Effects of noise from non-traffic-related ambient sources on sleep: Review of the literature of 1990–2010

Sarah Omlin, Georg F Bauer[1], Mark Brink

Department of Management, Technology and Economics, Public and Organizational Health, ETH Zurich, [1]Department of Medicine, Institute of Social and Preventive Medicine, University of Zurich, Zurich, Switzerland

Abstract

This article reviews the literature about the effects of specific non-traffic-related ambient noise sources on sleep that appeared in the last two decades. Although everybody is faced with noise of non-traffic and non-industry origin (e.g. sounds made by neighbors, talk, laughter, music, slamming doors, structural equipment, ventilation, heat pumps, noise from animals, barking dogs, outdoor events etc.), little scientific knowledge exists about its effects on sleep. The findings of the present extensive literature search and review are as follows: Only a small number of surveys, laboratory and field studies about mainly neighborhood, leisure and animal noise have been carried out. Most of them indicate that ambient noise has some effect on human sleep. However, a quantitative meta-analysis and comparison is not possible due to the small number of studies available and at times large differences in quality.

Keywords: Ambient noise, sleep disturbance, systematic review

Introduction

Sleep is "a physiological state of relative unconsciousness and inaction of the voluntary muscles, the need for which recurs periodically"[1] and is absolutely essential for humans. Noise pollution is the most important external cause of sleep disturbances.[2] Most research on noise and sleep disturbance considers transportation sources (road traffic, railways and aircraft)[2,3] although other sources of noise might equally lead to sleep disturbances in one way or another. In the present paper, we look at sleep disturbances from noise from non-traffic and non-industry sources, which will further be referred to as *ambient noise*. In this systematic review, we consider the following noise types as belonging to the category of *ambient* noise:

- neighborhood noise (people's voices, music, television, radio, footfalls, slamming of doors, air conditioning, air cooling systems, fans, ventilation, heat pumps etc.)
- leisure noise (noise from hotels, bars, clubs, restaurants, noise of cultural events such as concerts and parties, noise of sports events, noise from recreational facilities etc.)
- animal sounds (barking of dogs, croaking of frogs etc.)
- ringing of bells (church and cow bells)
- noise from recycling collection points.

The selection of the noise types from the above list is based on a non-systematic content analysis of filed noise complaints from Swiss local authorities.

To date, only very little scientific research has been conducted into sleep disturbance due to the noise sources enumerated above. Although ambient noise seems to affect many people, the literature reports only a few studies on this issue. A reason for the poor scientific treatment of ambient noise and its effects could be that it includes a broad range of sources, which are difficult to define and measure. In the present review (applying the guidelines of the prisma statement),[4] the scientific evidence accumulated over the last two decades from surveys, field and laboratory studies will be presented and suggestions for future research will be made.

Methods

To assess the effects of ambient noise on sleep, a review of the literature of the last twenty years (1990–2010) was conducted adopting the guidelines of the prisma statement for the reporting of systematic reviews.[4] Materials possibly relevant to this review were identified by searches of several literature databases and conference proceedings. Moreover, the references of the retrieved articles were searched for further relevant articles.

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Search strings

In this literature search, we applied two search sets with different search terms. The first search set contained the search terms 'noise' and 'sleep' related with the AND operator. In a second search set, the following key terms for some noise sources were searched combined with the AND operator and the term 'sleep':

Search terms for neighborhood noise: 'neighbourhood', 'neighborhood', 'neighbour*', 'neighbor*', 'community', 'habitation', 'ventilation', 'air condition*', 'air cooling system', 'heat pump', 'fan'.

Search terms for leisure noise: 'hotel*', 'restaurant*', 'sports centre', 'sports center', 'tennis court', football field', 'stadium', 'amphitheatre', 'amphitheater', 'arena', 'recreation centre', 'recreation center', 'night life', 'club', 'bar*', 'pub*', 'cafe*', 'diner*', 'fast food', 'food stand*', 'takeaway*'.

Search terms for noise of bells such as church and cow bells: 'church bell*', 'cow bell*', 'clock tower', 'bell tower'.

Search terms for noise from recycling collection points: 'recycling', 'collection points', 'bottle banks'.

The search strategy was developed by one author with the aid of a librarian and then discussed and adjusted with a second author.

Database search

The database search was carried out in the following databases: PubMed, Embase, Web of Science, PSYNDEXplus and PsycINFO. In some databases, the search sets were modified. The refinements of the searches are as follows:

PubMed: The terms 'sleep', 'noise' and 'adverse effects' were MeSH (Medical Subheading) terms and the search sets were restricted to humans. Search set 2 was further restricted to Meta-Analysis, Review, Congresses, Guideline, Journal Article, Technical Report and to the Field: Title. In this search set also some wildcards '*' were replaced directly with an 's' (e.g. search term bell* now as search terms 'bell' and 'bells').

Embase: Search set 1 was limited to the area of 'Public health' and both search sets to humans.

Web of Science: Both search sets were refined to the subject area of 'Public, environmental and Occupational Health', and search set 1 additionally also to the subject area of 'Acoustics'.

PsycINFO: Both search sets were restricted to humans.

No limitations were set concerning age groups and geography (detailed search strings are listed in the appendix (available online at: http://opac.nebis.ch/F/?local_base=NEBIS&func=find-b&find_code=SYS&request=006367713)). The database searches were all conducted on January 20, 2011.

The search results from the databases were imported into an Endnote library. From these 1479 hits, duplicate records were excluded, thus yielding 1425 references. In a next step, the relevant publications needed to be extracted from the resulting references. The following steps were carried out manually. Firstly, the title of each reference was examined, and if the paper contained 'traffic noise' or 'noise in hospital', it was excluded immediately as obviously beyond the scope of the current topic. If no exclusion was carried out, the abstract was read. Then, if the abstract contained one or several of the search terms mentioned above and could not be excluded, because it indicated research in another subject, the full text was read. Papers meeting the following criteria were included in the review:

- the paper comprises the previously mentioned search terms
- it contains results of one or several studies
- it is not a case study or reports only a single case.

Conference proceedings search

Furthermore, the proceedings of several acoustic or noise conferences of the last twenty years (a total of 62 conferences) were searched manually or with the help of an index (if provided). The following conferences, dating back to 1990, were searched (detailed information about the search in the appendix):

- Internoise: 1990–2009 (20 conferences)
- Deutsche Jahrestagung für Akustik (DAGA): 1990–2009 (20 conferences)
- Euronoise: 1992, 1995, 1998, 2001, 2003, 2006, 2008, 2009 (8 conferences)
- International Congress on Acoustics (ICA): 1992, 1995, 1998, 2001, 2004, 2007 (6 conferences)
- International Congress on Noise as a Public Health Problem (ICBEN): 1993, 1998, 2003, 2008 (4 conferences)
- Forum Acusticum: 1999, 2002, 2005, 2008 (four conferences)

The searches were restricted to the keywords 'sleep' and 'Schlaf' (German for 'sleep', DAGA conferences only). When searched manually, the topics in the program index of the conferences on the effects of noise (including environmental noise) were evaluated more closely. The same procedure was then carried out as for the selection from the database publications. The proceedings of sleep conferences were not searched systematically, because a small search in the last five conferences (2002–2010) of the European Sleep Research Society showed that noise effects is not a relevant subject of these conferences. In 2002 and 2004 it was not mentioned at all. At the conference in 2006 one abstract

regarding noise effects was presented, in 2008 it were nine abstracts and in 2010 were two abstracts. None of these abstracts concerned the ambient noise sources specified in this review. They were mainly associated with traffic noise.

Author's own libraries

Additionally to the searches of the databases and the conference proceedings, the bibliographies of the articles found and the author's own endnote libraries were also searched using the keywords 'sleep' and 'Schlaf'. Recommended literature by experts relating to the topic of our review were also added to our own libraries.

Data items and data collection process

Information was extracted from each included study on: (1) characteristics of participants (including age, sex, number, recruitment and selection of sample); (2) noise exposure (including type, exposure levels, measurement or presentation and its location); (3) effect on sleep (measurement) (4) study type (including examination time and location). These data items were collected in an excel sheet. This data extraction was conducted through one author.

Quality of the individual studies considered

To assess the quality of the studies included in the discussion section of the review the following criteria were considered:

1. Study population is well defined (age, gender, number)
2. Exposure is well defined (location and duration of noise measurement or presentation)
3. Potential confounding variables have been taken into account: In study design or in analysis by statistical adjustment
4. Complete reporting of basic data and outcome data (to avoid selective reporting bias)
5. Declaration of the statistical methods used
6. Sample size: Small (below number of participants (n)=50), medium (50=n=200), large (n<200)
7. Random sample selection
8. Exposure-effect curve: If the association is one, which can reveal an exposure-effect curve, then we should look most carefully for such evidence.

Criteria 1 to 5 were developed by the International Agency for Research on Cancer.[5] However, we divided the criterion "Study population and exposure is well defined" into two criteria and refined them. Criterion 8 is adapted from the Hill criteria "Biological gradient".[6]

The application of these criteria did not lead to a further exclusion of studies.

Results

Results of the literature search

The output of the literature search described in the method section amounted to just 23 studies in 24 papers relating to neighborhood, leisure or animal noise and sleep disturbance [Figure 1].

In [Table 1], the number of hits resulting from the searched databases relating to the two search sets is displayed.

Examination of these references as described in the previous chapter produced nine hits from database searches. They stem all from the general search with the search terms 'noise' and 'sleep'.

[Table 2] shows the results of the literature search within the conference proceedings.

Eight papers emerged from the search within the conference proceedings and seven papers from the search in the author's own libraries.

The following section gives a general overview over the studies investigating ambient noise effects and sleep disturbance. All the following studies [Tables 3 and, 4] were at least partly dedicated to the research question of this review.

Table 1: Number of references in the searched databases according to search sets 1 and 2

Databases	Pub Med	Embase	Web of Science	PSYNDEX plus	PsycINFO
No. of references from search set 1	400	122	175	33	250
No. of references from search set 2	293	70	31	120	0
Total	689	192	203	145	250

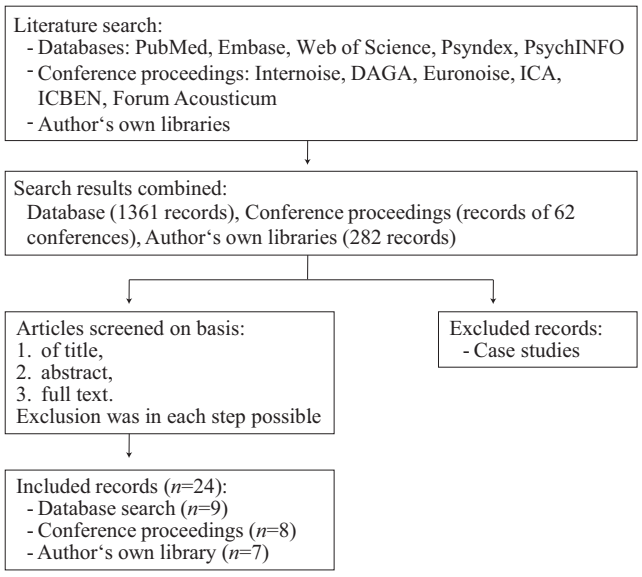

Figure 1: Flow diagram of record selection

Neighborhood noise

In a study from the Netherlands by Leidelmeier and Marsman (1997), 1242 households were interviewed about day and night time noise from neighbors.[3,8] The neighbor noise was divided into five categories (contact noise, noise from sanitary fittings, central heating, etc.; noise from radio, TV and hi-fi; do-it yourself noises; pets). For each of these categories the respondents were asked if the respective sound could be heard during the night in their master bedroom. The percentage of respondents who could hear the different noises varied, according to the corresponding noise category, between 6 and 22% (6% pets, 8% do-it yourself noises, 12% noise from radio, TV and hi-fi, 19% noise from sanitary fittings, central heating, etc. 22% contact noise). Between 30 and 50% of the respondents considered that neighbor noise at night is unacceptable. Thus, they conclude that annoyance due to night-time noise might be associated with disturbance of sleep.

Stansfeld *et al.* noted that Raw and Hamilton cite a study in which 12.6% of respondents suffered from sleep disturbance due to neighbor noise.[7] In an inventory study of nine municipalities in the Netherlands 7% of the 5250 participants responded to be highly sleep disturbed due to noise from neighbors.

The effect of civil impulse sounds such as door slamming from vans on sleep was investigated by Vos *et al.*[9,10] This was investigated as part of a study of sleep disturbance due to impulse sounds. In this field study with 23 subjects, the civil impulse sounds and aircraft noise recorded were presented during ten and five nights, respectively, through loudspeakers

Table 2: Number of conferences searches manually or electronically and number of references of the electronic searches

Conference name	No. of conferences searched manually or electronic search by heading	No. of conferences searched electronically	No. of references from electronic searches
Internoise	4	16	51
DAGA	1	19	87
Euronoise	1	7	21
ICBEN	4	0	0
ICA	6	0	0
Forum Acusticum	2	2	17
Total	18	44	176

Table 3: Studies investigating ambient noise effects on sleep

Author	Type of study	Location	Exposure (noise type)	Data source	Noise measurement/ presentation	Measurement of effect/s
			Neighborhood noise			
Raw and Hamilton (1995) cited by Stansfeld *et al.*[7]	Survey	UK	Neighbor noise	Own library: Journal Article	Not reported	Not reported
Leidelmeier and Marsmann (1997) cited by WHO[3] cited by the Health Council of the Netherlands[8]	Survey	Netherlands	Neighbor noise	Own library: Report	Noise measurement	Interview
Kok Md.GGD Noord-Kemmerland (2000) cited by the Health Council of the Netherlands[8]	Survey (inventory study)	Netherlands	Neighbor noise	Own library: Report	No measurement	Questionnaire
Vos *et al.*,[9,10]	Field study with presented sounds	Netherlands	Civil impulse noise	Own library: Report, Conference proceeding	Noise presentation; exposure-effect relationship	Pressing button on response box when awakened, questionnaire
Verzini *et al.*[11]	Field study	Argentina	Air conditioning noise	Conference proceeding	Noise measurement	Questionnaire
Persson *et al.*[12]	Field study	Sweden	Heat pump noise	Conference proceeding	Noise measurement	Questionnaire
Persson Waye *et al.*[13]	Field study	Sweden	Ventilation and heat pump noise	Database: Journal Article	Noise measurement	Questionnaire
Persson Waye *et al.*[14]	Field study	Sweden	Ventilation and air conditioning noise	Database: Journal Article	Noise measurement	Questionnaire
Persson Waye *et al.*[15]	Laboratory study	Sweden	Ventilation noise	Database: Journal Article	Noise presentation	Questionnaire
Persson Waye *et al.*[16]	Laboratory study	Sweden	Ventilation noise	Database: Journal Article	Noise presentation	Questionnaire
Öhrström *et al.*[17]	Field and laboratory study	Sweden	Ventilation noise	Database: Journal Article	Noise measurement, noise presentation	Wrist actigraph, questionnaire

Table 4: Studies investigating ambient noise effects on sleep

Author	Type of study	Location	Exposure (noise type)	Data source	Noise measurement/ presentation	Measurement of effect/s
			Leisure noise			
Feijoo[18]	Field study	Spain	Nightlife noise	Conference proceeding	Noise measurement	Questionnaire
Lothian *et al.*[19]	Field study	Scotland	Nightlife noise	Conference proceeding	No measurement	Questionnaire
DCMR Miieudienst Rijnmond (2004) cited by the Health Council of the Netherlands[8]	Problem desk (inventory study)	Netherlands	Leisure noise	Own library: Report	No measurement	Complaints reported to a problem desk
Hüttenmoser[20]	Survey	City in Switzerland	Noise of cultural events	Conference proceeding	Noise measurement	Questionnaire
			Animal noise			
Sasazawa *et al.*[21]	Laboratory study	Japan	Frog's croaking	Database: Journal article	Noise presentation	EEG, questionnaire
			Mixed noise			
Niemann *et al.*[22,23]	Survey	8 cities in Europe	Neighborhood and animal noise	Own library: Report, Journal article	No measurement	Questionnaire
Sasazawa *et al.*[24]	Survey	Japan	Community noise	Conference proceeding	No measurement	Questionnaire
Jong *et al.* cited by the Health Council of the Netherlands[8]	Survey (inventory study)	Netherlands	Neighborhood, leisure, animal and church bell noise, recycling noise	Own library: Report	No measurement	Questionnaire
Franssen *et al.*[25,26]	Survey (inventory study)	Netherlands	Neighborhood and leisure noise	Own library: Report	No measurement	Interview
Kuwano *et al.*[27]	Field study with presented sounds	Japan	Music, air conditioning noise	Conference proceeding	Noise presentation	Time when switching off the minidisk player, questionnaire
Kuwano *et al.*[28]	Field study with presented sounds	Japan	Music, talk, air conditioning noise	Database: Journal article	Noise presentation; exposure-effect relationship	Time when switching off the minidisk player, questionnaire
Namba *et al.*[29]	Field study with presented sounds	Japan	Music, air conditioning noise	Database: Journal article	Noise presentation; exposure-effect relationship	Time when switching off the minidisk player, questionnaire

in the subjects' bedrooms. A sound level meter was installed next to the pillow of the subjects to control the reproduction of the sound. The participants were given a response box, where they had to press a button each time they woke up, and they were instructed to complete a questionnaire about their sleep quality. The civil impulse sounds were presented in sound fragments with single events (A-weighted sound exposure levels varied from 29 to 64 dB) and with multiple events (containing four impulses, with the ASELs varying from 35 to 70 dB). Aircraft noise contained sound fragments with ASELs of 50 to 85 dB. The study showed that the probability of awakening due to multiple events was higher than that of single events at equal ASELs. The probability of awakening due to the noise of a door slamming was not significantly different from the probability of awakening due to aircraft noise at the same ASELs.

The next sections review the effects of low-frequency noise such as heat pump, ventilation and air-conditioning noise. The effects of low-frequency noise from air conditioning, factory equipment and traffic noise were investigated in a field study by Verzini *et al.* A total of 98 people, aged between 21 and 70, responded to a questionnaire that included questions about their sleep.[11] The respondents stem from ten selected areas, which were grouped in three noise zones, each including one of the three noise types mentioned above. Additionally, the noise levels in front of each subject's house were measured for two minutes. Correlations suggested that the higher the low-frequency noise levels were, the more negative effects of noise (also concerning sleep) were reported. These effects occurred more often due to ventilation noise and traffic noise than to factory equipment noise.

Persson Waye *et al.* conducted several studies of ambient low-frequency noise.[12-16] In a pilot study assessing the long-term effects on people exposed to the noise of heat pumps

(installed either inside or outside the house), 93 people from two preselected areas responded to a randomly mailed questionnaire that included questions on sleep.[12] The exact measurement of the noise levels was not mentioned. No differences in sleep disturbance were found between subjects exposed to indoor installed heat pumps compared to subjects exposed to outdoor heat pump installations.

Noise measurements from ventilation systems and heat pumps were conducted in a cross-sectional field study with 279 participants aged from 18 to 75 years in a random sample of each house type (which were not further described).[13] Equivalent sound pressure levels were measured in the corners of a room (not specified) at a distance of 0.5 m from the wall. Additionally, the participants had to complete a questionnaire about psychosocial symptoms and sleep disturbance. A total of 108 subjects were exposed to low-frequency noise and 171 subjects exposed to mid-frequency noise as a control group. In the homes exposed to equivalent low-frequency noise, the sound pressure levels were found to range from 26 to 36 dB(A) and 49 to 60 dB(C), whereas in the homes of the control group, levels from 24 to 33 dB(A) and from 41 to 49 dB(C) were measured. The result of this study was that significantly more subjects disturbed by low-frequency noise reported fatigue, difficulty falling asleep, feeling languid and tense in the morning.

In another field study by Persson Waye *et al.*, the effects of ventilation and air-conditioning noise were compared to those of road traffic noise in a sample of 41 subjects.[14] The bedrooms of 19 people participating in the study faced the quiet side with exposure to fans and compressors, while the other people's bedrooms faced the street. For closed windows, an L_{eq} (equivalent continuous sound pressure level) from 30 to 31 dB(A) and 50 to 51 dB(C) was measured, while an L_{eq} from 42 to 43 dB(A) and 55 to 57 dB(C) was measured for windows slightly open in a sample of ten different apartments at three positions in the room. Additionally, sleep quality was determined with a questionnaire. In both groups (ventilation/air conditioning noise and road traffic noise), 63% reported that their sleep was disturbed by noise.

In two laboratory studies, the effect of ventilation noise was further examined along with traffic noise. In the first study, 12 male subjects with an average age of 24.5 years were examined for five nights.[15] Ventilation noise was presented in the bedrooms through hidden loudspeakers with an L_{eq} of 40 dB(A) and traffic noise with L_{eq} of 35 dB(A) and an L_{max} of 50 dB(A). In the mornings and the evenings, the participants completed a questionnaire about mood, sleep quality and sensitivity to noise. The study showed that subjects took longer to fall asleep and felt more tense in the morning due to exposure to ventilation noise, and even more so due to traffic noise, than in the reference night. In the second study of ventilation noise, 26 males with an average age of 26 years participated.[16] The same methods were applied as in the previous study, except for the comparison with traffic noise. The result of this study was that the subjects felt more tired in the mornings after nights with exposure to ventilation noise.

Öhrström *et al.* dedicated a laboratory and field study to the topic of ventilation noise and road traffic noise.[17] Thirteen female and five male subjects aged between 18 and 30 were examined for six nights in a laboratory and six nights at home. Ventilation noise was presented with an L_{eq} of 40 dB(A), road traffic noise with an L_{eq} of 39 dB(A). L_{max} was 55±3 dB(A) and the combination of both noise types resulted in an L_{eq} of 43 dB(A) with an L_{max} of 55 dB(A) at the pillow position of the participants. The effect on sleep was measured with a wrist actigraph and questionnaires on sleep and mood and noise sensitivity. Sleep quality, assessed with the questionnaires, significantly decreased in the nights with exposure to ventilation noise compared to the reference nights, but was significantly better than for nights with exposure to traffic noise. However, according to the actigraphy measurements, the subjects slept better in the nights during which they were exposed to ventilation noise than in the quiet reference nights. No significant difference was detected between traffic noise exposure and the reference nights.

Leisure noise

In the field study by Feijoo, the reactions to night noise due to nightlife entertainment activities were observed.[18] Nightly measurements of sound pressure levels were carried out at the homes of 13 people on two busy nights (Thursday, Friday and Saturday), and a quiet night (Monday). The night was divided into fifteen-minute sections, and the L_{Aeq} was calculated for every 15 minutes. For busy nights, the $L_{eq,15}$ ranged from 57 to 69 dB(A) and on quiet nights from 50 to 62 dB(A). The L_{max} was 72–83 dB(A) during busy nights and 62–79 dB(A) at quiet nights. The exact locations of the measurements were not mentioned. The noise mainly consisted of leisure noise, as the participants lived in the old town where only residents were allowed to enter, so there was little traffic noise. The participants also completed a questionnaire about sleep quality and perception of noise for each measured night. During busy nights, 40% of the subjects showed difficulties in falling asleep, 56% were awakened by noise and it took them about an hour to fall asleep again. Compared to this result, only one person woke up due to noise on a quiet night. The nightly noise influenced the sleep quality of 80% of the residents.

In an inventory study in 2003 of a problem desk in the Netherlands the reported complaints of noise during the night (from midnight to 7am) were counted. Of the 1265 complaint, 27% were due to noise from bars, clubs, events etc.[8]

Lothian *et al.* surveyed the noise effects on residents two years after the enforcement of the smoking ban in Scotland in March 2006.[19] In six areas across Scotland, containing

city centre, suburban and rural areas, noise complaints were reported to local authority staff via an online questionnaire and subsequent telephone discussions. In the investigated study area, 57 complaints were made against licensed premises, which resulted in a ratio of one complaint for every 68 licensed premises. Groups of six or more smokers commonly outside pubs often caused noise leading to complaints. Sleep was considered the activity affected most by the nightly noise, triggered by the licensed premises.

In an investigation, Hüttenmoser applied the 'Community Noise Management' concept of the World Health Organization (WHO) on leisure noise at two public places in a Swiss city.[20] Hotels and restaurants with outdoor service and open-air concerts, theatres and cinemas are found at one location in summer. The other location is used for events such as commercial and animal exhibitions, sports events and circus performances. In the context of this investigation, a questionnaire on the disturbance of leisure noise and its effects was sent to a random sample of people living in two districts encompassing these two public locations. A total of 59% of the 352 respondents answered that leisure noise hindered them from falling asleep, and 46% mentioned that it disturbs their continuous sleep.

Animal noise

In a Japanese laboratory study, seven male students aged 19 to 21 were exposed for three nights to frogs' croaking.[21] The study was designed to investigate the effects of road traffic noise and frogs' croaking (L_{max} of 56.1 dB(A) and L_{eq} of 49.5 dB(A)) on sleep. To assess the sleep quality, EEG measurements were applied during the night and a structured sleep rating questionnaire was administered in the mornings. However, no significant effect could be found between the nights with exposure to frogs' croaking and non-exposure nights for both assessment methods.

Mixed noise

Two national inventory studies of the Netherlands inform about noise-related sleep disturbance associated with sources of various types. The respondents could indicate that their sleep was disturbed (scored 50 points or more on a scale of 100 points) or that it was highly disturbed (scored 72 points or more). The study carried out in 1998, gives an overview of the relevance of some common types of ambient noise.[8] The percentage of respondents reporting to be sleep disturbed (respective highly sleep disturbed) amounted to 26% (11%) for noises from neighbor dwellings, 8% (3%) for recreational activities, 5% (2%) for noise from neighbors' pets or animals, 3% (2%) for noise from church bells or mosques, 1% (0%) for noise from bottle banks and 14% (5%) for other noises in the residential environment. Compared to these ambient noise sources were 37% (15% highly) sleep disturbed due to road traffic noise, 7% (3%) due to aircraft noise, 2% /(0%) due to rail traffic noise, 0% due to shipping noise and 7% (1%) due to noise from commercial, industrial and professional activities. In a later national inventory study, conducted in 2003, recreational noise and noise from neighbor dwellings was defined slightly different. Thus under this definitions sleep disturbance respective high sleep disturbance was for recreational noise 5% resp. 2% for 1998 and 7% resp. 3% for 2003 and for noise from neighbor dwellings 11% resp. 5% for 1998 and 11% resp. 6% for 2003.[25,26]

The large WHO analysis and review of European housing and health status (LARES) shows also several types of ambient noise.[23] In this study, which was conducted in eight European cities in 2002 and 2003, one question was asked concerning sleep disturbance due to noise. The question was: "Has your sleep been disturbed by noise during the past four weeks?" Among the sleep-disturbed respondents (N=8519), 20.7% reported that they were disturbed by neighborhood noise (of which low-frequency noise was only about one-tenth), 3.4% by animals and birds, and 1.8% by playing children and playgrounds etc. These are all types of ambient noise and about 25% of the people were disturbed because of them, compared with about 20% who were disturbed because of traffic noise and noise from commercial sites (1.4%).[22]

Sasazawa *et al.* used a questionnaire to examine sleep disturbance in adult women living in the Japanese city of Maebashi.[24] The question relating to community noise was: "Have you been disturbed in your sleep by the following sounds: People sleeping in the same room, domestic electrical fittings, animal noises, passing vehicle noise on the adjacent road, motor cycle noise on the adjacent road, passing vehicle noise on another road, motor cycle noise on another road, voices from the road, noise from neighboring houses, sounds from restaurants/bars and karaoke singing, construction noise, airplane noise?" A total of 648 out of 1286 women completed the questionnaire. The survey showed that animal noises, voices from the road, sounds from restaurants or bars and karaoke singing, construction noise and airplane noise did not seem to be related to sleep disturbance. On the other hand, passing vehicle noise, motor cycle noise, sounds from people sleeping in the same room, domestic electrical fittings and noise from neighboring houses, did seem to be linked to sleep disturbance. Furthermore, the survey suggested that people seem to be more sensitive to the last three of these noise types than to traffic noise.

In the following Japanese studies, the effects on sleep were investigated of different noise types (air conditioning, sound of karaoke singing and talk) at relatively low sound levels. In a first study by Kuwano *et al.*, the effort to fall asleep while exposed to noise was examined for six subjects, aged 21 to 27 years.[27] The sound (air conditioning, karaoke singing and road traffic noise) was continuously presented in random order through the earphones of a minidisk player to the participants in bed in their bedroom, and they were only allowed to switch it off if they had not fallen asleep after one hour. The L_{eq} of the air conditioning and the karaoke through

the earphones was 25 dB(A) for both, and the L_{eqs} of the road traffic noise varied between 25 and 45 dB(A). Furthermore, they had to complete a questionnaire about their sleep the next morning. About 35% of the participants could not fall asleep due to the air conditioning, and almost 20% could not do so due to the karaoke. The effect of road traffic noise on the subjects was similar in the case of traffic noise with large-level fluctuations (range of 37 dB), or about 18% less than karaoke singing for traffic noise with low-level fluctuations (range of 18 dB), and between about 20% (traffic noise with large-level fluctuations) and 35% (traffic noise with low-level fluctuations) less than the noise of air conditioning at the same low equivalent sound pressure level of 25 dB(A).

In a subsequent study, Kuwano *et al.* applied the same methods to eighteen subjects (between 19 and 38 years old), but additionally examined the sound of 'talk' (presented at 25 dB(A)).[28] The results of the investigation showed that when exposed to either karaoke or talk at the same low equivalent level of sound pressure, about 70% of the participants were disturbed when falling asleep and 20% could not even fall asleep after switching off the sound. As regards air conditioning noise, more than 95% of the participants could fall asleep within an hour and about 10% fewer for traffic noise. The responses about sleep quality were similar to the previous results. The outcome of the study was that sounds containing meaningful information were found to be disturbing at very low levels compared to the sounds of air conditioning and traffic noise, which were considered much less disturbing at the same low level.

In a third Japanese study, the same methods were applied again.[29] The study contained 20 subjects aged between 20 and 42 years. The difference was that this time only the sound of karaoke and the noise of the air conditioning, either alone or combined, were the applied noise stimuli presented in random order. The L_{eq} of the sound of karaoke ranged from 25 to 40 dB(A), and that of air conditioning noise from 30 to 50 dB(A). The study showed that no effect on the sleep quality was found for the 30 and 35 dB(A) levels of air conditioning noise. Above these levels, an increase of sleep disturbance due to air conditioning was reported, which also occurred for all levels of karaoke alone conditions. Under the same conditions of equivalent sound pressure, the percentage of subjects who were unable to fall asleep within an hour due to karaoke noise was significantly higher than that due to air conditioning noise. No significant differences were found between the karaoke noise conditions and the combined sound conditions. The questionnaire on sleep quality suggested the same results for air conditioning noise alone and karaoke noise alone as the method of switching off of the minidisk player.

Discussion

Main results

This review has revealed that the number of studies concerning the effects of ambient noise on sleep is limited. Only 23 studies relating to this topic were found. Up to the present, mainly studies regarding neighborhood, leisure and animal noise have been conducted. Other noise types, such as the noise of church and cow bells and of recycling collection points, have been barely examined.

Judging from the available evidence on neighborhood noise, no general conclusion for all types of neighborhood noise can be drawn, even if we ignore the differences in study design, methods and varying measures. For example, three studies investigating the effect of neighborhood noise quite generally showed that sleep seemed to be disturbed.[3,7,8] In another study, the noise from door slamming and the transhipment of containers was found to be less disturbing than aircraft noise.[9,10] And yet, people would probably still sleep better without this noise. However, this study did not carry out a comparison with a control group (not exposed to any noise source). The results relating to the low-frequency noise (such as that from ventilation, air conditioning and heat pumps) part of neighborhood noise varied greatly. Most studies suggest a detrimental effect of noise exposure on sleep.[11,13-16] On the other hand, one study even measured a positive effect via actigraphy, although subjective sleep assessment showed disturbed sleep.[17]

The findings on leisure noise showed that this noise type has a negative effect on sleep.[8,18-20]

From the study of Sasazawa (2002), no general conclusions could be drawn for the effect on sleep of animal noises other than frogs.[21] Furthermore, the number of subjects was very small, so the risk of selection bias could not be excluded.

Given the present evidence from the studies of mixed noise types, the different types seem to lead to varying results. Meaningful sounds from leisure and neighbor noise showed a tendency to disturb sleep according to the national inventory studies from the Netherlands, the LARES study and the different Japanese studies of Kuwano *et al.* and Namba *et al.*[8,22,27-29] The national inventory study 1998 from the Netherlands detected also small sleep disturbances due to church bell and mosque noise and noise from recycling of bottles.[8] The study of Sasazawa *et al.* displayed mixed results as regards meaningful leisure and neighbor noise.[24] Neighbor noise was considered disturbing to sleep, but leisure noise was not. The studies looking at the effects of the low-frequency part of neighborhood noise mainly suggested a detrimental effect on sleep.[22,24,27-29] As regards the effects of animal noises on sleep, two studies showed sleep disturbance, but another study displayed opposite results.[8,22,24]

Studies included

Our study has several limitations. The studies carried out included surveys, laboratory and field studies as well as a

combination of both and the quality of these studies (view [Table 5]) varied.

In 65% of the studies the population and in only slightly less than 50% the exposure was well defined. All, except one, studies declared their statistical methods used. However, only 30% of the studies reported potential confounding variables. In half of the studies reporting the sample size, less than 50 persons participated, which is quite small. Additionally, only in one of these small studies and in four of the bigger studies random sample selection was reported. In the cases without random selection, a fully representative sample could not be guaranteed as self-selection is a problem. For example, perhaps only people who are highly noise-sensitive volunteered to participate in the studies. Furthermore, some sensitive subjects might have moved out of the noise-polluted areas, diluting the effect of interest. Moreover, in only three of the 23 studies an exposure-effect relationship was established, which would be the preferred outcome to compare among the studies. Incomplete reporting was also a problem occurring in more than 85% of the studies in this review.

Therefore, the authors decided that it was not possible to perform a meta-analysis, because of differences in the study designs regarding different participant's characteristics, exposure and effect measuring methods, study types and completion of reporting. Another limitation of this review is publication bias. If studies were not published either in conferences or in journals or then reported directly to the authors, they were left out.

Conclusions

We believe that our literature search was comprehensive, as we covered the most important databases and conference proceedings. Regarding the research question as to whether ambient noise has an effect on sleep, we can cautiously draw the following conclusions:

Table 5: Quality of the individual studies considered[1]

Author	1	2	3	4	5	6	7	8
Neighborhood noise								
Raw and Hamilton (1995) cited by Stansfeld *et al.*[7]	No	Not reported	Not reported	No	Yes	Not reported	Not reported	No
Leidelmeier and Marsmann (1997) cited by WHO[3], cited by the Health Council of the Netherlands[8]	No	No	Not reported	No	Yes	Large ($n = n$)	Not reported	No
Kok Md.GGD Noord-Kemmerland (2000) cited by the Health Council of the Netherlands[8]	No	No	Not reported	No	Yes	Large n=(5250)	Not reported	No
Vos *et al.*[9,10]	Yes	Yes	Yes	Yes	Yes	Small ($n = n$)	Not reported	Yes
Verzini *et al.*[11]	Yes	Yes	Not reported	No	Yes	Medium ($n = n$)	No (volunteers)	No
Persson *et al.*[12]	Yes	No	Not reported	No	No	Medium ($n = n$)	Yes (in defined area)	No
Persson Waye *et al.*[13]	Yes	No	Yes	No	Yes	Large ($n = n$)	Yes	No
Persson Waye *et al.*[14]	Yes	Yes	Yes	Yes	Yes	Small ($n = n$)	Yes (in defined area)	No
Persson Waye *et al.*[15]	Yes	Yes	Yes	Yes	Yes	Small ($n = n$)	No (volunteers)	No
Persson Waye *et al.*[16]	Yes	Yes	Not reported	No	Yes	Small ($n = n$)	Not reported	No
Öhrström *et al.*[17]	Yes	Yes	Yes	No	Yes	Small ($n = n$)	Not reported	No
Leisure noise								
Feijoo,[18]	No	No	Yes	No	Yes	Small ($n = n$)	Not reported	No
Lothian *et al.*[19]	No	Yes[2]	Not reported	No	Yes	Not reported	No	No
DCMR Miieudienst Rijnmond (2004) cited by the Health Council of the Netherlands[8]	No	Not reported	Not reported		Yes	Large ($n = n$)	No	No
Hüttenmoser[20]	No	Not reported	Not reported		Yes	Large ($n = n$)	Yes	No
Animal noise								
Sasazawa *et al.*[21]	Yes	Yes	Not reported	No	Yes	Small ($n = n$)	Not reported	No
Mixed noise								
Niemann *et al.*[22,23]	Yes	No	Yes	No	Yes	Large ($n = n$)	Not reported	No
Sasazawa *et al.*[24]	Yes				Yes	Large ($n = n$)	Yes (in defined area)	No
Jong et. al. (2000) cited by the Health Council of the Netherlands[8]	No	Not reported	Not reported	No	Yes	Not reported	Not reported	No
Franssen *et al.*[25,26]	Yes	Not reported	Not reported	No	Yes	Large ($n = n$)	Not reported	No
Kuwano *et al.*[27]	Yes	Yes	Not reported	No	Yes	Small ($n = n$)	Not reported	Yes
Kuwano *et al.*[28]	Yes	Yes	Not reported	No	Yes	Small ($n = n$)	Not reported	No
Namba *et al.*[29]	Yes	Yes	Not reported	No	Yes	Small ($n = n$)	Not reported	Yes

[1]Detailed definition in the method section (1= Study population is well defined; 2 – Exposure is well defined; 3 – Potential confounding variables; 4 – Complete reporting; 5 – Declaration of the statistical methods; 6 – Sample size; 7 – Random sample selection; 8 – Exposure-effect curve); [2]However, here noise is not measured with an acoustic measure, but a subjective assessment of the participants

Meaningful sounds such as those emanating from leisure and neighbor noise seem in most cases to lead to sleep disturbance,[3,7,8,18-20,22,23,27-29] an exception being the study of Sasazawa *et al.*,[24] where voices, animal noises, noise from bars and restaurants did not seem to have any effect on sleep. The findings on door slamming and sleep disturbance were compared with aircraft noise.[9,10] The probability of awakening due to aircraft noise at the same noise level is higher than that for the civil impulse sounds mentioned above. However, the probability of awakening due to multiple events was higher than that for single events at equal A-weighted levels of sound exposure. The survey of Sasazawa *et al.* did not suggest any association between animal noise and sleep disturbance.[24] Furthermore, no significant effect was found on sleep from frogs croaking.[21] However, the national inventory study of 1998 from the Netherlands and the LARES study reported a small disturbance on sleep due to animal noises.[8,22] Furthermore, the national inventory study of 1998 from the Netherlands was the only study displaying small detrimental effects on sleep emitted from bell and recycling noise.[8]

As regards objective measurements of the effects of ambient noise without meaning, such as from ventilation or air conditioning, the studies showed different[27-29] and sometimes even contradictory results.[17] But, subjectively measured data showed that this low-frequency noise does disturb sleep.[11,13-16] The higher the levels of low-frequency noise, the higher the effect on sleep.[11]

However, quantitative conclusions regarding the effect of ambient noise on sleep were very difficult to draw because of the limited number of studies and the different quality regarding:

- Definition of the study population and exposure
- Potential confounding variables
- Declaration of the statistical methods
- Sample size and random selection
- Study result (exposure-effect curve)
- Complete reporting

As an empirical data-driven analysis is impossible, it is difficult to get a pooled picture of the magnitude of the effect. A meta-analysis, for which studies with exposure-effect relationships would be required, would yield this information. Because the evidence adduced so far is rather inconclusive, more studies of all types of these selected ambient noise sources, of appropriate quality for a quantitative analysis are consequently needed.

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Address for correspondence:
Omlin Sarah,
ETH Zürich, MTEC ZOA - Public and Organizational Health Ergonomics & Environment WEP H15 CH-8092 Zürich (Switzerland)
E-mail: somlin@ethz.ch

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