Noise-related sleep disturbance

a brief overview of the scientific evidence

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Sleep and health

<table>
<thead>
<tr>
<th>N of studies</th>
<th>Risk Lower</th>
<th>Risk Upper</th>
<th>Risk ratio and 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>16</td>
<td>1.38</td>
<td>1.25 1.53</td>
</tr>
<tr>
<td>Aged 65 or over</td>
<td>1</td>
<td>1.45</td>
<td>0.89 2.36</td>
</tr>
<tr>
<td>Aged under 65</td>
<td>10</td>
<td>1.43</td>
<td>1.24 1.64</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>1.36</td>
<td>1.16 1.60</td>
</tr>
<tr>
<td>Male</td>
<td>8</td>
<td>1.39</td>
<td>1.10 1.75</td>
</tr>
<tr>
<td>Sleep defined by night</td>
<td>6</td>
<td>1.44</td>
<td>1.18 1.75</td>
</tr>
<tr>
<td>High quality on the NOS</td>
<td>2</td>
<td>1.30</td>
<td>1.04 1.63</td>
</tr>
<tr>
<td>Follow-up no less than 10 years</td>
<td>2</td>
<td>1.14</td>
<td>1.04 1.25</td>
</tr>
<tr>
<td>Non borrowed prevalence rate</td>
<td>7</td>
<td>1.30</td>
<td>1.11 1.52</td>
</tr>
<tr>
<td>True outcome</td>
<td>9</td>
<td>1.53</td>
<td>1.28 1.83</td>
</tr>
</tbody>
</table>

O. Itani et al. / Sleep Medicine 32 (2017) 246-256
“The presence of feedback loops in the system is an indication that it may be difficult to prove direct cause–effect relations. One example is the relation between sleep quality and depression. They are strongly associated, but it is uncertain if depression causes bad sleep, or bad sleep causes depression.”
Physiological reaction to external stimuli

**Arousal Degree**

- **Maximum Arousal**
  - ~1-5 per night
  - Long Awakening (>1 min) with Regaining of Consciousness
  - Short EEG Awakening (>15 s) with Body Movement
- **~20-25 per night**
  - Short EEG Awakening (>15 s) w/o Body Movement
- **~100-120 per night**
  - Sleep Stage Change and/or Short (3-30s) EEG Arousal without EEG awakening

**Methods**

- Push Button, Actigraphy, Polysomnography
- Actigraphy, Polysomnography
- Polysomnography

**Stimulation of ARAS through internal or external stimuli**

**Vegetative Arousal**

**Thalamo-Cortical Gating**

**ECG, RR-measurements, Pulse Transit Time**

Basner et al. / Noise Health 2012;14:321-9
Quantifying sleep disturbance

<table>
<thead>
<tr>
<th>Methods</th>
<th>Positive-predictive value</th>
<th>Usability</th>
<th>Ease of analysis</th>
<th>Cost</th>
<th>Description</th>
<th>Definition of awakening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polysonomography</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Classifications of sleep stages by using data from an EEG, EOG and EMG</td>
<td>Number of sleep stage changes to wake from any other sleep stage^{17}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Or</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Any change from any sleep stages to the state awake or stage S1^{14,30}</td>
</tr>
<tr>
<td>Seismosomography</td>
<td>Unknown</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Measurement of small vibrancies of the body caused by a change of heartbeat, breathing and movement</td>
<td>Body movement (motility) as a proxy to awakenings</td>
</tr>
<tr>
<td>Actigraphy^{24,26,30}</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Detection of motor activity at the wrist</td>
<td>Movement as a proxy to awakenings</td>
</tr>
<tr>
<td>Questionnaire^{21}</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Subjects describe their sleep quality and number of recalled awakenings</td>
<td></td>
</tr>
<tr>
<td>Push button</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Subjects press a button when awakened; hence, defined as behavioural awakenings</td>
<td></td>
</tr>
</tbody>
</table>

Perron et al./ Noise Health 2012;14:58-67

- **Electrocardiography** (Basner et al. Noise Health 2012;14:321-9)
Physiological measures

Basner et al. / Noise Health 2012;14:321-9

http://www.laermstudie.de/aktuelles/news/
Questionnaires

### Sleep quality

<table>
<thead>
<tr>
<th>Numerical disturbance from Exposure (E)</th>
<th>0–10</th>
<th>How disturbed was your sleep by vibration/noise from trains during the night? (not at all—extremely)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal E causing poor sleep</td>
<td>1–5</td>
<td>Do you think that vibration/noise during the night disturbed your sleep so that you slept poorly? (not at all, hardly at all, fairly, very, extremely)</td>
</tr>
<tr>
<td>Verbal E causing awakenings</td>
<td>1–5</td>
<td>Do you think that vibration/noise during the night disturbed your sleep so that you were awakened? (not at all, hardly at all, fairly, very, extremely)</td>
</tr>
<tr>
<td>Verbal E causing difficulties to continue sleeping</td>
<td>1–5</td>
<td>Do you think that vibration/noise during the night disturbed your sleep so that you had difficulty falling asleep? (not at all, hardly at all, fairly, very, extremely)</td>
</tr>
<tr>
<td>Verbal E causing tiredness in the morning</td>
<td>1–5</td>
<td>Do you think that vibration/noise during the night disturbed your sleep so that you felt tired in the morning? (not at all, hardly at all, fairly, very, extremely)</td>
</tr>
</tbody>
</table>

| Numerical tense | 0–10 | How are you feeling right now? (very relaxed—very tense) |
| Verbal tense    | 1–5  | How do you normally feel when you wake up in the morning? (very at ease, rather at ease, neither at ease nor tense, tense, very tense) |
| Numerical irritated | 0–10 | How are you feeling right now? (very glad, very irritated) |
Questionnaires vs objective measurements

“Although most of the night is spent in an unconscious state, subjects were not only able to differentiate between nights with and without noise, but also between nights with low and high degrees of traffic noise exposure. Hence, if these findings extend to the field, morning questionnaires, although prone to manipulation, may be a very cost-effective way for the investigation of traffic noise effects on sleep.”

Basner et al. / SLEEP, Vol. 34, No. 1, 2011

Croy et al. / Behavioral Sleep Medicine, 00:1–17, 2016
Laboratory vs field studies

FIG. 7. Per cent change in sleep stage. The difference is shown as a function of wake time.

The Sound Environment Laboratory

The new-built laboratory (finished 2004) is equipped with modern sound environment facilities and has very low background levels (Leq 13 dB). The lab is also used for studies of effects at low and moderate sound levels under controlled conditions. The large exposure room with daylight can be used to simulate different environments (e.g., a courtyard, a living room) and three smaller rooms to simulate office settings or bedrooms. There is also a "home-like apartment" with separate entrance, a hall, two toilets (one with shower), a living room and a kitchen, in which the people involved in different sleep studies can cook, watch TV or just relax.

Sound demonstration

The Sound Environment Laboratory is also used for sound demonstrations. For example, employees at the Swedish Transport Administration (Trafikverket) visited the lab and got to experience how it feels to be exposed to road traffic noise, sounds like in different environments, or how vibrations from trains feels like when lying in a bed.

Leasing

It is possible to rent the sound environmental laboratory. Please contact karin.oberer.wage for more information, we are also open to collaborating in interesting research projects.
Habituation

Potential reason for cardiac arousal habituation not taking place across nights:
- hierarchal nature of arousal response

Demonstrates the potential relevance of cardiac arousals to long-term cardiovascular consequences of noise-induced sleep disturbance

Basner et al. / SLEEP, Vol. 34, No.1, 2011
Griefahn et al. / SLEEP, Vol. 31, No. 4, 2008
Modifiers / moderators

- **acoustic factors** (e.g. SPL, SPL above background, SPL rise time, duration of noise event), energy in high frequency ranges ($\geq 4$kHz), vibration
- **significance of noise** for sleeper
- **situational factors** (e.g. elapsed sleep time, current sleep stage, …)
- **personal factors** (e.g. sex, age, noise sensitivity)
- **inter-individual differences**

Basner et al. / SLEEP, Vol. 34, No.1, 2011
Influence of vibration

Inter-individual differences

Road

Rail

Aircraft

FIG. 1. Probability of sleep stage change to stage S1 or awake depending on maximum SPL $L_{A,\text{max}}$ based on the regression results from Table I. Assumptions: Background noise level $L_{B0}$ median=27.1 dB constant (median), prior sleep stage = stage 2, elapsed sleep time = 601 epochs (middle of second half of the night). Point estimates (black line), 95% confidence limits (gray lines), and spontaneous reaction probabilities (dashed line) are shown.

Perron et al./ Noise Health 2012;14:58-67
http://www.laermstudie.de/aktuelles/news/
Impact of interventions
road tunnel Göteborg city, Sweden

Fig. 2. Residents’ own comparisons of sleep after the change in road traffic.
Impact of interventions

NOise-Related Annoyance, cognition, and Health (NORAH)

“The results of the sleep study show that with the initiation of the night flight ban […] the frequency of awakenings associated with aircraft noise decreased on average from 2.0 per night in 2011 to 0.8 per night in 2012. Thus, an important objective of the night flight ban has been reached.”

“The subjective experience of sleep worsened statistically significantly from 2011 to 2013 by 5% and 11%, respectively, despite the introduction of the night flight ban, regardless of the aircraft noise exposure.”
Opportunities & challenges

- we have good-quality evidence to underpin risk assessments and inform decision-making
  - but most studies to date carried out on healthy subjects
- we need more evidence on sleep disturbance in population groups at higher risk (children, elderly, shift workers, people with pre-existing chronic diseases or sleep disorders)
- we need a better understanding of the link between acute arousals/awakenings and long term health conditions to inform noise interventions