



ELSEVIER

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

Spatial clusters of daytime sleepiness and association with nighttime noise levels in a Swiss general population (GeoHypnoLaus)

Stéphane Joost^{a,b,c,1}, José Haba-Rubio^{d,1}, Rebecca Hims^{a,b,c}, Peter Vollenweider^e, Martin Preisig^g, Gérard Waeber^e, Pedro Marques-Vidal^{c,e}, Raphaël Heinzer^{d,2}, Idris Guessous^{b,c,f,2,*}^a Laboratory of Geographic Information Systems (LASIG), School of Architecture, Civil and Environmental Engineering (ENAC), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland^b Unit of Population Epidemiology, Division of Primary Care Medicine, Department of Community Medicine, Primary Care and Emergency Medicine, Geneva University Hospitals, Geneva, Switzerland^c GIRAPH Lab (Geographic information for research and analyses in public health), Switzerland^d Center for Investigation and Research in Sleep, Lausanne University Hospital (CHUV) and Lausanne University, Lausanne, Switzerland^e Department of Medicine, Internal Medicine, Lausanne University Hospital (CHUV) and Lausanne University, Lausanne, Switzerland^f Department for Ambulatory Care and Community Medicine, University of Lausanne, Lausanne, Switzerland^g Department of Psychiatry, Lausanne University Hospital and Lausanne University, Lausanne, Switzerland

ARTICLE INFO

Keywords:

Epworth sleepiness scale
Traffic noise exposure
Spatial clustering
GIS
General population

ABSTRACT

Introduction: Daytime sleepiness is highly prevalent in the general adult population and has been linked to an increased risk of workplace and vehicle accidents, lower professional performance and poorer health. Despite the established relationship between noise and daytime sleepiness, little research has explored the individual-level spatial distribution of noise-related sleep disturbances. We assessed the spatial dependence of daytime sleepiness and tested whether clusters of individuals exhibiting higher daytime sleepiness were characterized by higher nocturnal noise levels than other clusters.

Design and Methods: Population-based cross-sectional study, in the city of Lausanne, Switzerland.

Sleepiness was measured using the Epworth Sleepiness Scale (ESS) for 3697 georeferenced individuals from the CoLaus|PsyCoLaus cohort (period = 2009–2012). We used the sonBASE georeferenced database produced by the Swiss Federal Office for the Environment to characterize nighttime road traffic noise exposure throughout the city. We used the GeoDa software program to calculate the Getis-Ord G_i^* statistics for unadjusted and adjusted ESS in order to detect spatial clusters of high and low ESS values. Modeled nighttime noise exposure from road and rail traffic was compared across ESS clusters.

Results: Daytime sleepiness was not randomly distributed and showed a significant spatial dependence. The median nighttime traffic noise exposure was significantly different across the three ESS Getis cluster classes ($p < 0.001$). The mean nighttime noise exposure in the high ESS cluster class was 47.6, dB(A) 5.2 dB(A) higher than in low clusters ($p < 0.001$) and 2.1 dB(A) higher than in the neutral class ($p < 0.001$). These associations were independent of major potential confounders including body mass index and neighborhood income level.

Conclusions: Clusters of higher daytime sleepiness in adults are associated with higher median nighttime noise levels. The identification of these clusters can guide tailored public health interventions.

1. Introduction

Daytime sleepiness can be defined as the inability to maintain

wakefulness and alertness during the major waking hours (American Academy of Sleep Medicine, 2014). Excessive daytime sleepiness, defined by the occurrence of multiple unintentional sleep episodes

Abbreviations: ESS, epworth sleepiness scale; FOEN, Swiss Federal Office for the Environment; GIS, geographic information systems; LISA, Local Indicators of Spatial Association

* Corresponding author at: Unit of Population Epidemiology, Division of Primary Care Medicine, Department of Community Medicine, Primary Care and Emergency Medicine, Geneva University Hospitals, 4 Rue Gabrielle-Perret-Gentil 1211, Geneva 14, Switzerland.

E-mail address: idriss.guessous@hcuge.ch (I. Guessous).

¹ Co-first authors.

² Co-last authors.

<https://doi.org/10.1016/j.ijheh.2018.05.004>

Received 13 January 2018; Received in revised form 10 April 2018; Accepted 15 May 2018

1438-4639/© 2018 The Authors. Published by Elsevier GmbH. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

throughout the day (Ohayon, 2006), has been linked to an increased risk of workplace and vehicle accidents (Horne and Reyner, 1995) as well as with lower professional performance and poorer health (Pagel, 2009). Even at non-excessive levels, daytime sleepiness has been also directly associated with cognitive impairment (Williamson and Feyer, 2000) as well as with an increased risk of stroke, congestive heart disease, cardiovascular and all-cause mortality (Blachier et al., 2012; Newman et al., 2000; Qureshi et al., 1997).

Daytime sleepiness is highly prevalent in the general adult population. In European countries, between 5 and 20% of adults present excessive daytime sleepiness (Ohayon, 2006), thereby substantiating the need to better understand the causes.

Intrinsic and extrinsic sleep disorders, as well as obesity, smoking, depression, and medications (Bixler et al., 2005), can enhance daytime sleepiness through the disruption of sleep or biological rhythms (Stepanski et al., 1984). Among the environmental factors that cause sleep disruptions, nighttime noise has been related to daytime sleepiness through nocturnal arousals and premature awakenings (Muzet, 2007), whereby the regenerative power of sleep is reduced in response to the magnitude and frequency of noise events (Basner et al., 2008; Öhrström and Rylander, 1982). One lab-based study investigating this relationship found that intermittent noises above 45 dB can be directly linked to daytime fatigue (Öhrström, 1993). More targeted studies have identified positive correlations between daytime sleepiness and exposure to noise from wind turbines (Abbasi et al., 2015; Nissenbaum et al., 2012), airplanes (Kwak et al., 2016; Callejas et al., 2015), railways and vehicular traffic (Gislason et al., 2016; Basner et al., 2011).

While air and neighborhood noise are important contributors to urban noise pollution, vehicular and rail traffic are the largest contributors (WHO Regional Office for Europe, 2009). In 2010, an estimated 22,500 hospital days were attributed to the effects of transportation noise in Switzerland (Vienneau et al., 2015). Because road traffic noise is strongly associated with road type (e.g. arterial, one way) (Barrigón Morillas et al., 2002) and road network density (Mehdi et al., 2011), urban traffic noise is inherently geographically localized. Despite the demonstrated relationship between noise and daytime sleepiness, and the considerable amount of research dedicated to the spatial distribution of noise (Licitra, 2013), relatively little research has explored the individual-level spatial distribution of noise-related sleep disturbances (Evandt et al., 2017; Jakovljević et al., 2006). Further, we are aware of only one study that has previously explored the spatial distribution of daytime sleepiness in particular (Grandner et al., 2012); yet data were collected and analyzed at the state level so that comparisons with localized environmental phenomena – such as noise – are not possible.

Spatial analysis methods have been developed and introduced in epidemiological research to explore the link between place of residence and health (Auchincloss et al., 2012). Spatial clusters of a trait can be detected by its spatial dependence (spatial autocorrelation), defined as the covariation of properties in geographic space. Thus, geographic information systems (GIS) and high-resolution spatial modeling can be used to better localize individuals suffering from daytime sleepiness and to increase the understanding of the influence of local-level factors, such as noise, on sleepiness.

Our study had two aims: first, we calculated the spatial dependence of daytime sleepiness using a large population-based cohort. Second, we used georeferenced models of road and rail nighttime noise exposure to evaluate the noise levels in the different spatial clusters obtained and determine whether clusters of individuals showing daytime sleepiness were characterized by higher noise levels than observed in other clusters.

2. Data and methods

2.1. Population

The HypnoLaus Sleep study is based on the first follow-up of the CoLaus|PsyCoLaus study (Heinzer et al., 2015; Preisig et al., 2009; Firmann et al., 2008). Briefly, the baseline CoLaus|PsyCoLaus study was conducted between 2003 and 2006 and included a random sample of 6733 subjects (age range: 35 to 75 years) representative of the residents of the city of Lausanne (Switzerland, 140,738 inhabitants in July 2017). The distributions of age groups, gender, and zip codes of participants were similar to the source population. The original aim of this cohort was to study cardiovascular risk factors and psychiatric disorders in the general population and to determine their associations. Between 2009 and 2012, 5064 subjects from the baseline sample also participated in the first follow-up, which included data on daytime sleepiness. In addition to questions on demographic, medical, and treatment history as well as smoking and alcohol consumption, the subjective sleep characteristics of this cohort were evaluated through questionnaires given by trained interviewers. Only individuals living within the urban area of the Lausanne municipality were considered for this analysis (Joost et al., 2016).

CoLaus|PsyCoLaus data were geocoded in QGIS using the MMQGIS extension (<http://michaelminn.com/linux/mmqgis/>), which contains a geocoding Python plugin facilitating the use of the Google Maps API.

2.2. Ethics

The institutional Ethics Committee of the University of Lausanne, which afterwards became the Ethics Commission of Canton Vaud (www.cer-vd.ch) approved the baseline CoLaus study (reference 16/03, decisions of 13th January and 10th February 2003); the approval was renewed for the first (reference 33/09, decision of 23rd February 2009) and the second (reference 26/14, decision of 11th March 2014) follow-up. The HypnoLaus nested study was also approved by the Ethic Committee of Canton de Vaud in 2009 (reference 33/09). The full decisions of the CER-VD can be obtained from the authors upon request. The study was performed in agreement with the Declaration of Helsinki and its former amendments, and in accordance with the applicable Swiss legislation (LRH 810.30, approved by the Swiss Federal Parliament on 30th of September 2011). All participants gave their signed informed consent before entering the study.

2.3. The Epworth Sleepiness Scale

Sleepiness was measured at the first physical follow-up exam using the Epworth Sleepiness Scale (ESS) (Johns, 1991). The ESS is a self-administered questionnaire with 8 questions. Respondents are asked to rate, on a 4-point scale (0–3), their usual chances of dozing off or falling asleep while engaged in eight different activities. The ESS score (the sum of 8 item scores, 0–3) can range from 0 to 24. A score of 10 or lower is suggestive of normal daytime sleepiness, scores from 11 to 14 are indicative of mild excessive daytime sleepiness, 15 to 17 - of moderate excessive daytime sleepiness, and a score above 18 indicates severe excessive daytime sleepiness (Johns, 1991). The ESS internal and external validity were further demonstrated in different population samples (Johns, 2000; Parkes et al., 1998; Johns, 1992).

2.4. Variables used for adjustment

Age, gender, anthropometry and medication regimens were recorded during the CoLaus physical visit. Body weight and height were measured by trained health care professionals with participants standing without shoes in light indoor clothing. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m²). Medication regimens were self-reported.

To account for the potential influence of socioeconomic status on daytime sleepiness (Stringhini et al., 2015), we adjusted our analyses for neighborhood-level income. Data on area's income level were obtained from the 2009 Lausanne Census (Office Cantonal de la Statistique, www.scris.vd.ch). Information on median annual income covered 81 statistical sectors of the city and was expressed in Swiss francs (1 CHF = 0.85 €, January 2018). The income value was attributed to individuals on the basis of the inclusion of their place of residence within the corresponding sector.

2.5. Road and rail noise exposure

To characterize nighttime traffic noise exposure throughout the city of Lausanne, we used the sonBASE georeferenced database produced by the Swiss Federal Office for the Environment (FOEN, 2014). These nationwide data deliver exposure to nighttime road and rail noise sources in a georeferenced 10 x 10 m grid. The emissions from noise sources were computed in a GIS using the original data available (Federal Offices for Spatial Development [ARE], Roads [FEDRO], Transport [FOT], Civil Aviation [FOCA], Statistics [FSO] and Civil Protection and Sport [DDPS]). Then, propagation losses were calculated using CadnaA noise prediction software (<http://www.datakustik.com>) which incorporates a digital elevation model (DEM) to determine the modeled noise exposure at the reception points. Noise exposure from road and rail traffic were modeled independently of one another. The noise models were first computed in 2008, based on traffic data calculated over 72,000 km of roads and 3000 km of rail. The analysis carried out in this study use updated sonBASE datasets from 2014.

For each 10 x 10 m grid cell, total noise exposure from road and rail traffic was calculated using the following formula (Hansen, 2001):

$$L_{total} = 10 \log_{10} (10^{L_{road}/10} + 10^{L_{rail}/10})$$

The generated nighttime rail and road traffic noise exposure maps are illustrated in Fig. S1 of the Supplementary materials.

The sonBASE data were used to quantify the nighttime noise at the place of residence of the GeoHypnoLaus participants. To capture a representative noise level in the area surrounding the place of residence, we calculated the median value in dB(A) within a 25-meter radius of each participant's address; the median values were then used in the subsequent analysis.

2.6. Spatial statistics and lags

Using the geographical coordinates of the places of residence of the GeoHypnoLaus participants, the GeoDa program was used to calculate the Getis-Ord G_i^* statistics (hereafter Getis) for the unadjusted and adjusted ESS (Ord and Getis, 1995; Getis and Ord, 1992) in order to assess where clusters of high and low ESS values might occur throughout the city. Getis indicators measure spatial dependence and evaluate the existence of local clusters in the spatial arrangement of a given variable (here ESS). They compare the sum of individuals' ESS values in a given neighborhood (spatial lag) proportionally to the sum of individuals' ESS values throughout the whole study area (Getis and Ord, 1992). The Getis statistic is a Z-score. The null hypothesis is that the values being analyzed exhibit a random spatial pattern. Here, statistical significance testing was based on a conditional randomization procedure (Anselin, 1995) using a sample of 999 permutations as well as on the Bonferroni/Sidak procedure to correct for multiple comparisons (Anselin, 1995). All maps shown in this paper correspond to a significance level of 0.05, with Supplementary Fig. S2 illustrating how the significance may vary according to different α levels. Large statistically significant positive and negative Z scores reveal clustering of high and low ESS values respectively. A hot spot (Getis and Ord, 1992) is a statistically significant cluster of high values. A cold spot is a statistically significant cluster of low values. All sampling sites which are

not significant - or neutral - are displayed in white.

To test the robustness of our findings, we ran the following additional sensitivity analyses: (1) we present results based on a 400 m spatial lag (which provided the largest differences in nighttime noise level), but also tested four other spatial lags (200 m, 600 m, 800 m, 1000 m); (2) we also evaluated the Local Indicators of Spatial Association – LISA (Anselin, 1995), which - unlike the Getis method - also identifies dissimilar values among the local high and low spots (high–low and low–high), thus preventing misclassification of individuals in areas with relatively high numbers of dissimilar neighboring individuals. The LISA statistics are detailed in the Supplementary materials.

2.7. Statistical analyses

All statistical analyses were performed using R Statistical Software (version 3.3.1 R Foundation for Statistical Computing, Vienna, Austria). For the descriptive analysis, participants were categorized into four ESS severity categories (normal, mild, moderate, and severe sleepiness according to Johns, 1991), and associations between ESS categories and covariates were tested using either chi-square or ANOVA tests. Quantitative variables were expressed for each sleepiness category by their mean \pm standard deviation; categorical variables were described by counts and percentages.

ESS was transformed to fulfill normality assumptions through a Box-Cox power transformation based on the Maximum Likelihood method (Box and Cox, 1964). Multivariate linear regression was used to model the effects of BMI, age, gender, neighborhood income, betablockers and antihypertensive medications on the observed Epworth scores. Predicted Epworth scores were then extracted from the model and used for all subsequent analysis.

Pearson's correlation was used to assess the relationships between adjusted ESS and nighttime traffic noise exposure without accounting for spatial association.

Based on the ESS clusters generated using the different spatial lags, we computed the mean nighttime noise (in dB(A)) in each of the three Getis groups constituted by all individuals respectively belonging to a) high ESS clusters, b) neutral ESS clusters, and c) low ESS clusters. We processed ANOVA tests to assess whether the difference in mean dB(A) was significant between the groups of interest and Tukey's HSD to test for significant differences between individual clusters. We additionally ran a similar comparison analysis using the five groups generated using the LISA method (see the Supplementary materials).

3. Results

3.1. Participant selection and characteristics

Of the 5064 participants who participated in the first CoLaus|PsyCoLaus follow-up (which included data on ESS), 499 (9.9%) were excluded from this analysis because they lived in municipal districts located in the countryside, and 17 participants (0.34%) could not be geocoded. After excluding participants because of missing data (either ESS or covariates), or because they had reported taking neuroleptics, sleeping pills, or anti-depressants, which can be used as sleeping pills (see Fig. S3 in the Supplementary materials), 3697 participants were included in this analysis. These participants were similar to the baseline CoLaus|PsyCoLaus sample in terms of their age, gender and spatial distribution, but differed in terms of median neighborhood revenue, participant BMI, betablockers and hypertensive medications potentially inviting a minor selection bias.

Table 1 summarizes the characteristics of the GeoHypnoLaus participants according to the four ESS severity categories.

Among the 3697 GeoHypnoLaus participants, 53.8% were women, the mean (\pm SD) age was 56.2 (\pm 10.5) years, and the mean BMI was 26.1 (\pm 4.5) kg/m². Median (min - max range) area's annual income

Table 1
Characteristics of GeoHypnoLau participants across Epworth sleepiness severity categories.

	Epworth sleepiness severity categories				p-value
	Normal 0–10 N = 3,314	Mild 11–14 N = 293	Moderate 15–17 N = 58	Severe 18–24 N = 32	
Women (%)	1804 (54.4)	147 (50.2)	24 (41.4)	15 (46.9)	0.098
Age, years	56.7 (10.5)	52.2 (9.3)	50.7 (8.8)	52.6 (8.0)	< 0.001
BMI, kg/m ²	26.0 (4.5)	26.3 (4.5)	26.5 (4.5)	26.6 (4.5)	0.147
Taking betablockers (%)	294 (8.9)	16 (5.5)	6 (10.3)	0	0.064
Antihypertensive medication (%)	905 (27.3)	62 (21.2)	11 (19.0)	4 (12.5)	0.015
Median revenue in 2009, CHF	51,139 (5488)	50,882 (5653)	51,382 (5628)	45,991 (3439)	0.069

For age, BMI and median revenue, the mean value is given with the standard deviation in brackets, and the significance is assessed with ANOVA. For the other qualitative variables, the count is given with the percentage in brackets; the significance is assessed with a X2-test or Fischer test.

level was 51,139 (31,306–98,586) CHF. Normal, mild, moderate and severe daytime sleepiness were present in 89.6%, 7.9%, 1.6% and 0.9% of the participants respectively. The cohort differed by age and self-reported use of antihypertensive drugs when compared across ESS categories. The modeled nighttime noise exposure levels in Lausanne ranged from 0.0 to 83.0 dB(A) and had a mean of 46.3 (\pm 9.2) dB(A).

Without accounting for the spatial component, median nighttime noise and adjusted ESS were weakly correlated (Pearson's $r = 0.02$; $p = 0.003$). There was no significant correlation between median nighttime noise and unadjusted ESS.

3.2. ESS Getis clusters

The unadjusted (Panel A) and adjusted (Panel B) ESS Getis clusters based on a 400 m neighborhood are shown in Fig. 1. In both the unadjusted and adjusted Getis clustering, multiple significant clusters were identified. Overall, the ESS clusters persisted after adjustment and some additional clusters were identified. One exception exists in the north-eastern corner of the city where the cluster changes from a hot- to cold spot after adjustment; this occurs because the neighborhood is characteristically older and more female than elsewhere in the study – both factors that contribute to a lower predicted Epworth value.

For the adjusted ESS, 310 individuals (8.4%) were in the high cluster class, 3008 (81.4%) presented no spatial dependence (neutral class), and 379 (10.2%) were in the low cluster class. High and low clusters tended to orient themselves latitudinally with the high ESS clusters being primarily located in the city center and with a second hotspot located in the north-east of the city. The low clusters were generally located in the East.

The clusters generated by the LISA method showed the same spatial distributions (see Fig. S4 in the Supplementary materials). For the adjusted ESS, 186 individuals (5.0%) were in the high-high cluster class, 172 (4.7%) were in the low-high cluster class, 2905 (78.6%) presented no spatial dependence (neutral class), 216 (5.8%) were in the high-low cluster class, and 218 (5.9%) were in the low-low cluster class.

3.3. Nighttime traffic noise exposure and ESS spatial clusters

The median nighttime noise exposure from road and rail traffic was significantly different across the three ESS Getis cluster classes

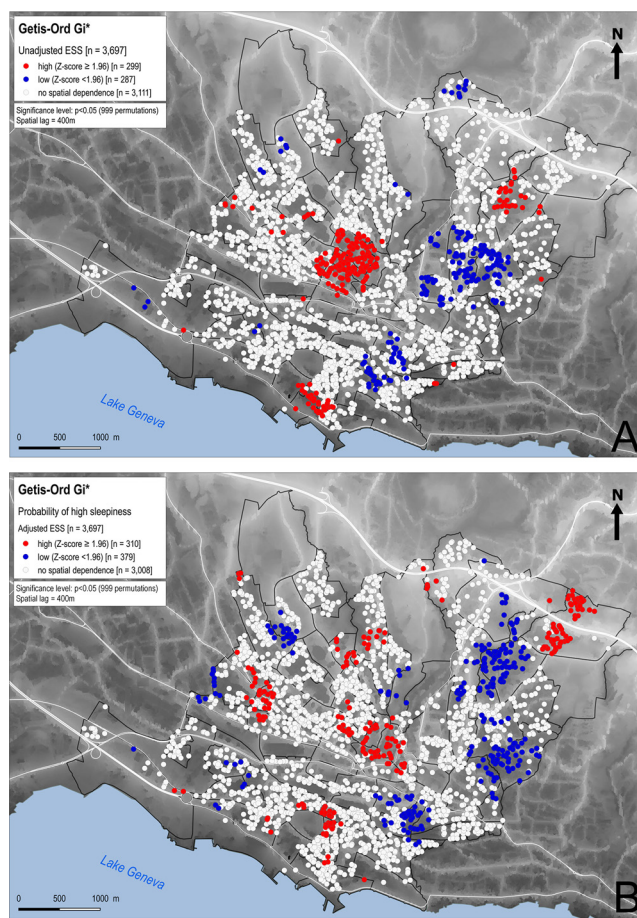


Fig. 1. Clusters of 3697 GeoHypnoLau participants for the unadjusted Epworth Sleepiness Scale (ESS) (A) and ESS adjusted for gender, age, body mass index (BMI), median neighborhood income, betablockers, antihypertensive medications (B). White dots correspond to participant's residences where ESS is not spatially dependent. Red dots correspond to participants with a statistically significant positive Z score ($\alpha = 0.05$), meaning that within a 400 m neighborhood, high ESS values cluster more than would be expected if the underlying process were random. Blue dots show individuals with a statistically significant negative Z score ($\alpha = -0.05$), meaning that within a 400 m neighborhood, low ESS values cluster more than would be expected if the underlying process were random. Polygons show the 81 Lausanne's statistical sectors (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

($p < 0.001$), with the majority of noise exposure being sourced from road traffic. The mean nighttime noise exposure in each of the three classes is illustrated in Fig. 2. We observed a dose-response effect; the median nighttime noise in the high clusters was 2.10 dB(A) higher than in the neutral class ($p < 0.001$) and 5.16 dB(A) higher than in low clusters ($p < 0.001$). The mean nighttime noise exposure in each of the three clusters was 47.64, 45.54, and 42.47 dB(A) respectively.

The nighttime noise distributions also exhibited a clear dose-response effect between the LISA clusters. The difference between the nighttime noise levels in the high-high and low-low clusters was 4.49 dB(A) ($p < 0.001$), and 1.80 dB(A) between high-high and the neutral class ($p < 0.05$). Median nighttime noise levels in all five classes were above 40 dB(A). Statistically, the median nighttime noise exposure distributions exhibit the same patterns across the hot (high-high and low-high) and cold (low-low and high-low) neighborhoods defined by the LISA clusters (i.e., the difference in median nighttime noise levels between high-high and low-high and in between low-low and high-low clusters were not significant: $p = 0.99$ and $p = 0.065$ respectively) (see Fig. S5 in Supplementary material). “More precisely,

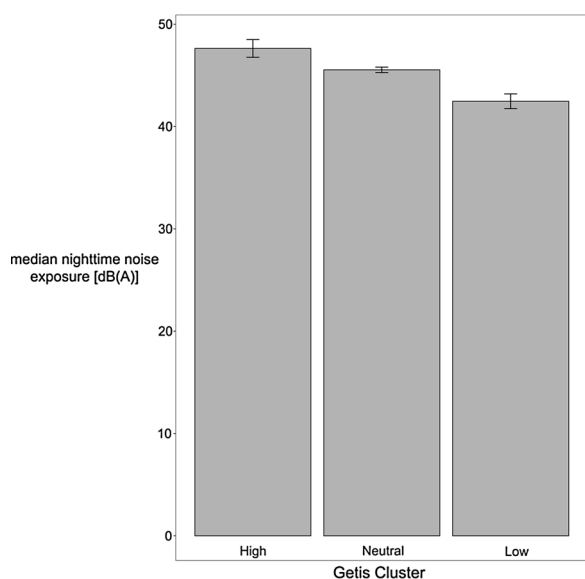


Fig. 2. Average median nighttime road traffic noise exposure levels according to ESS Getis clusters (p -value across ESS Getis clusters < 0.001). Error bars show 95% confidence intervals.

individuals belonging to the low-high or high-low class are exposed to similar noise levels as those in the high-high or low-low class respectively, but they exhibit opposite daytime sleepiness levels compared to their neighbors. For example, for an individual belonging to the low-high class, this could suggest that they might have additional noise shielding measures (e.g. residence located on a quieter street within the neighborhood, building has better sound-proofing) or that they may be generally less disturbed by noise.”

4. Discussion

Using geo-referenced measurements of daytime sleepiness at the individual level from adults in the general population, we identified hot and cold spots of daytime sleepiness in the Swiss city of Lausanne. Daytime sleepiness was not randomly distributed and showed a significant spatial dependence. Clusters of daytime sleepiness were associated with higher median nighttime noise levels than clusters of lower daytime sleepiness. These associations were independent of major potential confounders including BMI and neighborhood income level.

Our results are based on a fine-scale geographic analysis rather than spatial aggregation. Studies that use predefined units as neighborhoods focus on the internal characteristics of the unit and ignore the effects on individual attributes resulting from interactions between nearby neighborhoods (Guessous et al., 2014). Further, the distributions of local-scale phenomena, such as daytime sleepiness, can be smoothed out by aggregating to a spatial unit that is too large. An avoidance of spatial aggregation is particularly important when an understanding of the influence of local-scale covariates is sought. Thus, to identify daytime sleepiness clusters, we did not use a predefined unit, but instead considered space as a continuum. The cluster-based approach also provides additional advantages over regression-based approaches that do not address the principle of spatial association. First, it provides a statistical basis for the identification of problem areas and the justification of considering a spatial component when evaluating daytime sleepiness. Second, and more importantly, hotspots or priority areas for intervention are clearly identified.

The traffic in the city of Lausanne is amongst the noisiest in Switzerland (EEA, 2017). Our analysis confirmed that noise exposure from the city’s rail line and major roads exceeds Swiss urban limits (50 dB(A) nighttime limit). We used high-resolution spatial modeling to localize nighttime noise and individuals suffering from daytime

sleepiness to better understand the influence of local-level nighttime noise exposure. Without accounting for the spatial component, median nighttime noise and daytime sleepiness were only weakly correlated. After considering the spatial distribution of daytime sleepiness and identifying spatial clusters of high and low daytime sleepiness, we found strong associations between daytime sleepiness clusters and nighttime noise level. The differences in nighttime noise exposure between high and low clusters of daytime sleepiness were important: more than a 5 dB(A) difference after controlling for major confounders. Such a difference corresponds to more than a doubling of sound intensity and provides evidence for a dose-response effect of traffic nighttime noise exposure on daytime sleepiness.

Dose-response relationships between self-reported sleep disturbances and environmental noise have been well documented (Frei et al., 2014; Miedema and Vos, 2007). The relationships between nighttime noise and daytime sleepiness have been explored less, with only one study identifying a dose-dependent association between daytime sleepiness and proximity to wind turbines (Nissenbaum et al., 2012). To our knowledge, our study is the first that has identified a dose-response effect of traffic noise on daytime sleepiness.

Our results suggest that 10% of adults in Lausanne suffer from excessive daytime sleepiness, and 0.9% from severe daytime sleepiness - a relatively low prevalence when compared to other western countries (Ohayon, 2006). This could be largely attributed to the inconsistent operational definition of excessive daytime sleepiness, which makes comparison across studies difficult. Indeed, the criteria for excessive daytime sleepiness as per the ESS method tend to be more stringent than other subjective evaluations that, for example, assess the tendency to fall asleep over a week (Janson et al., 1995) or are based on napping frequency (Asplund, 1996).

Among factors that influence daytime sleepiness, environmental factors such as noise from road and rail traffic present the advantage of being modifiable, and noise abatement is now considered an essential element of public health (Halperin, 2014). Several interventions have therefore been proposed to mitigate road traffic noise and its human health effects (Brown and van Kamp, 2017). Our results suggest that such interventions could be even more cost-effective in terms of public health services if they are guided by spatial information that helps identifying noisy roads in clusters of high daytime sleepiness. Noise mapping platforms and programs (e.g. NoiseSPY, CadnaA) have been developed under the EU’s Environmental Noise Directive. Such platforms and programs have become an integral element for urban planning and development of noise control policy (Directive 2002/49/EC, Art. 4–8). Results from clustering on health attributes, as demonstrated here with daytime sleepiness, could be integrated into such platforms to add further information for effective noise abatement strategies.

5. Study limitations and strengths

Our study presents several limitations. First, information relating to the quality of noise was missing. Noise is known to affect sleep not only through the number of noise events, but also through their acoustical properties (Basner et al., 2011). For example, peak noise levels – which may impact subjective sleep quality more than continuous noise (Öhrström and Rylander, 1982) – were not considered. Second, Marks and Griefahn (2007) found that alterations of subjective evaluation of sleep were modified by noise sensitivity. Although we controlled for age, gender, BMI, neighborhood revenue, and certain confounding medications, we could not account for other factors of individual noise susceptibility (e.g. shift workers) (Basner et al., 2014) or alternative factors influencing daytime sleepiness (e.g. stress levels or presence of small children in the home). Third, participants with frequent causes of daytime sleepiness (medication, depressions) were excluded from this analysis, but other causes including restless leg syndrome, sleep apnea and primary hypersomnia of central origin such as narcolepsy and idiopathic hypersomnia were not. Nevertheless, central hypersomnia

are extremely rare and were unlikely to influence results. Fourth, noise was modeled for the outside environment and we did not account for bedroom location, building-level noise isolation, or whether the participants were likely to sleep with their window open (Pirrerera et al., 2014). Further, the sonBASE nighttime noise exposure model used in this analysis was based on data collected over several years, and despite traffic having remained relatively stable in Lausanne over this time, the model is unlikely to be a perfect estimator of noise exposure at the time of the first CoLauS|PsyCoLauS follow-up. Additionally, the effects of vehicular pollution on daytime sleepiness were not considered (Gislason et al., 2016). Finally, subjective evaluations of daytime sleepiness have been shown to be correlated with a number of health and socio-economic factors (Kim and Young, 2005). While we adjusted the ESS values to account for potential confounders, objective measurements, such as the multiple sleep latency test (MSLT) are considered the gold standard for the assessment of daytime sleepiness (Ohayon, 2006). Still, a systematic review concluded that the ESS can be particularly useful for group level comparisons (Kendzierska et al., 2014).

The main strengths of our study are the large and representative sample and the availability of information at the individual address level, which allows for fine-scale analysis and enables the detection of an important local-scale dose-response effect. Contrastingly, while conventional multivariate regression also identifies a positive relationship between Epworth Sleepiness Score and nighttime noise exposure, only a 0.7 dB(A) difference is detected between normal and excessive sleepiness categories (see Fig. S6 in the Supplementary materials). Additionally, the use of a high-resolution noise exposure model eliminated the subjective bias introduced in other studies where participants are asked to rate their level of noise exposure or annoyance (Pedersen and Persson Waye, 2004). Finally, we present a cluster-based method that has not previously been tested in the context of noise-sleep relationships to detect noise-related daytime sleepiness hot spots that can be targeted for effective intervention.

6. Conclusions

Daytime sleepiness is not randomly distributed and shows a spatial dependence. Clusters of higher daytime sleepiness in adults are associated with higher median nighttime noise levels. The identification of these clusters can guide tailored public health interventions.

Funding

The CoLauS|PsyCoLauS study was and is supported by research grants from GlaxoSmithKline, the Faculty of Biology and Medicine of Lausanne, and the Swiss National Science Foundation (grants 3200B0-105993, 3200B0-118308, 33CS00-122661, 33CS30-139468 and 33CS30-148401). The nested HypnoLauS study was further supported by the Faculty of Biology and Medicine of the University of Lausanne, the Leenaards Foundation, and the Vaud Pulmonary League (Ligue Pulmonaire Vaudoise).

The funding sources had no involvement in the study design, data collection, analysis and interpretation, writing of the report, or decision to submit the article for publication.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors are grateful to the participants and the investigators of the CoLauS|PsyCoLauS study.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.ijheh.2018.05.004>.

References

- Abbasi, M., Monazzam, M.R., Akbarzadeh, A., Zakerian, S.A., Ebrahimi, M.H., 2015. Impact of wind turbine sound on general health, sleep disturbance and annoyance of workers: a pilot-study in Manjil wind farm, Iran. *J. Environ. Health Sci. Eng.* 13. <http://dx.doi.org/10.1186/s40201-015-0225-8>.
- American Academy of Sleep Medicine, 2014. *International Classification of Sleep Disorders*, 3rd ed. American Academy of Sleep Medicine, Darien, IL.
- Anselin, L., 1995. Local Indicators of Spatial Association - LISA. *Geogr. Anal.* 27, 93–115. <http://dx.doi.org/10.1111/j.1538-4632.1995.tb00338.x>.
- Asplund, R., 1996. Daytime sleepiness and napping amongst the elderly in relation to somatic health and medical treatment. *J. Intern. Med.* 239, 261–267. <http://dx.doi.org/10.1046/j.1365-2796.1996.453806000.x>.
- Auchincloss, A.H., Gebreab, S.Y., Mair, C., Diez Roux, A.V., 2012. A review of spatial methods in epidemiology, 2000–2010. *Annu. Rev. Public Health* 33, 107–122. <http://dx.doi.org/10.1146/annurev-publhealth-031811-124655>.
- Barrigón Morillas, J.M., Gómez Escobar, V., Méndez Sierra, J.A., Vilchez Gómez, R., Trujillo Carmona, J., 2002. An environmental noise study in the city of Cáceres, Spain. *Appl. Acoust.* 63, 1061–1070. [http://dx.doi.org/10.1016/S0003-682X\(02\)00030-0](http://dx.doi.org/10.1016/S0003-682X(02)00030-0).
- Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., Stansfeld, S., 2014. Auditory and non-auditory effects of noise on health. *Lancet* 383, 1325–1332. [http://dx.doi.org/10.1016/S0140-6736\(13\)61613-X](http://dx.doi.org/10.1016/S0140-6736(13)61613-X).
- Basner, M., Glatz, C., Griefahn, B., Penzel, T., Samel, A., 2008. Aircraft noise: effects on macro- and microstructure of sleep. *Sleep Med.* 9, 382–387. <http://dx.doi.org/10.1016/j.sleep.2007.07.002>.
- Basner, M., Müller, U., Elmenhorst, E.-M., 2011. Single and combined effects of air, Road, and rail traffic noise on sleep and recuperation. *Sleep* 34, 11–23. <http://dx.doi.org/10.1093/sleep/34.1.11>.
- Bixler, E.O., Vgontzas, A.N., Lin, H.-M., Calhoun, S.L., Vela-Bueno, A., Kales, A., 2005. Excessive daytime sleepiness in a general population sample: the role of sleep apnea, age, obesity, diabetes, and depression. *J. Clin. Endocrinol. Metab.* 90, 4510–4515. <http://dx.doi.org/10.1210/jc.2005-0035>.
- Blachier, M., Dauvilliers, Y., Jaussent, I., Helmer, C., Ritchie, K., Jouven, X., Tzourio, C., Amouyel, P., Besset, A., Ducimetiere, P., Empana, J.-P., 2012. Excessive daytime sleepiness and vascular events: the Three City study. *Ann. Neurol.* 71, 661–667. <http://dx.doi.org/10.1002/ana.22656>.
- Box, G.E.P., Cox, D.R., 1964. An analysis of transformations. *J. R. Stat. Soc. Ser. B Stat. Methodol.* 26, 211–252.
- Brown, A.L., van Kamp, I., 2017. WHO environmental noise guidelines for the European region: a systematic review of transport noise interventions and their impacts on health. *Int. J. Environ. Res. Public Health* 14. <http://dx.doi.org/10.3390/ijerph14080873>.
- Callejas, L.M., Sarmiento, R., Medina, K., Sepúlveda, H., Deluque, D., Escobar-Córdoba, F.E., 2015. Sleep quality in an adult population exposed to the noise of El Dorado Airport, Bogotá, 2012. *Biomédica* 35, 103–109. <http://dx.doi.org/10.7705/biomedica.v35i0.2465>.
- EEA, 2017. *Switzerland noise fact sheet 2017. 2017 Overview of Policy-Related Data*.
- Evandt, J., Oftedal, B., Hjertager Krog, N., Nafstad, P., Schwarze, P.E., Marit Aasvang, G., 2017. A population-based study on nighttime road traffic noise and insomnia. *Sleep* 40. <http://dx.doi.org/10.1093/sleep/zsw055>.
- Firmann, M., Mayor, V., Vidal, P.M., Bochud, M., Pécoud, A., Hayoz, D., Paccaud, F., Preisig, M., Song, K.S., Yuan, X., Danoff, T.M., Stirnadel, H.A., Waterworth, D., Mooser, V., Waeber, G., Vollenweider, P., 2008. The CoLauS study: a population-based study to investigate the epidemiology and genetic determinants of cardiovascular risk factors and metabolic syndrome. *BMC Cardiovasc. Disord.* 8 (6). <http://dx.doi.org/10.1186/1471-2261-8-6>.
- Frei, P., Mohler, E., Rösli, M., 2014. Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality. *Int. J. Hyg. Environ. Health* 217, 188–195. <http://dx.doi.org/10.1016/j.ijheh.2013.04.003>.
- FOEN, 2014. sonBASE – noise levels: road traffic noise (night). Web GIS. (dataset). <https://www.bafu.admin.ch/bafu/en/home/topics/noise/state/gis-laermdatenbank-sonbase.html>.
- Getis, A., Ord, J., 1992. The analysis of spatial association by use of distance statistics. *Geogr. Anal.* 24, 189–206. <http://dx.doi.org/10.1111/j.1538-4632.1992.tb00261.x>.
- Gislason, T., Bertelsen, R.J., Real, F.G., Sigsgaard, T., Franklin, K.A., Lindberg, E., Janson, C., Arnardottir, E.S., Hellgren, J., Benediktsson, B., Forsberg, B., Johannessen, A., 2016. Self-reported exposure to traffic pollution in relation to daytime sleepiness and habitual snoring: a questionnaire study in seven North-European cities. *Sleep Med.* 24, 93–99. <http://dx.doi.org/10.1016/j.sleep.2016.08.007>.
- Grandner, M.A., Jackson, N.J., Pigeon, W.R., Gooneratne, N.S., Patel, N.P., 2012. State and regional prevalence of sleep disturbance and daytime fatigue. *J. Clin. Sleep Med.* 8, 77–86. <http://dx.doi.org/10.5664/jcs.m.1668>.
- Guessous, I., Joost, S., Jeannot, E., Theler, J.-M., Mahler, P., Gaspoz, J.-M., Group, G.I.R.A.P.H., 2014. A comparison of the spatial dependence of body mass index among adults and children in a Swiss general population. *Nutr. Diabetes* 4, e111. <http://dx.doi.org/10.1038/nutd.2014.8>.
- Halperin, D., 2014. Environmental noise and sleep disturbances: a threat to health? *Sleep Sci.* 7, 209–212. <http://dx.doi.org/10.1016/j.slsci.2014.11.003>.

- Hansen, C.H., 2001. Fundamentals of acoustics. In: Goelzer, B.H., Hansen, C.H., Sehrndt, G.A. (Eds.), *Occupational Exposure to Noise: Evaluation, Prevention and Control*. World Health Organization, Geneva.
- Heinzer, R., Vat, S., Marques-Vidal, P., Marti-Soler, H., Andries, D., Tobback, N., Mooser, V., Preisig, M., Malhotra, A., Waeber, G., Vollenweider, P., Tafti, M., Haba-Rubio, J., 2015. Prevalence of sleep-disordered breathing in the general population: the HypnoLaus study. *Lancet Respir. Med.* 3, 310–318. [http://dx.doi.org/10.1016/S2213-2600\(15\)00043-0](http://dx.doi.org/10.1016/S2213-2600(15)00043-0).
- Horne, J.A., Reyner, L.A., 1995. Sleep related vehicle accidents. *BMJ* 310, 565–567. <http://dx.doi.org/10.1136/bmj.310.6979.565>.
- Jakovljević, B., Belojević, G., Paunović, K., Stojanov, V., 2006. Road traffic noise and sleep disturbances in an urban population: cross-sectional study. *Croat. Med. J.* 47, 125–133.
- Janson, C., Gislason, T., De Backer, W., Plaschke, P., Björnsson, E., Hetta, J., Kristbjarnason, H., Vermeire, P., Boman, G., 1995. Daytime sleepiness, snoring and gastro-oesophageal reflux amongst young adults in three European countries. *J. Intern. Med.* 237, 277–285. <http://dx.doi.org/10.1111/j.1365-2796.1995.tb01176.x>.
- Johns, M.W., 2000. Sensitivity and specificity of the multiple sleep latency test (MSLT), the maintenance of wakefulness test and the Epworth sleepiness scale: failure of the MSLT as a gold standard. *J. Sleep Res.* 9, 5–11. <http://dx.doi.org/10.1046/j.1365-2869.2000.00177.x>.
- Johns, M.W., 1992. Reliability and factor analysis of the Epworth sleepiness scale. *Sleep* 15, 376–381. <http://dx.doi.org/10.1093/sleep/15.4.376>.
- Johns, M.W., 1991. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep* 14, 540–545. <http://dx.doi.org/10.1093/sleep/14.6.540>.
- Joost, S., Duruz, S., Marques-Vidal, P., Bochud, M., Stringhini, S., Paccaud, F., Gaspoz, J.-M., Theler, J.-M., Chételat, J., Waeber, G., Vollenweider, P., Guessous, I., 2016. Persistent spatial clusters of high body mass index in a Swiss urban population as revealed by the 5-year GeoCoLaus longitudinal study. *BMJ Open* 6, e010145. <http://dx.doi.org/10.1136/bmjopen-2015-010145>.
- Kendzierska, T.B., Smith, P.M., Brignardello-Petersen, R., Leung, R.S., Tomlinson, G.A., 2014. Evaluation of the measurement properties of the Epworth sleepiness scale: a systematic review. *Sleep Med. Rev.* 18, 321–331. <http://dx.doi.org/10.1016/j.smrv.2013.08.002>.
- Kim, H., Young, T., 2005. Subjective daytime sleepiness: dimensions and correlates in the General population. *Sleep* 28, 625–634. <http://dx.doi.org/10.1093/sleep/28.5.625>.
- Kwak, K.M., Ju, Y.-S., Kwon, Y.-J., Chung, Y.K., Kim, B.K., Kim, H., Youn, K., 2016. The effect of aircraft noise on sleep disturbance among the residents near a civilian airport: a cross-sectional study. *Ann. Occup. Environ. Med.* 28, 38. <http://dx.doi.org/10.1186/s40557-016-0123-2>.
- Licitra, G. (Ed.), 2013. *Noise Mapping in the EU: Models and Procedures*. CRC Press, Boca Raton, FL.
- Marks, A., Griefahn, B., 2007. Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise. *Noise Health* 9, 1–7.
- Mehdi, M.R., Kim, M., Seong, J.C., Arsalan, M.H., 2011. Spatio-temporal patterns of road traffic noise pollution in Karachi, Pakistan. *Environ. Int.* 37, 97–104. <http://dx.doi.org/10.1016/j.envint.2010.08.003>.
- Miedema, H.M.E., Vos, H., 2007. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. *Behav. Sleep Med.* 5, 1–20. http://dx.doi.org/10.1207/s15402010bsm0501_1.
- Muzet, A., 2007. Environmental noise, sleep and health. *Sleep Med. Rev.* 11, 135–142. <http://dx.doi.org/10.1016/j.smrv.2006.09.001>.
- Newman, A.B., Spiekerman, C.F., Md, P.E., Lefkowitz, D., Manolio, T., Reynolds, C.F., Robbins, J., 2000. Daytime sleepiness predicts mortality and cardiovascular disease in older adults. *J. Am. Geriatr. Soc.* 48, 115–123. <http://dx.doi.org/10.1111/j.1532-5415.2000.tb03901.x>.
- Nissenbaum, M.A., Aramini, J.J., Hanning, C.D., 2012. Effects of industrial wind turbine noise on sleep and health. *Noise Health* 14, 237. <http://dx.doi.org/10.4103/1463-1741.102961>.
- Ohayon, M.M., 2006. Epidemiology of excessive daytime sleepiness. *Sleep Med. Clin.* 1, 9–16. <http://dx.doi.org/10.1016/j.jsmc.2005.11.004>. Excessive Sleepiness.
- Öhrström, E., 1993. Research on noise and sleep: present state. In: *Proceedings of Noise and Man*. Presented at the ICEBN, INERTS, NICE. p. 52.
- Öhrström, E., Rylander, R., 1982. Sleep disturbance effects of traffic noise—a laboratory study on after effects. *J. Sound Vib.* 84, 87–103. [http://dx.doi.org/10.1016/0022-460X\(82\)90434-5](http://dx.doi.org/10.1016/0022-460X(82)90434-5).
- Ord, J., Getis, A., 1995. Local spatial autocorrelation statistics - distributional issues and an application. *Geogr. Anal.* 27, 286–306. <http://dx.doi.org/10.1111/j.1538-4632.1995.tb00912.x>.
- Pagel, J.F., 2009. Excessive daytime sleepiness. *Am. Fam. Physician* 79, 391–396.
- Parkes, J.D., Chen, S.Y., Clift, S.J., Dahlitz, M.J., Dunn, G., 1998. The clinical diagnosis of the narcoleptic syndrome. *J. Sleep Res.* 7, 41–52. <http://dx.doi.org/10.1046/j.1365-2869.1998.00093.x>.
- Pedersen, E., Persson Wayne, K., 2004. Perception and annoyance due to wind turbine noise—a dose–response relationship. *J. Acoust. Soc. Am.* 116, 3460–3470. <http://dx.doi.org/10.1121/1.1815091>.
- Pirrer, S., De Valck, E., Cluydts, R., 2014. Field study on the impact of nocturnal road traffic noise on sleep: the importance of in- and outdoor noise assessment, the bedroom location and nighttime noise disturbances. *Sci. Total Environ.* 500–501, 84–90. <http://dx.doi.org/10.1016/j.scitotenv.2014.08.061>.
- Preisig, M., Waeber, G., Vollenweider, P., Bovet, P., Rothen, S., Vandeleur, C., Guex, P., Middleton, L., Waterworth, D., Mooser, V., Tozzi, F., Muglia, P., 2009. The PsyCoLaus study: methodology and characteristics of the sample of a population-based survey on psychiatric disorders and their association with genetic and cardiovascular risk factors. *BMC Psychiatry* 9 (9). <http://dx.doi.org/10.1186/1471-244X-9-9>.
- Qureshi, A.I., Giles, W.H., Croft, J.B., Bliwise, D.L., 1997. Habitual sleep patterns and risk for stroke and coronary heart disease: a 10-year follow-up from NHANES I. *Neurology* 48, 904–911. <http://dx.doi.org/10.1212/WNL.48.4.904>.
- Stepanski, E., Lamphere, J., Badia, P., Zorick, F., Roth, T., 1984. Sleep fragmentation and daytime sleepiness. *Sleep* 7, 18–26. <http://dx.doi.org/10.1093/sleep/7.1.18>.
- Stringhini, S., Haba-Rubio, J., Marques-Vidal, P., Waeber, G., Preisig, M., Guessous, I., Bovet, P., Vollenweider, P., Tafti, M., Heinzer, R., 2015. Association of socioeconomic status with sleep disturbances in the Swiss population-based CoLaus study. *Sleep Med.* 16, 469–476. <http://dx.doi.org/10.1016/j.sleep.2014.12.014>.
- Vienneau, D., Perez, L., Schindler, C., Lieb, C., Sommer, H., Probst-Hensch, N., Künzli, N., Rösli, M., 2015. Years of life lost and morbidity cases attributable to transportation noise and air pollution: a comparative health risk assessment for Switzerland in 2010. *Int. J. Hyg. Environ. Health* 218, 514–521. <http://dx.doi.org/10.1016/j.ijheh.2015.05.003>.
- WHO Regional Office for Europe, 2009. *Night Noise Guidelines for Europe*. Copenhagen.
- Williamson, A.M., Feyer, A.-M., 2000. Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication. *J. Occup. Environ. Med.* 57, 649–655. <http://dx.doi.org/10.1136/oem.57.10.649>.