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Noise
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4aNSc3. The effects of noise disturbed sleep on children?s health and cognitive development

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Undisturbed sleep is essential for physiological and psychological health. Children have a special need for uninterrupted sleep for growth and cognitive development. Noise is an environmental factor that affects most children. In addition to noise in schools and preschools, many are exposed to potentially disturbing traffic related noise at night. The knowledge of how children's health, wellbeing and cognitive development are affected by noise disturbed sleep due to road traffic is still incomplete. Nor do we know how children are able to handle noisy situations (coping) and if learned noise-related behavior in the long term has a negative influence on children's health and learning. The need for a restorative home environment can be particularly important when the child is simultaneous exposed to noise in the school environment. Moreover it has been shown that although children are less sensitive for awakenings and sleep cycle shifts due to nighttime exposure they are more sensitive for physiological effects such as blood pressure reactions and related motility during sleep. This paper reviews existing knowledge on how children's health and cognitive development are affected by noise in the home and school environment, with special focus on the importance of noise-disturbed sleep.

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INTRODUCTION

In the recently published guideline by the WHO (2011) for the burden of disease from environmental noise it is concluded that future epidemiological noise research will need to focus on vulnerable groups; some noise exposures may be worse for particular subgroups than for others such as children, older people and lower socioeconomic groups. This conclusion supports the notion that noise effects can and should be differentiated between subgroups. In most recent reviews on noise and health, this topic has been touched upon, but evidence is still scarce and scattered. A recent review (van Kamp and Davies, 2013) identified thirty seven papers (2007-2011) pertaining to primary school children, two to preschool children and four to neonates. Four papers concerned effects of noise in specific patient groups such as children with autism, asthma and Attention Deficit Hyperactivity Disorder (ADHD) . Health effects most frequently described in the literature are annoyance, sleep disturbance, cardiovascular disease, cognitive effects and effects on hearing. Knowledge of how these effects are influences by noise disturbed sleep is very incomplete. In this paper we are particularly interested in the role of sleep disturbance in cognitive and cardiovascular effects in children. The aim of the review is to formulate a set of hypotheses as a base for future studies into the effects of noise induced sleep deprivation on health and child development. After a short introduction on sleep, we will discuss the role of sleep per outcome.

Nighttime Noise and Health

Conceptual models

It has been shown that nighttime noise can negatively affect people's sleep. The relationship between environmental noise and different aspects of sleep, and long term health effects, is a complex one. Several researchers have presented conceptual models to describe this complex interplay (see e.g. Porter et al., 2000; Ising and Babisch,1999; Passchier, 2003). The model described by Porter et al. (2000) is presented below as representative example of current thinking about the mechanism by which environmental noise can lead to sleep disturbance and health effects. This model shows that noise can directly lead to acute effects and then through a chain to long term health consequences. Feedback mechanisms and modifying factors are assumed meaning that noise can lead to health consequences through indirect pathswayes. This complex web of interactions makes it difficult to quantify any simple exposure-response relationship between noise exposure and health effects.

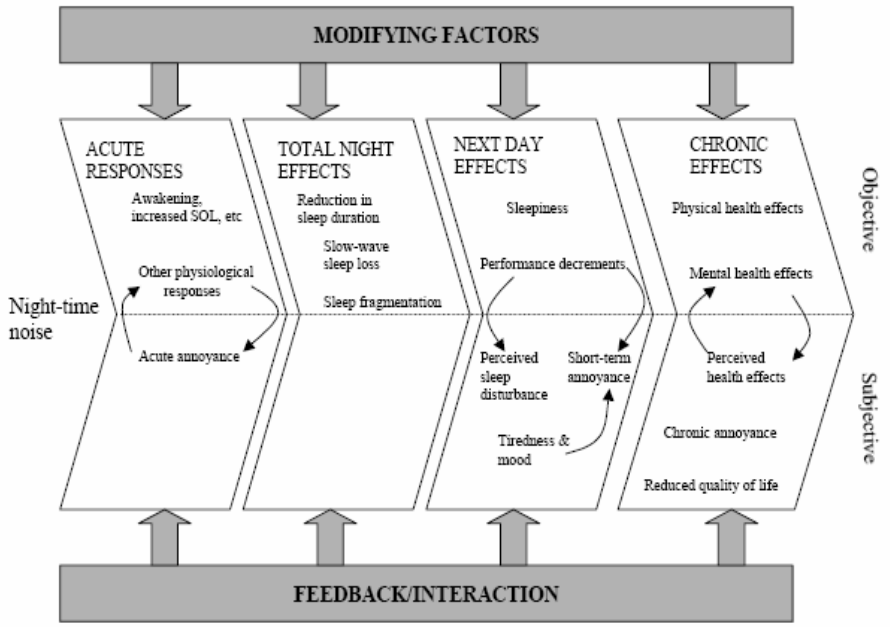

Figure 1. The conceptual model of noise and sleep of Porter et al. (2000)
* SOL: Sleep Onset

In the model a distinction is made between:

1. acute responses that include immediate or direct disturbances caused by noise events,
2. total night effects that are aggregations of (1) over the whole night,
3. next day effects that are a result of (1) and (2), and
4. chronic effects that are pervasive long-term consequences of (1), (2) and (3).

Sleep disturbance is generally seen as an intermediate effect. It is assumed to be an initiator of diseases and/or it aggravates existing disease. Whether this will happen depends on the person's vulnerability and/or sensitivity (Cohen et al., 1986) (Berglund et al., 1999) (Van Kamp et al., 2004) (Staatsen et al., 2004). Potential vulnerable groups are people with a somatic or mental disorder, shiftworkers and the elderly. Studies tend to show (Eberhardt, 1990; Öhrström, 2006) that children are less sensitive for awakenings and sleep cycle shifts, but more sensitive for physiological effects such as blood pressure reactions (Muzet, 2007).

Normal sleep in children

Sleep patterns can be decribed by ways of brain activity (elektroencephalogram cq EEG), information about eye movement (elektro-oculogram cq EOG) and muscletone (elektromyogram cq EMG). The sleep cycle contains two main states: rapid eye movement (REM) and non-rapid-eye movement (NREM), while NREM is subsequently separated into 3 sleep stages (Iber et al, 2007).

REM sleep features a low-amplitude, mixed frequency electroencephalogram EEG, with eye movements (EOG) showing bursts of REM activity similar to that seen during eyes-open wakefulness, and absent EMG activity due to brainstem-mediated muscle atonia that is characteristic of REM sleep. NREM (including slow wave) sleep is required for the brain to recover from fatigue, and REM sleep was for a long time considered as necessary for physical recovery and essential for the maintenance of quality sleep. Today there is no consensus on the exact relative functions of the various sleep stages for mental and physical health. Though N3 stage is generally considered to be important for physical restoration (Bonnet 1985) (Borbely, 1982) Young et al., 2008) and memory (Diekelman et al., 2009), while REM sleep is also believed to be important for cognition (Walker et al, 2002).

The sleep cycle begins with the shallow stage 1 of NREM sleep, progressing through to NREM stage 3 within 45-60 minutes, followed by 15 minutes of deeper REM sleep, then the cycle re-commences as NREM sleep, and so on. Figure 2 shows a normal sleep pattern of chidlren. Sleep patterns change with age, only in chldren the deep sleep stage is observed in the later parts of the night.

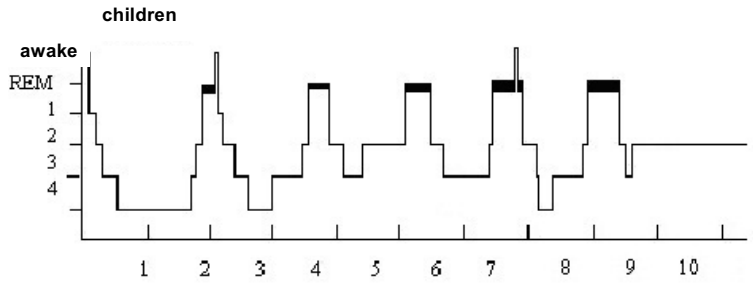

Figure 2. Time structure of a normal sleep pattern in children (source: Hofman, 2013)

Short and long term health effect of noise disturbed sleep

Undisturbed sleep is essential for physiological and psychological health. Children have a special need for uninterrupted sleep for growth and cognitive development. Noise is an environmental factor that affects most children. In addition to noise in schools and preschools, many are exposed to potentially disturbing traffic related noise at night. One of the most serious effects of community noise is sleep disturbance (Griefahn, 2002). In the Night noise guidelines of WHO (2009) it was concluded that children with disturbed sleep present cognitive dysfunction and behavioural disturbances, abnormal growth hormone release, increase of diastolic BP and an increased risk of accidents and use of sleeping pills. However these findings are primarily based on older studies in specific patient groups . One out of seven 12-year-old in Sweden (Socialstyrelsen, 2005) indicates that noise prevents them from falling asleep. For about 25.000 schoolchildren aged 7-14 years this occurs several times a week. Approximately half of these children state that several times a week they had difficulties to sleep the whole night without waking up. There are a few examples of studies of how children are affected by sleep due to road traffic noise (Bistrup et al., 2006). A study of 9-12 year olds in the EU project RANCH showed that children's problems with daytime sleepiness is higher with increasing road traffic noise exposure levels outside the children's home (Öhrström E. et al. ,2006). Sadeh et al. (2002) found an association between poor sleep quality and worsened performance on complex cognitive tasks in school. In specific these children experienced difficulty in sustaining attention. A sub-study (Stansfeld et al., 2010) on aircraft noise at night in RANCH found no effect on children's reading comprehension or memory in addition to the effect of aircraft noise during daytime. However, the aircraft noise exposure during the day at school and at night at home were so strongly correlated that the variation was insufficient to test whether day time noise at school and night noise at home had independent effects.The long-term effects of poor sleep in children exposed to noisy sleep environments are still very uncertain.

Cognitive Effects

Regarding **cognitive after effects** of sleep deprivation, Hygge (WHO background paper NNGL) deduced that noise in the early night, e.g. aircraft noise before midnight, could be particularly damaging to memory and related cognitive functions. Although these effects have been fond in adults, this implication has not yet been explicitly tested in children. At the moment it is known that sleep affects memory, but not clear is how. New evidence primarily based on in adult studies points in the direction of an increased effect on memory due to noise in the early night, but there is as yet no graded quantification about whether ordinary before-midnight noise levels around large airports are sufficient to make a difference. Further, since children's memory systems pass through developmental changes and are not structured in the same way as in adults, it would be interesting to know to what extent the results found for adults are also valid for children, and whether the depth of children's sleep counteract or enhance the SWS dominance in the early night. An important conclusion is that studies into the cognitive effects of daytime noise levels cannot be used as a proxy for effects of night time exposure. Wilhelm et al. (2008) studied the beneficial effects of sleep on retention of declarative memories and concluded that this was comparable to results in adults. Children showed smaller improvement in finger-tapping skill across retention sleep than wakefulness, indicating that sleep-dependent procedural memory consolidation depends on developmental stage. Secondary analysis of two large airport data (Stansfeld et al, 2010) showed that nighttime aircraft noise exposure has no additional impact on reading or recognition memory beyond the effects of daytime noise exposure. It also showed no effects of nighttime noise exposure on self-rated health or overall mental health. Effects on motivation and further studies into the restorative function of sleep (Hartig, 2004) are mentioned as important topics for future studies. Healthy normal children with fragmented sleep (measured by actigraphy) also showed lower performance on neurobehavioural functioning (NBF) measures, particularly those associated with more complex tasks, and also had higher rates of behavioural problems (Sadeh, Gruber and Raviv, 2002). Also in normal children without sleep disorders, modest sleep restriction was found to affect children's neuro-behavioural functioning (NBF). Sadeh, Gruber and Raviv (2003) monitored 77 children for 5 nights with activity monitors. On the third evening, the children were asked to extend or restrict their sleep by an hour on the following three nights. Their NBF was reassessed on the sixth day following the experimental sleep manipulation and showed that sleep restriction led to improved sleep quality and to reduced reported alertness.

Mental Effects

Important finding on the relation between (noise-related) insomnia and **mental health**, reported in the background paper of Stansfeld for the WHO NNGL, is that insomnia more often precedes rather than follows incident cases of a mood disorders (Ohayon, Roth 2003). Compared to good sleepers, severe insomniacs reported more medical problems, had more physician-office visits, were hospitalized twice as often, and used more medication. Severe insomniacs had a higher rate of absenteeism, missing work twice as often as did good sleepers. They also had more problems at work (including decreased concentration, difficulty performing duties, and more work-related accidents (Leger et al, 2002). It is concluded that evidence regarding the role of noise exposure, sleep and the development of depression, is still scarce. Secondary analysis of two large airport data (Stansfeld et al, 2010) showed that nighttime aircraft noise exposure had no additional impact on self-rated health or overall mental health in schoolchildren. Longitudinal studies needed to fully evaluate the consequences for children are lacking.

Cardiovascular Effects

Only a few epidemiological studies exist on the **cardiovascular effects** of long-term noise exposure in the bedroom during the night. An exception is a study of Maschke et al. (2003b), the results of which suggested slightly higher effect estimates (odds ration 1.9 vs. 1.5), for the prevalence of hypertension with respect to the noise exposure of the bedroom (during the night) compared with the exposure of the living room (during the day). Critique on these findings is directed at the composition of the sample (older and health conscious group) There is some new evidence that the association between annoyance and CVD outcomes is stronger for sleep related annoyance/disturbance (Babisch et al., 2005; Maschke et al., 2003a; Niemann and Maschke, 2004). Sleeping behaviour such as closing windows, changing rooms etc are assumed to play a role in this association. Analysis on the pooled data set (Heathrow, Schiphol) of the RANCH study (Van Kempen et al., 2006) [21] indicated that aircraft noise exposure at school was related to a statistically non-significant increase in BP and heart rate in children. Road traffic noise showed an unexplained negative effect. Significant associations with night-time exposure were found and based on this it is concluded that blood pressure elevations might also be seen as an effect of sleep disturbance.(Maschke) Babisch and van Kamp (2009) and a later review of UK (Stansfeld et al, 2010) concluded that there was an inconsistent association between aircraft noise and children's BP. In their recent review, Paunovic et al.[24] concluded a tendency toward positive associations, but observed large methodological differences between

studies. A study among children aged 8-14 years by Babisch et al.(2010) concluded that road traffic noise at home as a stressor could affect children's BP. There is some evidence that short-term cardiovascular reactions during sleep are more pronounced in children (Griefahn et al., 2002, Lepore et al., 2010) concluded that compared with quiet-school children, noisy-school children had significantly lower increases in BP when exposed to either acute noise or non-noise stressors, indicative of a generalized habituation effect. Studies in Serbia (Belojevic et al, 2008, 2011) among schoolchildren and pre-school children indicated a raised BP among children from noisy schools and quiet residences compared with children from quiet school and quiet home environments.

Long term effects

As stated before, we still lack evidence regarding the **long term effects** of instantaneous sleep-disturbances, but more recently there is evidence of increased risk for several diseases. For example there is increasing evidence that chronic sleep deprivation and cardiovascular disease are associated. Also it has been put forward that an elevated BP during childhood might be a good predictor of hypertension (Babisch 2006). Non night-time dipping effect DBP as indicator of a lack of restoration has lately received more attention; In a study on a sub-sample of the EU HYENA project (N=149) a non-dipping effect of diastolic BP at night was found in the noise exposed group, which has previously been identified as independent risk factor for CVD (Haralabidis et al., 2008). Patients with chronic insomnia show a disturbed balance in their immune system (Irwin et al., 2003; Savard et al., 2003). Circadian disorganization in relation to sleep deprivation may also be important: changed body metabolism and potential effects on obesity showed in a study of Taheri (2004, 2007). A unbalance between *leptine* and *ghreline* can lead to an increased sense of hunger with weight gain as a consequence. Obesity in its own turn is a risk factor for cardiovascular disease and diabetes, by creating a disturbance of the glucose metabolism (Knutson et al., 2007). Also the risk of diabetes due to sleep disturbance (Donga et al, 2010) and poorer cognitive performance (Buckhalt et al. 2007; Sadeh et al. 2002) have been identified as accompanying long term effects of disturbed circadian rhythms.

Conclusion: potential mechanisms

Stansfeld at al. (2010) mentioned several mechanisms by which nighttime noise exposure and sleep disturbance could lead to cognitive impairments. Evidence is still lacking but narrowing of the attention focus, impairments of auditory discrimination and speech perception, and communication difficulties in the classroom and learned helplessness were brought forward as plausible candidates. Especially the role of learned helplessness needs more attention. It is not clear yet if and how noise-related behavior in the long term has a negative influence on children's health and learning. Evidence is increasing that chronic sleep disturbance can increase the risk of obesity and diabetes through the mechanisms of circadian disorganization and via this pathways could affect the cardiovascular system. Childhood elevated blood pressure is seen as a risk factor for hypertension. The mechanism of non-dipping of diastolic blood pressure might play an important role in this, as indicator of poor restoration during sleep. Finally childhood noise related sleep disturbance could lead to more serious sleep disturbance and insomnia later on in life. And finally, new notions include the early gene-environment interaction model (Lupien et al. 2009) suggesting that lifespan exposure to stress influences brain structures involved in cognition and mental health and emphasize the importance of **developmental sensitive periods.**

Future studies into the health effect of environmental noise exposure in early life should address these potential mechanisms and pay specific attention to the mediating role of sleep related aspects, including noise as well as other environmental exposures such as indoor climate and exposure to sounds and light from electronic devices.

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