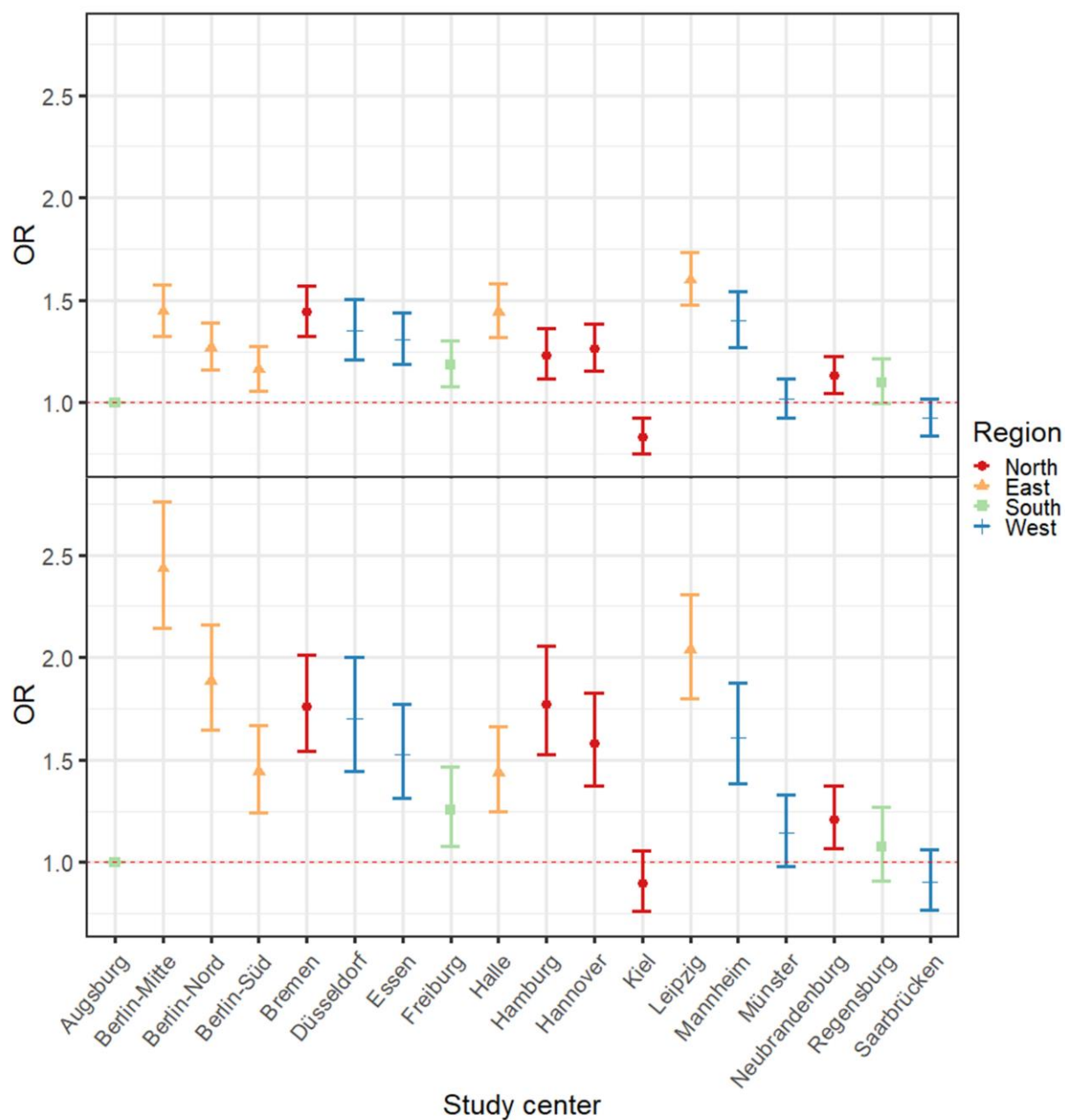


Figure 3. Study center fixed effects (odds ratio (OR) and 95% confidence interval) for slight/moderate (top) or strong/extreme (bottom) transportation noise annoyance during nighttime compared to none using multiple multinomial logistic regression (reference category: Augsburg).



TABLES

Table 1. Descriptive statistics of personal factors for all participants (N=86,080) and for participants categorized by noise annoyance.

	All	Noise annoyance		
		None	Slight/moderate	Strong/extreme
Noise annoyance N (%)		53,602 (62.3)	23,518 (27.3)	8,960 (10.4)
	N (%) or mean (SD)	N (%) or mean (SD) referring to the noise annoyance group		
Demographic factors				
Age in years	51.1 (12.4)	51.4 (12.4)	50.4 (12.5)	50.8 (12.2)
Missing	6 (0.0)	4 (0.0)	0 (0.0)	2 (0.0)
Sex				
Male	40,611 (47.2)	25,519 (47.6)	11,439 (48.6)	3,653 (40.8)
Female	45,469 (52.8)	28,083 (52.4)	12,079 (51.4)	5,307 (59.2)
Nationality				
German	82,870 (96.3)	51,547 (96.2)	22,687 (96.5)	8,636 (96.4)
Non-German	3,199 (3.7)	2,050 (3.8)	826 (3.5)	323 (3.6)
Missing	11 (0.0)	5 (0.0)	5 (0.0)	1 (0.0)
Socio-economic factors				
Marital Status				
Married	52,784 (61.3)	34,091 (63.6)	13,779 (58.6)	4,914 (54.8)
Not married	33,275 (38.7)	19,495 (36.4)	9,735 (41.4)	4,045 (45.1)
Missing	21 (0.0)	16 (0.0)	4 (0.0)	1 (0.0)
Education ^a				
Low	12,227 (14.2)	8,130 (15.2)	2,922 (12.4)	1,175 (13.1)
Medium	28,648 (33.3)	17,722 (33.1)	7,797 (33.2)	3,129 (34.9)
High	45,145 (52.4)	27,722 (51.7)	12,776 (54.3)	4,647 (51.9)
Missing	60 (0.1)	28 (0.1)	23 (0.1)	9 (0.1)
Income per month ^b				
Low	13,179 (15.3)	7,479 (14.0)	3,889 (16.5)	1,811 (20.2)
Medium	47,892 (55.6)	29,490 (55.0)	13,331 (56.7)	5,071 (56.6)
High	19,926 (23.1)	13,373 (24.9)	4,960 (21.1)	1,593 (17.8)
Missing	5083 (5.9)	3,260 (6.1)	1,338 (5.7)	485 (5.4)

Employment status				
Employed	63,543 (73.8)	39,567 (73.8)	17,556 (74.6)	6,420 (71.7)
Not employed	22,462 (26.1)	13,977 (26.1)	5,955 (25.3)	2,530 (28.2)
<i>Missing</i>	<i>75 (0.1)</i>	<i>58 (0.1)</i>	<i>7 (0.0)</i>	<i>10 (0.1)</i>
Housing conditions				
Home ownership				
Rented apartment/ house	40,800 (47.4)	23,290 (43.5)	12,434 (52.9)	5,076 (56.7)
Own apartment/house	45,167 (52.5)	30,242 (56.4)	11,052 (47.0)	3,873 (43.2)
Assisted living/senior home/nursing home	62 (0.1)	42 (0.1)	14 (0.1)	6 (0.1)
<i>Missing</i>	<i>51 (0.01)</i>	<i>28 (0.01)</i>	<i>18 (0.01)</i>	<i>5 (0.01)</i>
Number of persons in the household				
1 person	16,604 (19.3)	9,604 (17.9)	4,842 (20.6)	2,158 (24.1)
2 persons	40,465 (47.0)	25,160 (46.9)	11,061 (47.0)	4,244 (47.4)
3 + persons	28,986 (33.7)	18,821 (35.1)	7,611 (32.4)	2,554 (28.5)
<i>Missing</i>	<i>25 (0.0)</i>	<i>17 (0.0)</i>	<i>4 (0.0)</i>	<i>4 (0.0)</i>
Floor position of bedroom				
Basement	1,117 (1.3)	888 (1.7)	161 (0.7)	68 (0.8)
Ground floor	18,608 (21.6)	12,843 (24.0)	4,293 (18.3)	1,472 (16.4)
Upper floor	66,355 (77.1)	39,871 (74.4)	19,064 (81.1)	7,420 (82.8)
Position of bedroom				
Towards				
Major road	8,755 (10.2)	2,587 (4.8)	3,275 (13.9)	2,893 (32.3)
Minor road	29,156 (33.9)	15,872 (29.6)	10,156 (43.2)	3,128 (34.9)
Garden/inner courtyard	48,166 (56.0)	35,142 (65.6)	10,086 (42.9)	2,938 (32.8)
<i>Missing</i>	<i>3 (0.0)</i>	<i>1 (0.0)</i>	<i>1 (0.0)</i>	<i>1 (0.0)</i>

^a Categories defined as low: secondary school or no graduation, medium: high-school and high: higher education entrance qualification; ^b Categories defined as low: < 1,700€, medium: 1,700€ - 4,499€ and high: ≥ 4,500€. N: absolute number; SD: standard deviation.

Table 2. Odds ratios (OR) and 95% confidence interval (95% CI) of personal factors in association with slight/moderate or strong/extreme transportation noise annoyance during nighttime compared to none using multiple multinomial logistic regression (N= 80,828). Study centers were incorporated as fixed effects.

	Noise annoyance	
	Slight/moderate OR (95% CI)	Strong/extreme OR (95% CI)
Female (vs. male)	0.92 (0.89; 0.95)	1.25 (1.19; 1.31)
Non-German nationality (vs. German)	0.82 (0.75; 0.89)	0.77 (0.67; 0.88)
Not married (vs. married)	1.03 (0.99; 1.08)	1.10 (1.03; 1.18)
Education (reference: high)		
Medium	0.90 (0.86; 0.93)	0.89 (0.84; 0.94)
Low	0.79 (0.74; 0.83)	0.80 (0.74; 0.87)
Income (reference: high)		
Medium	1.17 (1.12; 1.22)	1.23 (1.15; 1.32)
Low	1.19 (1.11; 1.27)	1.31 (1.19; 1.44)
Not employed (vs. employed)	1.08 (1.03; 1.13)	1.29 (1.21; 1.38)
Rented apartment/house (vs. own)	1.17 (1.13; 1.22)	1.10 (1.04; 1.17)
Number of persons in household (Reference: 1 person)		
2 persons	1.05 (1.00; 1.11)	1.02 (0.94; 1.10)
3+ persons	0.94 (0.88; 1.00)	0.82 (0.75; 0.90)
Bedroom in upper floor (vs. basement/ground floor)	1.37 (1.31; 1.42)	1.49 (1.40; 1.59)
Position of bedroom (reference: garden/inner courtyard)		
Minor road	2.17 (2.09; 2.24)	2.30 (2.18; 2.44)
Major road	4.26 (4.01; 4.52)	13.36 (12.47; 14.32)

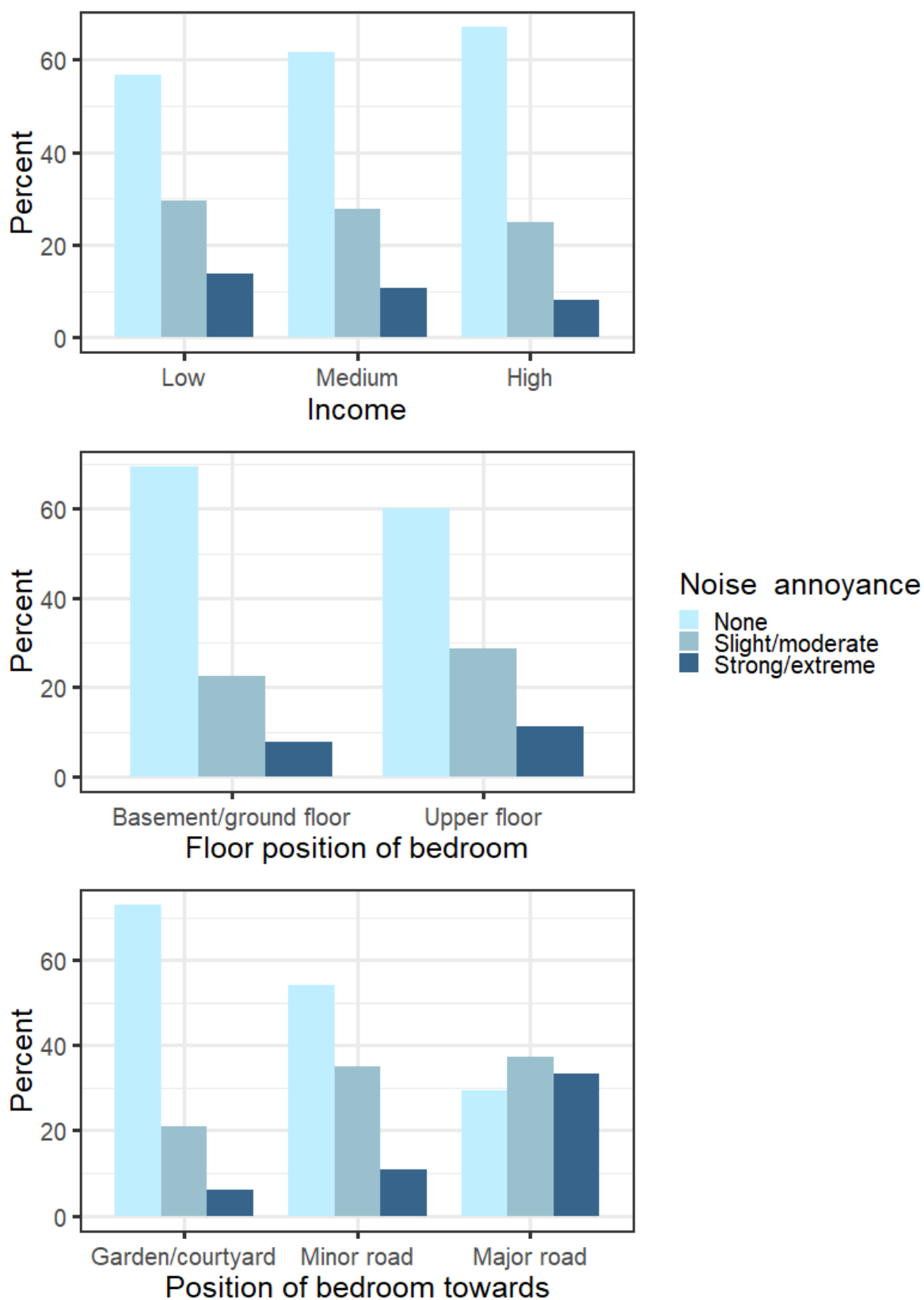
Table 3: Comparison of the GNC with previous surveys on noise annoyance in the German population.

Study	German National Cohort (GNC)	Survey of the German Environment Agency (UBA; [17])	Survey of the Robert Koch Institute: „German Health Update“ (GEDA; [11])	Survey of the Robert Koch Institut: “German Health Interview and Examination Survey for Adults” (DEGS1; [16])	German Socio-Economic Panel (GSOEP; [23])	German Federal Health Survey (BGS 1998; [29])
Question	“How much are you disturbed during nighttime (22 - 6 o'clock) by traffic noise from car, truck, train or plane in your bedroom when you have the window open (tilted or completely open)?” Scale: not at all, slightly/moderately, strongly/extremely	“If you ever think about the last 12 months here at home, how much have you personally felt disturbed or annoyed by the following?” Scale: don't know, not at all, slightly, moderately, strongly, extremely	“Thinking about the last 12 months, when you are at home, how much does noise - all in all - bother, disturb, or annoy you?” (same for different noise sources) Scale: not at all, slightly, moderately, very/extremely	“In your current dwelling, to what extent do you feel annoyed by noise from the sources listed below?” Scale: strong to extreme, slight to moderate, not at all	„How strongly do you feel affected by noise exposure in your neighborhood?” Scale: no, low/medium/high, very high	„Do you have outside noise in your apartment? What causes the noise in general? How strong would you call it in each case?” Scale: very strong, moderately strong, not strong (in case of a positive answer to the first question)
Study population	Random sample of the German-speaking resident population	Random sample of the German-speaking resident population in private households	Random sample of the German-speaking resident population in private households; reachable by fixed network	Population living in Germany; residents' registration office sample and participants of the Federal Health Survey 1998	Representative sample of the German-speaking resident population in private households	Representative sample of the adult population in Germany
Age	20-69 years	≥ 14 years	≥ 18 years	18-79 years	17-98 years	18-79 years
Study period*	2014-2017	07-08/2016	02/2012-03/2013	2008-2011	1999	Autumn 1997 - Spring 1999
Population size*	86.080	2.030	19.294	7.988	7.275	6.644

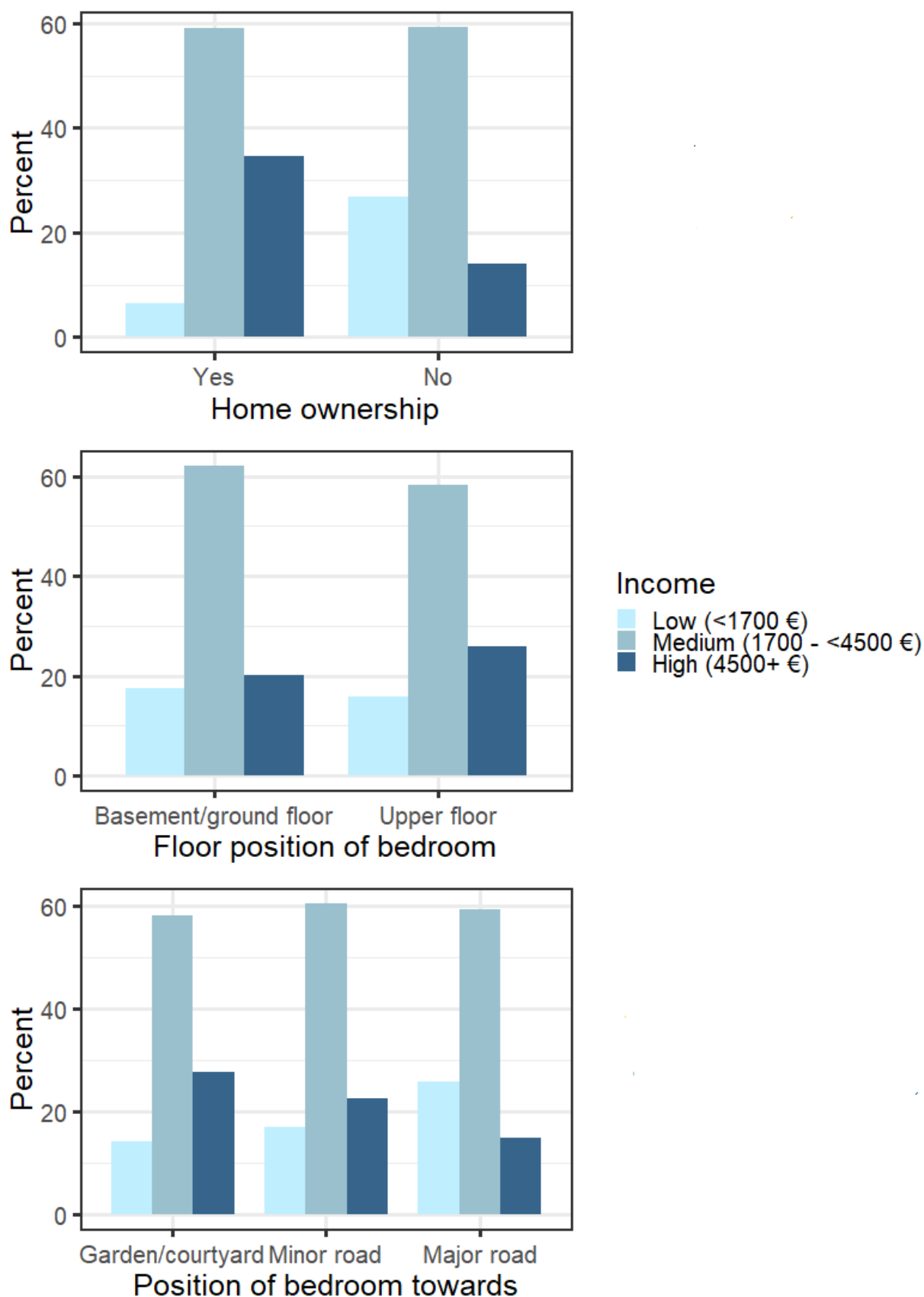
*with regard to the respective publication

ONLINE SUPPLEMENT

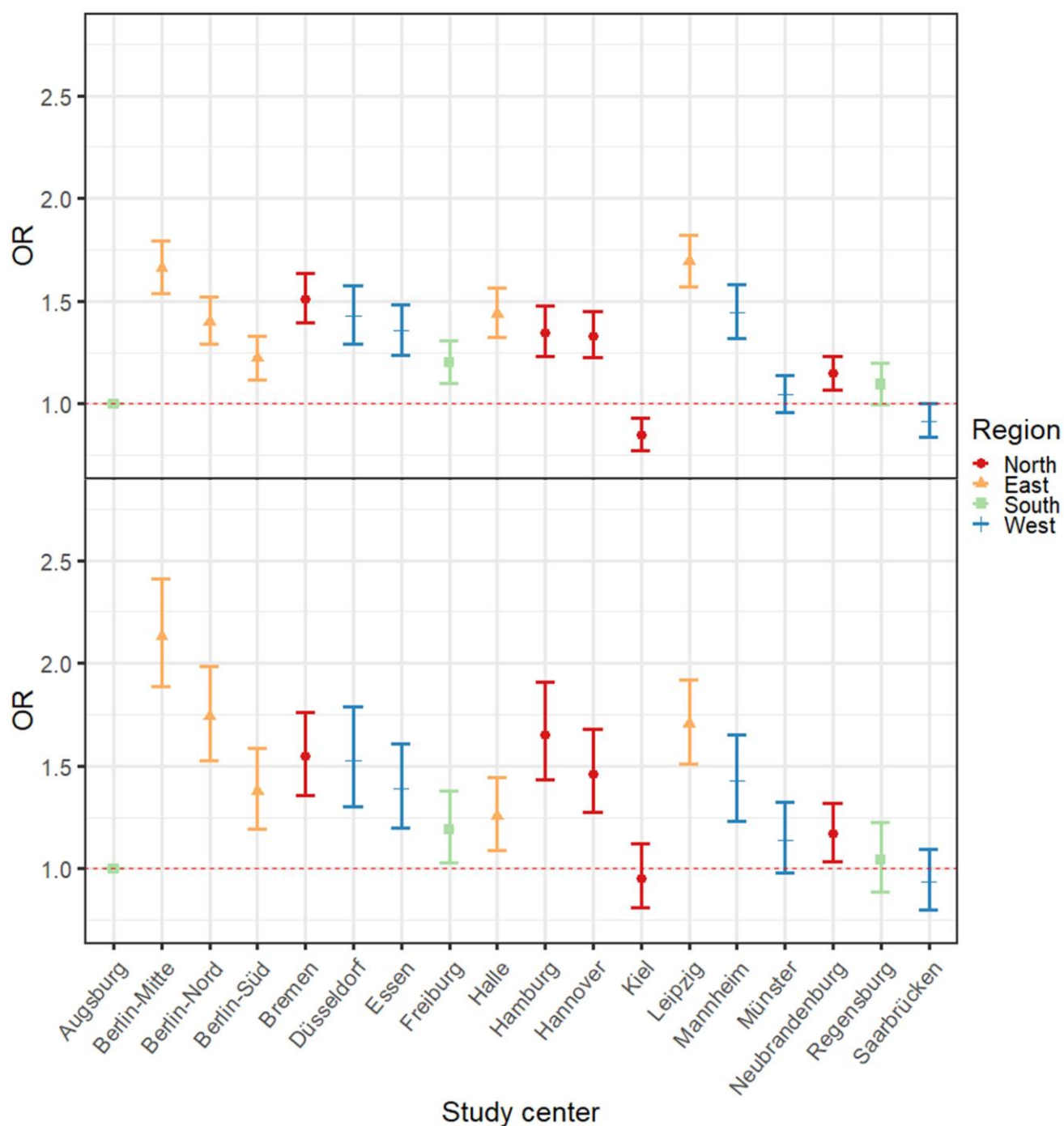
Supplementary Figure Z1. Distribution of transportation noise annoyance during nighttime by household income (top); floor position of bedroom (center); position of bedroom (bottom).



Supplementary Figure Z2. Distribution of household income by home ownership (top); floor position of bedroom (center); position of bedroom (bottom).



Supplementary Figure Z3. Study center fixed effects (odds ratio (OR) and 95% confidence interval) from two separate binary logistic regression models comparing at least slightly annoyed vs. not annoyed (top) and strongly/extremely annoyed vs. not/slightly/moderately annoyed (bottom); reference category: Augsburg.



Supplementary Table Z1. Odds ratios (OR) and 95% confidence interval (95% CI) of personal factors in association with at least slightly annoyed compared to not annoyed (left column) and strongly/extremely annoyed compared to not/slightly/moderately annoyed (right column) from two separate binary logistic regression models. Study centers were incorporated as fixed effects.

	Noise annoyance	
	At least slightly annoyed vs. not annoyed	Strongly/extremely annoyed vs. not/slightly/moderately annoyed
	OR (95% CI)	OR (95% CI)
Female (vs. male)	0.99 (0.96; 1.02)	1.29 (1.23; 1.36)
Non-German nationality (vs. German)	0.80 (0.74; 0.87)	0.83 (0.73; 0.95)
Not married (vs. married)	1.05 (1.01; 1.09)	1.09 (1.02; 1.16)
Education (reference: high)		
Medium	0.89 (0.86; 0.93)	0.93 (0.88; 0.98)
Low	0.79 (0.75; 0.83)	0.88 (0.81; 0.95)
Income (reference: high)		
Medium	1.18 (1.14; 1.23)	1.17 (1.09; 1.25)
Low	1.22 (1.15; 1.29)	1.23 (1.12; 1.35)
Not employed (vs. employed)	1.13 (1.08; 1.18)	1.25 (1.17; 1.34)
Rented apartment /house (vs. own)	1.15 (1.11; 1.20)	1.04 (0.98; 1.10)
Number of persons in household (Reference: 1 person)		
2 persons	1.04 (0.99; 1.09)	1.00 (0.93; 1.07)
3+ persons	0.91 (0.86; 0.96)	0.84 (0.77; 0.92)
Bedroom in upper floor (vs. basement/ground floor)	1.40 (1.34; 1.45)	1.34 (1.26; 1.42)
Position of bedroom (reference: garden/inner courtyard)		
Minor road	2.20 (2.13; 2.27)	1.81 (1.71; 1.91)
Major road	6.24 (5.91; 6.58)	7.53 (7.07; 8.01)