Child & Noise

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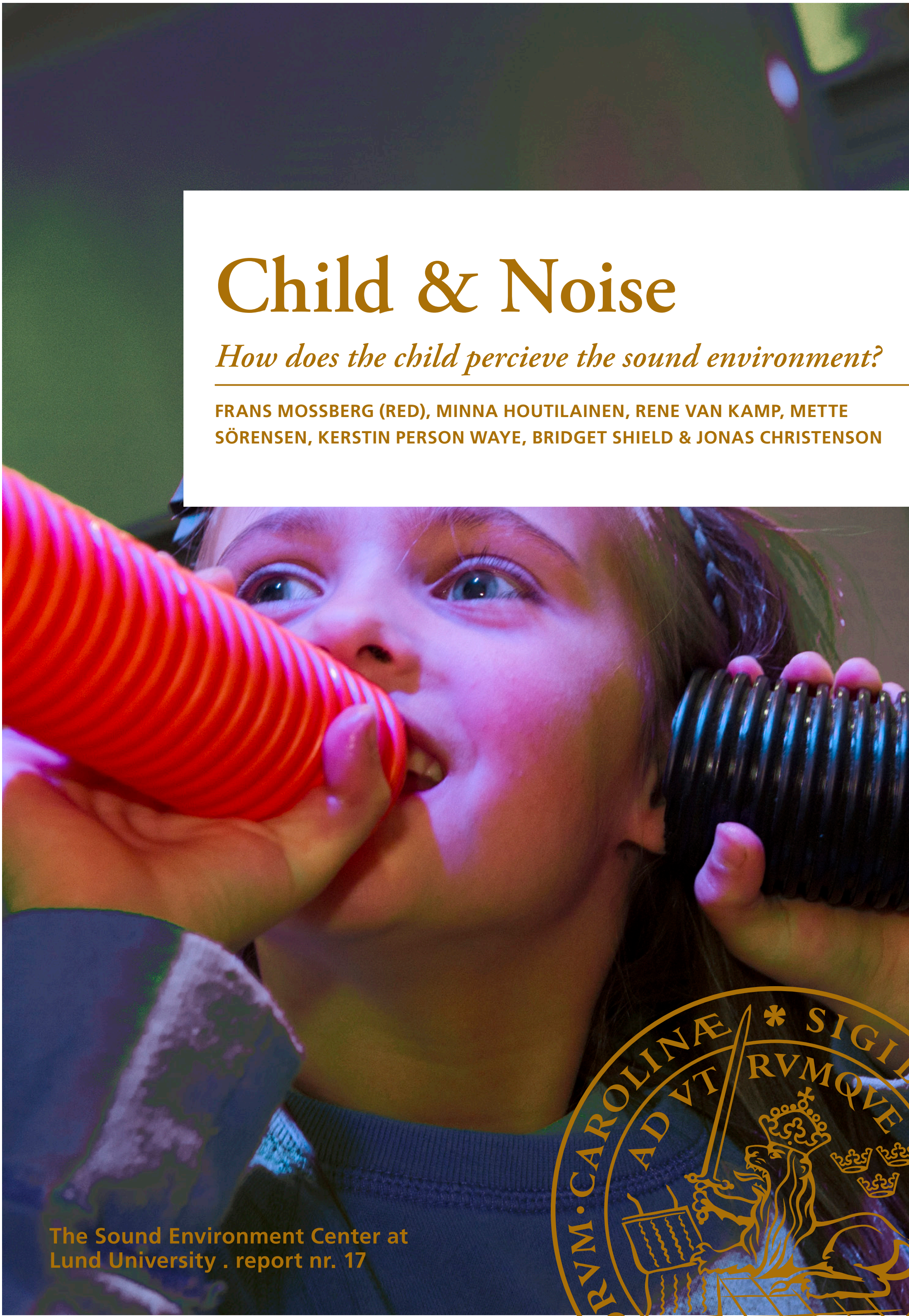

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How does the child percieve the sound environment?

Editor: Frans Mossberg

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Content

Preface

Frans Mossberg

An interdisciplinary symposium was held at Lund University in Sweden in march 2017 arranged by the Sound Environment Center aimed at shedding light on how the sound environment affects children, spanning all the way from the prenatal stage to the young person enjoying loud music or engaging in other loud activities. Too seldom the question is asked of how the child percieves the surrounding sound environment.

With the ambition to take a holistic grasp on the childs´ chronological exposure to sound and noise, the research here spans over many different disciplines, like audiology, acoustics, logopedy psychology, environmental medicine and neuroscience to name a few. Top researchers are taking part and the child´s exposure to sound is scrutinized both in detail and at meta levels.

Can the background to our noise sensitivity be traced back to our early life? Is the fetus affected by its mothers´ exposure to external occupational noise? Does it react to musical sounds before birth? Could experiences of music and sound before birth have impact after delivery for the child? What can brain research reveal about early auditory learning? What do we know of lifecourse effects of early exposure? What do we know of the child´s experiences of noise levels at preschools? How are the acoustic realities today experienced and what improvements can be made to the situation? What about kids with hearing disabilities? How do mobile music players affect young ears and to what extent can performance and learning be improved by practicing carefulness regarding soundscape in childhood and youth? Looking at gaps in knowledge and research, questions like these are addressed in the report from the Child & Noise symposium.

Minna Houtilainen of the Cognitive research unit of University of Helsinki as well as The Swedish Collegium for advanced study in Uppsala has dwelled into how the human brain reacts to auditory input in the first few months of life before birth, and explores neonatal auditory learning as well as the noise exposure of pregnant mothers. Sketching outlinlines for an optimal sound environment for the developing brain on the basis of her research, she pinpoints five preferrable conditions. A suitable environment for the infant would 1. contain speech for several hours a day, 2. not contain too much repetitive non-speech sounds, 3. include music, especially unaccompanied singing which has proved benficial for language development and the whole auditory system, 4. include the acoustic environment in a multisensory experience, 5. be both adaptive and responsive to the needs of the infant. These five principles calls for high quality stimulation from speech and singing.

Mette Sörensen of the Danish Cancer Society has made major studies of epidemiological data of associations between traffic noise and various hazardous health effects. In this report she studies noise exposure to mothers during pregnancy as well as childens exposure to residential road traffic noise and behavioral problems in 7-year olds, using data from a large population-based birth cohort of over 57000 mother-and-child pairs. Although no association were found at the pregnancy level, exposure during childhood could be associated with behavioural problems especially hyperactivity and inattention symptoms.

Irene van Kamp from *National Institute for Public Health and the Environment in the Netherlands* writes that although children are less likely to wake up or react with sleep cycle shifts due to nighttime exposure, they might be more likely to react with physiological effects such as blood pressure reactions and related motility during sleep, and sets out to formulate a set of hypotheses as a base for future studies into the short and long term effects of noise induced sleep deprivation. According to van Kamp the effects of sleep deprivation can be divided into four groups consisting of acute biological effects, allnight effects, day after effects on performance and cognition, and more chronic effects of sleep disturbance on health, wellbeing and cognitive impacts later on in life. She notes that this “complex web of interactions” makes it difficult to quantify any simple exposure-response relationships.

However it is well known that preschools are noisy environments for children and staff alike, and the health implications of this is the topic for the contribution of professor **Kerstin Persson Waye** in this report. The risk of hearing damage in relation to childrens age specific hearing is a unique perspective not often adressed that she describes in this article. It is appearent from this study that staff considers preschool childrens behaviour rather strongly affected by noise in various ways, and that they develop their own strategies to cope with the noise, either by raising their voices, losing concentration or withdraw.

Scientific acoustic evidence of the detrimental impact of noise on childrens cognitive performance is provided by prof.**Bridget Shield** in investigations of primary and secondary schools in London. Through measurements, surveys and experimental testing and simulations, childrens sensitivity to noise from external sources or inside classrooms are revealed with all desired clarity. Much of the adverse effects of noise in schools can be prevented by attention to acoustic design of school buildings, she writes and warns that the particular vulnerability of children with special needs must be observed. It must be essential for school buildings to be designed to reduce noise and provide optimal acoustic environment for teaching and learning.

Ending up in acoustic realities both indoors and outdoors **Jonas Christensson** of *Saint Gobain Ecophon* notes that indoor sound environments provides only a small number of ”natural sounds” compared to the outdoor environment. With all evidence of research identifying bad acoustics a major problem behind problems of learning and cognition in school premisses Chistensson turns to the outdoors, the free range woods, for remedy and inspiration for developing indoor school acoustics. Discussing differences in the capability to reflect different frequencies in vowels and consonants between the two environmental types, he stresses the absorption of lower frequencies to promote better speech intelligibility in learning environments.

All in all, the research in this report highlights and shows the vulnerability of the infant, the child and the young person to surrounding sound environments, and the importance of careful and conscious handling of acoustics and noise from the adult world.

What electromagnetic brain responses reveal of the fetal and neonatal auditory exposure and learning

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The human brain receives auditory input already several months before birth. The auditory system is very active during the first few months of life after birth. Behavioural methods fail completely or are inaccurate in showing how such exposure to auditory input would affect the developing auditory system and the fetal and neonatal brain. This paper shows evidence obtained with electromagnetic measurements that the exposure is indeed important and useful. In addition, the paper discusses possible adverse effects of auditory exposure during the fetal and neonatal periods.

EEG and MEG are powerful methods to understand the fetal and neonatal brain

Brain responses recorded with electric (ERP and EEG) and magnetic (ERF and MEG) methods reveal that the human fetal and neonatal brain is inclined towards learning from sounds. EEG or *electroencephalogram* is an old brain research method that records microvolt-scale alterations in the electric potentials on the surface of the scalp. These alterations are due to the electric activity of the neurons in the brain, and the potentials are transferred to the surface of the scalp with millisecond-scale temporal accuracy. Unfortunately the skull and the scalp distort the signals so that it is very difficult to estimate the original location of the signal in the brain. EEG is completely non-invasive and silent and it can be performed with portable devices or bed-side. Because of these great advantages, even though the lack of spatial resolution is an obvious problem, the EEG is still extremely popular and is even gaining in popularity compared to some other brain research methods.

The ERPs or *event-related potentials* are repeatable brain reactions to specific events such as the presentation of a syllable in a sentence, or a note in a musical piece. The ERPs require averaging of the EEG signal and the paradigms include a lot of repetition in order to extract the repeatable part of the brain reactions from the underlying noisy signals. ERPs are especially powerful in showing the brain reactions related to perception, comparison, memory or attentive events in the brain. Due to the high temporal resolution, the unfolding of such cognitive processes can be followed accurately. The ERP has a poor spatial resolution since it is completely based on the EEG signal. The ERP methodology relies on decades of careful and systematic investigations of ERP responses in adults and children specifically deducting cognitive processes related to sounds. For this reason, the ERPs of infants can be interpreted with respect to the ERPs of adults and children.

Since the EEG signal is heavily smeared and attenuated when it travels through human tissues, the EEG and ERP signals cannot be measured from a human fetus. On the contrary, the MEG signal does not smear and is much less attenuated, so that MEG and ERF recordings from fetuses have been published already decades ago.

MEG or *magnetoencephalogram* is a measurement technique very similar to EEG, but it records the magnetic fields that are produced by neural activity in the brain. The magnetic fields travel out from the head and can be recorded with the MEG device, a measurement instrument housing superconducting devices for the recordings of extremely small magnetic fields. The MEG measurement is conducted in a magnetically shielded room. The MEG signal from a neonate allows both a temporally precise investigation of neural activity at the millisecond time range as well as estimation of the location of the neural activity. The good combination of temporal and spatial accuracy is the key benefit of the MEG method. The ERF or *event-related magnetic fields* are similar signals as the ERPs and can be recorded in neonates and also in fetuses.

Evidence of neonatal auditory learning and skills

Studies of the auditory system of the newborn human infant have revealed a large amount of capabilities that were previously unknown. They can be called "innate" capabilities in the sense that they are present at birth, but several of them still *require learning*. This learning has taken place during the fetal period. Newborn human infants can segregate sounds into separate streams according to the features of the sounds. This skill requires a thorough analysis of the sound features and their continuity, and processes that try to predict the future auditory input. The *mismatch negativity* (MMN) brain response is an example of such prediction. The MMN response has been recorded in newborn infants both with ERP and ERF as well as in fetuses with ERF, showing that the predictive capacity of the auditory system is present already prior to birth.

The auditory input to the fetus and neonate contains plenty of information on the environment. The way that the mother is speaking, the sound from her environment, and the type of music that she likes to listen to, are all examples of repeating auditory input. The auditory system makes use of such input: statistical and memory-related learning has been shown to occur during the last trimester of pregnancy and in infancy. Such learning is crucial for the later development of language skills, the precedents of which are observed already in the new-born infant. For example, the stress patterns of the native language of the mother are well known to the infant's auditory system and this knowledge will help the infant learn that specific language since the stress patterns of the language constitute a coherent rhythmic or timing element against which the relevant features of the language are easier to grasp.

The initial auditory processing is universal, i.e., not specific to any language, but the learning patterns turn the auditory processing quickly towards preferring the acoustic input crucial for the native language perception. Such learning requires a large amount of exposure to the native language so that its characteristic features can be learnt.

Possible effects of noise exposure for pregnant mothers

The right type of sound exposure to the auditory system prior to and right after birth is essential in the light of offering possibilities for the learning and development of the auditory system capacities for sound analysis. There are cases when the sound exposure differs from that typically containing the mother's voice speaking, laughing, humming, etc. for several hours per day, plus some music, and some environmental sounds. One situation is occupational noise: When a pregnant mother during the very late part of the pregnancy works in a noisy environment (for example in a factory), the noises from her work are received by the auditory system of the fetus. If these noises are not random (as occupational noises typically aren't), but contain specific repeating patterns of sets of sounds, the fetal auditory system may start to tune towards these patterns. Such *adverse learning* may hamper the learning possibilities of language later. In a very noisy work place, the mother does not speak as much as she normally would during the days. This decreases the relative and absolute amount of maternal speech heard by the fetus, especially compared to the amount of occupational noise. Even if the occupational noise is low enough so that we can be sure that it is not causing elevated hearing levels or tinnitus in the newborn, it is still possible that the fetal learning of its features will compromise the later possibilities of language learning during infancy. We are studying this in a Finnish population in which we try to investigate the levels of occupational noise during pregnancy and its connections to later language learning of the children.

Possible effects of hospital sound environment for prematurely-born infants

When an infant is born very prematurely, he/she typically spends 2-3 months in the hospital before being released home. During this time, the sound environment of the hospital replaces the sound environment that would have naturally been present during the pregnancy, if it had continued to term. These few last months before term are a time of fast development and learning for the auditory system. Several investigators have proposed that the sound environment in the neonatal wards in hospitals might have a negative impact on the learning of language later in life.

Evidence from human and animal models show that auditory input is crucial for the normal development of the auditory system in this fragile and malleable phase. Brain plasticity, allowing the auditory system to develop language-specific memory traces needed for fast and accurate perception of the native language, has its caveats - in a non-optimal, noisy environment without speech sounds and other human voices, the plasticity may adapt the auditory system networks towards non-optimal directions.

We are studying the possible beneficial effects of additional sound exposure in the form of singing to prematurely born infants. In Kangaroo families study, we investigate whether singing during kangaroo care of prematurely born infants could help the auditory system grasp the essential features of the human voice and thus later learn language-relevant features faster. We propose that singing could be even more beneficial than speaking since it contains several acoustic characteristics that place it ahead of speaking in terms of clarity, repeatability, feature consistency and predictability. Our ongoing experiences show that parents of prematurely born infants find singing to be a good way to interact with their infant.

Optimal sound environment for the developing brain

What would be the optimal sound environment for fetal and neonatal development on the basis of the research presented above? It is impossible to make a full draft of such an environment, but some characteristics seem quite clear.

First, the environment should contain *human speech for several hours per day*. This is the natural learning environment of the human fetus during the last weeks and months before term, and it is also important after birth. Second, the environment should *not contain too much repetitive non-speech sounds* like sounds from machines etc. These sounds are acoustically extremely different from speech sounds due to their frequency content and other acoustic characteristics. For this reason, learning the features of the machine sounds may not be very beneficial to the infant. The learning of the machine sounds is especially effective if the machine sounds have relevancy value for the infant, i.e., if the sounds are in connection to something that the infant experiences. Third, music, and especially *unaccompanied singing* or singing with a light accompaniment with one instrument only can be very beneficial. There is evidence that involvement in music, musical play and singing is very beneficial for toddlers' language development, and similar observations exist also from older children. Singing has the same acoustic characteristics as speech, but presented in an easier-to-grasp manner. For example, syllables in speech occur one after the other without pauses or any signs to show that one syllable is ending and another one is starting, while in music, changes of syllables are coinciding with changes in pitch. Also, repetition in singing is much more constant and stabile compared to speech. Further, the repetitive patterns in music automatically give rise to memory models in the infant's brain, which support the development of the predictive systems and auditory short-term memory functions. For these and several other reasons we can propose that singing is a very good acoustic environment for the developing auditory system. Fourth, it may be beneficial for the auditory development that the acoustic environment is a part of a *multisensory* experience. Prior to birth, mother's speaking and singing voice is always in connection to some somatosensory and proprioceptive sensations. When the mother speaks or sings, her body moves both in vibrations but also in breathing movements in concordance to the acoustic signal. A similar event can be achieved with prematurely born infants during kangaroo care or when holding the infant in the lap. When the adult is speaking or singing, an infant in the lap or especially in kangaroo care experiences not only the acoustic input but also the somatosensory input from the adults movements which coincide with the sounds. Fifth, the sound environment of a prematurely born infant should be *responsive and adaptive*. Since the sleep-wake cycle of the infant is very fragile, and since for the brain development and also for the development of bodily functions and weight gain it is important to achieve good sleep wake rhythms, the sound environment should not disturb these. Abrupt beginnings of loud sounds should be avoided. In acoustic terms, sounds with clear attacks should be presented with soft volume. When the infant is in a good state, be it either asleep or awake, the sound environment can be lively and varying, but when the infant is trying to achieve sleep, the sound environment should support this attempt with soft, slow sound patterns like singing or humming slow lullabies. Practically, to achieve a responsive and adaptive sound environment, it is required that parents and hospital personnel monitor the infant's behavior and change the sound environment dynamically according to his/her needs.

These five basic principles of planning an optimal sound environment for neonatal hospital wards are supported by scientific evidence. There are plenty of reports of small experiments and trials in which the sound environment has been changed and parents or hospital personnel report changes in the behavior or other metrics of the infants. Such experimental testing is important and highly encouraged as long as it follows the five basic principles listed above.

> Silence is not the best sound environment for small brains. Fetuses and infants need high-quality stimulation in the form of speech and singing.

Figure 1.
The measurement of the EEG being performed on a full-term healthy infant. Sounds are presented in order to obtain the ERP responses. Photo: Veikko Somerpuro.

Figure 2.
The MEG measurement on a full-term healthy infant performed with the Elekta VectorView magnetometer provides a high-resolution result of underlying neural activity. Photo: Neuromag.

Figure 3.
The MEG measurement of a late-pregnancy fetus performed with Neuromag-99 magnetometer in BioMag Laboratory, Helsinki. Sounds are delivered via a plastic tube to the fetus, while the mother is listening to music in order not to know when the fetus is being stimulated. Photo: Minna Huotilainen

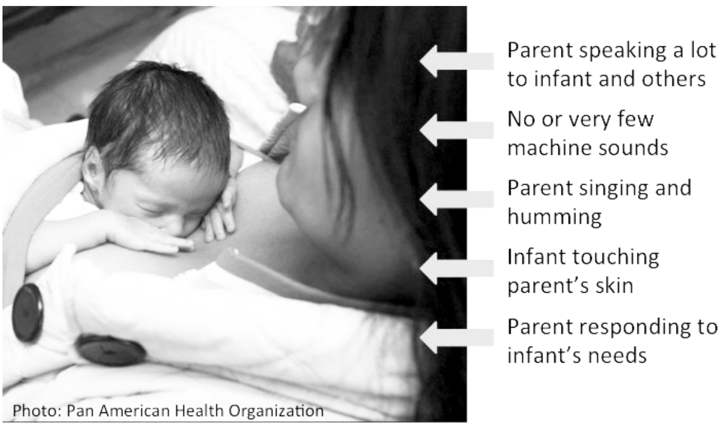

Figure 4.
Characteristics of an optimal sound environment for small brains. Photo: Pan American Health Organization.

The effects of noise disturbed sleep in children on cognitive development and long term health

Irene van Kamp[1], Kerstin Persson Waye[2], Anita Gidlöf-Gunnarsson[3]

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Abstract

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, but the knowledge of how children's health, wellbeing and cognitive development are affected by noise disturbed sleep due to road traffic is very incomplete. It has been shown that although children are less likely to wake up or react with sleep cycle shifts due to nighttime exposure, they might be more likely to react with physiological effects such as blood pressure reactions and related motility during sleep. The aim of this paper is to formulate a set of hypotheses as a base for future studies into the short and long term effects of noise induced sleep deprivation on health and child development and how this effects health and wellbeing later on in life. Because the literature is still trying to understand the nature of sleep disturbance among children in general a scoping review was used to achieve this, combining conceptual issues with a description of the scarce literature on noise and sleep disturbance in children as example. Based on this a set of hypotheses was formulated. It is concluded that future studies into the health effect of

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

Main messages

Effects of noise disturbed sleep in children is an understudied topic;

In specific more information is needed on longterm health effects and development;

Future studies into the effects of noise on children should be placed in a broader environmental and cultural context.

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Introduction

In the recently published guideline by the WHO [1] for the burden of disease from environmental noise and elsewhere [2] 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 [3] identified thirty seven papers (2007-2011) pertaining to primary school children, two to preschool children and four to neonates. Four papers addressed 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 cognitive and long term health effects are mediated by noise disturbed sleep is very incomplete. It is generally accepted that undisturbed sleep is essential for physiological and psychological health. Children have a special need for uninterrupted sleep for growth and cognitive development. Environmental noise is a well known factor to disturb sleep and it can be assumed to affect most children living in urbanised areas. In addition to noise in schools and preschools, many children are exposed to potentially disturbing traffic related noise at night. One of the most serious effects of community noise is sleep disturbance. [4] In this paper we are particularly interested in the role of sleep disturbance in cognitive development and cardiovascular effects in children and the (health) effects of chidlhood noise exposure and sleep disturbance later on in life. The aim of this narrative 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 general introduction on sleep and indicators of sleep disturbance, existing evidence in children is described in terms of prevalence and effects moving from acute biological effects, day after effects on performance and cognition to more chronic effects of sleep disturbance on health, wellbeing and cognitive impacts later on in life. The possible mechanisms are described and a set of hyptheses is formulated.

A conceptual model

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 [5][6][7]. The model described by Porter et al. [5], which is presented below, can be considered as representative for current thinking about the mechanism by which environmental noise can lead to sleep disturbance and (long term) health effects. This model shows that noise can directly lead to acute effects and then through a chain of negative consequences to long term health consequences. Feedback mechanisms and modifying factors are hereby assumed, meaning that noise can lead to health consequences through indirect pathways. This complex web of interactions makes it difficult to quantify any simple exposure-response relationship between noise exposure and health effects.

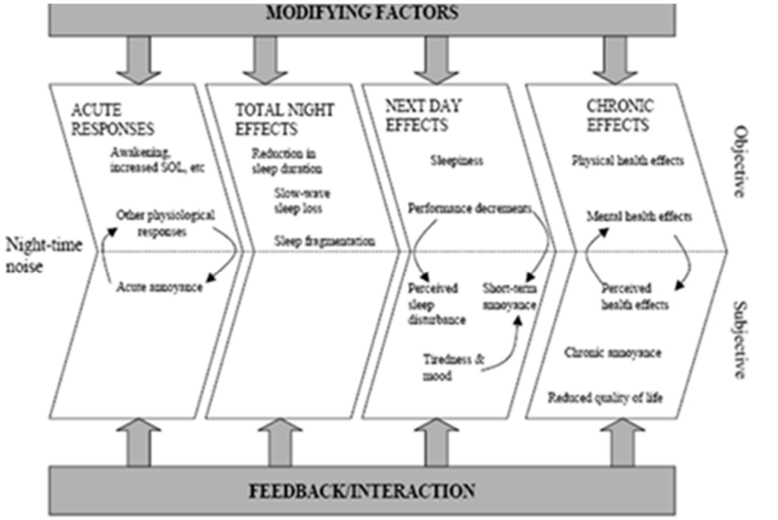

Figure 1.
The conceptual model of noise and sleep of Porter et al. [4] * SOL: Sleep Onset

The model distinguishes:

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 of noise and is assumed to be a potential initiator of diseases and/or a potential aggravator of existing disease. Whether this will happen depends on the person's vulnerability and/or sensitivity. [8][9][10][11] Potentially vulnerable groups are people with a somatic or mental disorder, shiftworkers and the elderly. Although some studies have shown that children are less sensitive for awakenings and sleep cycle shifts [12][13], it is often hypthesised that children are especially more sensitive for physiological effects during sleep such as blood pressure reactions. [14] [15] [16] [17] However, in 2004 the Dutch Health Council [18] concluded that the strength of the evidence for children's sensitivity for acute cardiovascular effects in relation to noise disturbed sleep is weak and even weaker for other biological responses. In general this conclusion still holds at this point in time: no additional evidence has accumulated on this since then.

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. [18] [19]

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. N3 stage sleep is generally considered to be important for physical restoration [20][21][22] and memory [23], while REM sleep is also believed to be important for cognition. [24]

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 children. Sleep patterns change with age, e.g. only in children the deep sleep stage is observed in the later parts of the night.

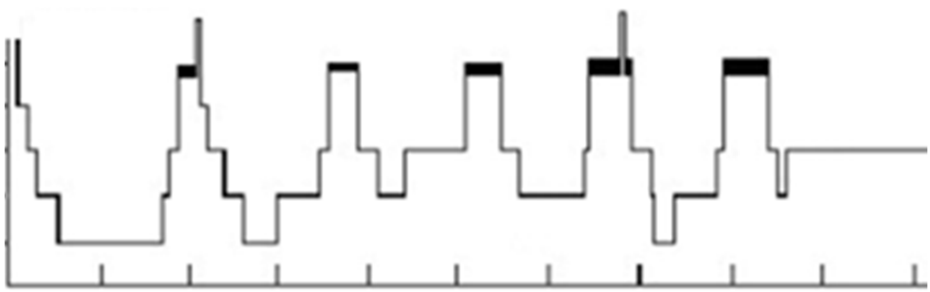

Figure 2.
Time structure of a normal sleep pattern in children (source: Hofman [16])

Indicators of disturbed sleep

Sleep disturbance is a multi-faceted concept, referring to a broad range of effects from awakening to subtle changes in autonomic physiology, and these changes are not necessarily consistent within an individual for a given level of noise stimulus as there are complex patterns of neurophysiology associated with the different EEG defined sleep stages and the time of night. Given this complex process there are various end-points that can be chosen to assess the degree of sleep disturbance These range from measures extracted from the EEG based polysomnography, which is considered the 'gold-standard' of sleep recording and provides a direct measure of cerebral activity from which a number of macro and microstructural features can be extracted. [15] Sleep disturbance also refers to subjective effects such as perceived quality of sleep or nighttime annoyance.

As a consequence, many different methods and techniques are used to investigate the possible effects of noise on sleep disturbance which vary widely depending on the responses/effects being studied (see the model of Porter in figure 1). These methods can roughly be divided into two categories: physiological measures and self-report measures such as diaries and questionnaires.

Table 1 gives an overview of physiological parameters, the underlying concept and their operationalisation.

Table 1.
Overview of physiologic examinations used in studies investigating the possible effects of noise on sleep. (Source: van Kempen, Staatsen, and van Kamp, 2005 [25]).

Type of examination	Indicator for	What is examined ?
Electroencephalograph (EEG)1)	The sleep stages	Total sleep time, total time spent overnight in Slow Wave Sleep(SWS; deeper sleep) and in the stage of Rapid Eye Movement (REM; dream sleep)
EMG1 EOG1 Electrocardiography (ECG) Plethysmography Actimetry	Muscle tone Eye-movements Cardiac function Heart rate and blood pressure Motility	Heart rate Total sleep time, time of falling asleep, wake-up time, Number of awakenings
Overnight cortisol in blood or fluvia Overnight urinary catecholamine	Level of circulating catecholamine Level of total catecholamine released during sleep, not taken up by sympathetic nerve endings	Sympathetic nervous activity

[1]The measurement of brain activity by means of EEG, EMG and EOG is also called polysomnography.

As table 1 shows, awakenings can be measured and defined in several ways. A distinction is made between arousals (or EEG awakenings) and behavioral awakenings. An arousal is defined as an EEG response that has all the characteristics of an individual awake; behavioral awakening is confined to a verbal or motor response, indicating the subject is awake. The quality of sleep can also be measured in a subjective way, usually as (non-acute) after effect.

Indicators used in child studies

Sleep studies in children using these different methods described above are rare and even more so are studies into the effect on sleep due to noise exposure. In 2004 a committee of the NL Health Council [18] concluded that very little is known about the biological effects on children of exposure to noise when sleeping, or about the impact on children's health and well-being and this conclusion still holds today. Although the findings of the European research project Road traffic and Aircraft Noise exposure and children's cognition and Health (RANCH) and the Munich study [26] [27] have shed some light on the effects of noise on children as compared to their parents, there is still an overall lack of knowledge regarding the issue of childhood exposure to noise when sleeping. During a noise-disturbed night effects might show during the different stages, e.g. the sleep onset might be slightly delayed or while REM sleep might still shows clear rhythmic occurrence some of the episodes might be fragmented. Also significant awakenings might occur throughout the sleep process and overall sleep efficiency is reduced as was shown by Muzet [14] in a hypnogram of a young adult during a noise disturbed sleep, as compared to a normal night. To our knowledge no such example is available for children. More objective measures of after effects include excretion of hormones, sleepiness, task performance tests, and cognitive functioning tests.

The quality of the sleep can also be measured in a subjective way using questionnaires on sleep quality, tiredness and annoyance. After effects (non-acute) are usually measured subjectively using questionnaires on sleep quality, tiredness, and annoyance. Subjective ´measures are rarely applied to children. One of the few exceptions is the study of Öhrström et al [13] among 9-12 year old children, in which both the parents and children were asked to rate their overall sleep quality, frequency of movement and extent of sleepiness when waking up on an 11 point scale.

Methods

In view of the main aim of this paper to formulate a set of hypotheses regarding the short and long term effects of sleep disturbance in children, this paper combines a conceptual approach with a more narrative review method, which both build on the work we have previously performed in the field of noise and sleep disturbance in adults and children. Primarily, previous reviews on the topic have been used as a basis as well as a systematic review on the association between environmental noise and sleep disturbance performed for the EPD Hong Kong [3a] and an ICBEN review on health effects of noise in vulnerable groups [3]. More recent literature on the topic was sought making use of the major literature data bases (MEDLINE, PUBMED, SCOPUS and GOOGLE SCHOLAR). Since the current literature is still trying to understand the mechanisms and meaning of sleep disturbance in children it is still too early for a proper systematic review on this topic.

Results

Prevalence

Estimates of the prevalence of sleep disorders in children vary on average between 10% to 25% [28] [29]. In a large epidemiological study in the USA based on GP registry data and using the ICD-9 sleep diagnoses, Meltzer et al [30] found much lower figures with prevalences in the range of 3-5%. This might be indicative of underreporting by GP's, as the authors suggest, but more likely these low prevalence rates are associated with the way sleep disturbance was defined. The GP registry data seem to only 'catch' the more serious and chronic forms of disturbance; milder cases of child's sleep disturbance are not per se reported to the GP's by the parents. Comparable rates were reported by Rona et al [31], based on a large epidemiological study in the UK and Schotland which found that 4% of the 14 372 children experienced sleepdisturbances at least once a week. Important risk factors identified were socioeconomic factors associated with ethnicity and respiratory illnes. In 1999 Thunstrom [32] found in Sweden that 16% of the parents of children aged 6 to 18 months resported moderate to severe problems with falling asleep en and up to 30% frequent awakenings per night. Parental worry and anxiety were found to be the ost common causes of the child's sleeping problems. In 6% of the children severe sleep disorders as defined by the ICSD were diagnosed. A Finnish study performed in 2000 [33] among a sample of 8 to 9 year old schoolchildren estimated the prevalence of sleepproblems by asking the children as well as the parents. Disturbed sleep was resported by 22% of the parents and 18% of the children. Remarkable was that these did not always overlap and adding the prevalences up resulted in an estimate of 32%, concerning mild cases. In less than 0,5 % the probelems were serious. It was concluded that sleepproblems are often overlooked by parents and therefor parents as well as the children should be asked to provide information.

A Swedish survey at the national level [34] perfomed in 2005 reports that one out of seven 12-year-old children (15%) indicated themselves that noise prevented them from falling asleep. For about 25.000 schoolchildren aged 7-14 years this occurred 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 only a few examples of studies of how children are affected by sleep due to road traffic noise. [17]

Evidence for noise disturbed sleep in children

The Night Noise Guidelines of WHO [17] 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. These effects form a mix of accute, next day and long term outcomes and are primarily based on older studies from before 1990 in specific patient groups. Below more recent evidence on the effect on environmental noise on children' s sleep per outcome category is summarized.

Accute effects and effects over a night

The Health Council Netherlands[18] made the following distinction of effect within the category of acute effects of noise on sleep: Heart rate acceleration, a change in the quantity of a stress hormone, sleep stage changes (EEG), EEG awakening, motility and motility onset and finally behavioural awakening (self indicated/registered). Because of the lack of research data on children, it is not possible to say with confidence whether children are more sensitive than adults to other acute biological responses.

Next day effects

A study of 9-12 year olds in the EU project RANCH showed that children's problems with daytime sleepiness was higher with increasing road traffic noise exposure levels outside the children's home. [13] Sadeh et al. [35] found an association between poor sleep quality and worsened performance on complex cognitive tasks in school related to difficulty in sustaining attention. A sub-study [26] 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.

Regarding cognitive after effects of sleep deprivation, Hygge et al. [27] (see also 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 found 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 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 slow wave sleep (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. [36] 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 [26] 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 [37] are brought forward 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. [38] In normal children without sleep disorders, modest sleep restriction was found to affect children's neuro-behavioural functioning (NBF). Sadeh, Gruber and Raviv [39] 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.

Long term health effects of disturbed sleep

Long term health effects of disturbed sleep have been studied primarily in adults. In general 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 in adults. For example there is increasing evidence that chronic sleep deprivation and cardiovascular disease are associated. 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. [41] Patients with chronic insomnia show a disturbed balance in their immune system. [42,43] 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. [44,45] An imbalance between leptin and ghrelin 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. [46] Also the risk of diabetes due to sleep disturbance [53] and poorer cognitive performance [30,47] have been identified as accompanying long term effects of disturbed circadian rhythms.

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. [42] 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. [43] It is concluded that evidence regarding the role of noise exposure, sleep and the development of depression, is still scarce.

Studies on long term health effects due to noise disturbed children are practically rare. It has been put forward that an elevated BP during childhood might be a good predictor of hypertension later on in life. [40] However, secondary analysis of two large airport data on the health effects of noise in children (aged 9-11) [26] showed that nighttime aircraft noise exposure had no additional impact on selfrated health or overall mental health in schoolchildren. Longitudinal studies are urgently needed in order to evaluate long term consequences of a disturbed sleep.

Cardiovascular effects of noise and the role of sleep disturbance

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. [48] , 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. [40][49][50] Sleeping behavior such as closing windows, changing rooms etc are assumed to play a mediating role in this association. Analysis on the pooled data set (Heathrow, Schiphol) of the RANCH study. [51] 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. [49] Babisch and van Kamp [52] and a later review of UK [53] concluded that there was an inconsistent association between aircraft noise and children's BP. In their recent review, Paunovic et al. [54] 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. [55] 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 [25][56] 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 [57,58] among schoolchildren and pre-school children indicated a raised BP among children from noisy schools who live in quiet residences compared with children from quiet school and quiet home environments. This indicates that the effects due to daytime noise exposures while at school were not compensated for by quiet periods while at home.

Discussion

This scoping review has shown that studies into the short and long term effects of noise disturbed sleep in children on health and cognition are scarce. This is expected to change in the near future. In the context of continuing urbanization noise exposure will increase in the coming decades also for young children. Due to the 24 hour economy noise exposure starts earlier and ends later in the day and will continue over the weekend. Since sleep patterns change with age these developments might primarily affect young children and noise policies have to account for these differences in their noise regulations. For example: only in children the deep sleep stage is observed in the later parts of the nights and current curfews around airports do not take this into account. These developments include that not only the moments and places of quiet and restoration are diminishing, but also that sleep disturbance in children might be an increasing problem. In particular the combination with other environmental stressors such as frequent use of computer screens, which has been shown to affect sleep duration as well as sleep quality, will be of concern. New developments in the field of genomics and gene- environment [64] interactions will allow for studying the effects of early childhood exposures later on in life and sleep disturbance is identified as a potentially important mediator in this process. There are new but still highly theoretical notions on early gene-environment interactions [59] which suggest that lifespan exposure to stress influences brain structures involved in cognition and mental health. This sheds new light on the importance of developmental sensitive periods.

In line with the Health Council Netherlands [18] in reviewing the results a distinction was made between acute effects, next day effects, after effects and long term effects. There is insufficient evidence to know whether children are more responsive than adults to other acute biological responses than those found for adults. Studies into the next day or after effects have shown that exposure to increased transport related noise levels were associated with daytime sleepiness and performance on complex tests and problems with sustaining attention. [62] After effects on cognition and performance have been studied in adults only and for adults early night exposure, e.g. aircraft noise before midnight, was shown to be particularly damaging to memory and related cognitive functions [27]. However it is not clear whether these findings apply to children in the same way. 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 slow wave sleep (N3) dominance in the early night.

A more recent study [63] indicated that nighttime noise was found in particular to be associated with more emotional symptoms. This association may be confounded by the presence of sleeping problems and the authors recommend that more longitudinal studies are required to explore the temporal sequence of noise exposure, sleep disturbances and behavioral problems.

Effects on motivation and further studies into the restorative function of sleep have also been brought forward in the literature as important topics for future studies. Regarding the long term health effects of sleep disturbance it has been put forward that an elevated BP during childhood might be a good predictor of hypertension later on in life. The non-dipping effect of diastolic BP at night was found in noise exposed groups, which has previously been identified as independent risk factor for CVD. How this effect is related to early childhood exposure should be studied in more depth.

Several mechanisms were described to explain the association between sleep disturbance and obesity as well as diabetes type 2. Circadian disorganization in relation to sleep deprivation is one of them. An imbalance between leptin and ghrelin can lead to an increased sense of hunger with weight gain as a consequence. [46,64] The risk of diabetes due to sleep disturbance and poorer cognitive performance have been identified as accompanying long term effects of disturbed circadian rhythms. The hypothesis that childhood noise related sleep disturbance could lead to more serious sleep disturbance and insomnia later on in life is mentioned in the literature, but would need much more attention in prospective cohort studies. Potential mechanisms brought forward in relation to the effect of sleep disturbance and cognitive effects were extensively described by Stansfeld at al. [26] 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. 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.

Future studies into the mechanisms behind the issue of noise and sleep in children should be placed in a broader environmental and cultural context as was canvassed by Knutson [46] in her model presenting the environmental factors that can impair sleep in conjunction with biological and cultural factors.

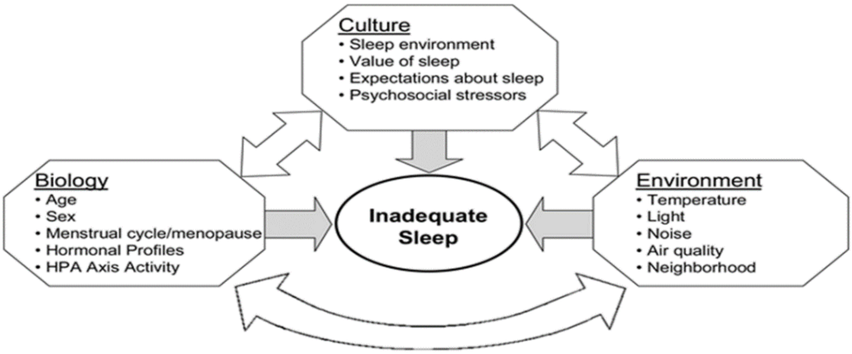

Figure 3:
Factors associated with biology, culture and environment that can impact and interact with sleep to increase (source: Knutson [46] with permission)

It is known from previous studies that sleep could be disturbed when the ambient temperature is too hot, too humid or too cold. [60] Another factor of influence is light, either caused by natural light (Northern hemisphere) or artificial sources in the bedroom due to street lamps, green-houses, indoorl lighting or daytime sleep. One mechanism through which exposure to light at night can impair sleep is the inhibition of melatonin. Transport related pollutions which are common characteristics of large urban areas according to the model are noise that can impair sleep via physiological arousal as measured by (motility, EEG awakenings, BP changes and heart rate variability) and airpollution both inoor and outdoor via breathing. Recently it was shown [65] that bruxism during sleep was more prevalent in children exposed to light and noise.

Lastly the model mentions neighbourhood characteristics which primarily refers to social safety. Studies addressing the joint effect of environmental and neighbourhood aspects on sleepquality are rare but can be considered as important in particular to understand the disparities in sleep between different populations [46].

Conclusion

Future studies into the health effect of environmental noise exposure in early life should address these potential hypotheses and 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 [61].

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Traffic noise and behavioral problems in children

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Traffic noise has been associated with a number of major diseases among adults, including cardiovascular diseases and diabetes [1, 2]. Traffic noise are also thought hazardous for children, especially during sensitive stages of development. Studies investigating effects on neuropsychological development due to traffic noise exposure in children have mainly focused on learning and cognitive performance, with consistent findings of impairment in reading and memory [3]. One previous study has investigated associations between traffic noise exposure at the home address and risk for behavioral problems in children [4]. This study was based on 900 German children, and found an increased risk for hyperactivity and possibly emotional symptoms [4].

Childhood exposure to traffic noise at home may increase risk for hyperactivity among children, by inducing stress through activation of the hypothalamic-pituitary-adrenal axis and by disturbing sleep [5]. Furthermore, maternal stress and sleep disturbance during pregnancy have been associated with psychological effects in children [6], and, therefore, pregnancy exposure to traffic noise may be relevant in relation to risk for hyperactivity (Figure 1).

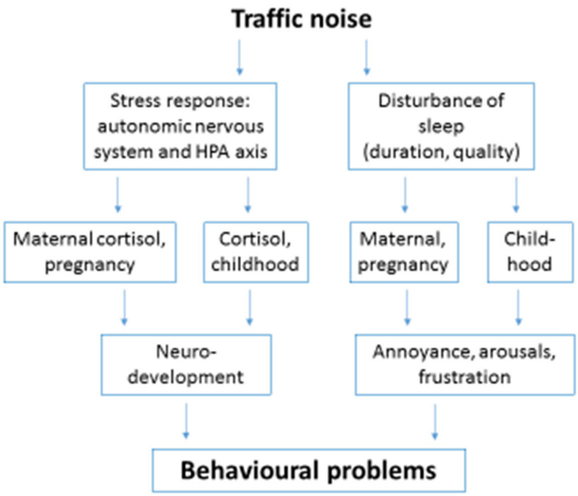

Figure 1
Potential mechanisms between traffic noise and behavioral problems

We aimed to study the relationship between exposure to residential traffic noise during pregnancy and early life and behavioral problems in 7-year-old children, using data from a large population-based birth cohort.

Study population

We conducted a study based on the population-based Danish National Birth Cohort (DNBC) [7]. During 1996-2002, pregnant women were invited to participate in the DNBC when visiting their general practitioner. Participation involved a prenatal computer-assisted telephone interview at the 12th pregnancy week, including questions on maternal lifestyle factors during pregnancy, such as alcohol consumption and smoking habits as well as questions related to maternal mental health. Also, a follow-up questionnaire was mailed to the parents when the child was 7 years old, including questions regarding behavioral problems of the child, based on the Strengths and Difficulties Questionnaire (SDQ). In total, 57,281 replied to this 7-years questionnaire.

Assessment of behavioral problems

Behavioral problems at 7 years of age were assessed by the Danish parent-reported version of the SDQ (SDQ-Dan) [8, 9]. The SDQ is an internationally validated behavioral screening questionnaire, that allows systematically to assess the mental well-being and function of children and adolescents. The questions address the behavior of the child the preceding 6 months. It consists of 25 items and generates scores within five subscales: emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behaviors. Each subscale is covered by 5 items, rated with a three-point scale option: *'not true'* (0), *'somewhat true'* (1) or *'certainly true'* (2), and each subscale score is generated by summing up the ratings, and subsequently divided into the categories: *normal, borderline or abnormal*. The total difficulties score is obtained by summing up all subscale score except the prosocial behavior score.

Assessment of residential exposure to traffic noise

Residential address history from start of pregnancy and until 7 years of age was collected from the Danish civil registration system for all mother/child pairs in the cohort. We estimated exposure to both road traffic and railway noise at all addresses using SoundPLAN, and based on the Nordic Prediction Method for road traffic noise [10] and NORD2000 for railway noise. Input variables for the model included all Danish building polygons, and for estimation of road traffic noise information on road lines of yearly average daily traffic, vehicle distribution, traffic speed and road type, and for railway noise information on railway lines of annual average daily train lengths, train types and travel speed. Noise levels were expressed as L_{den} at the most exposed facade of the dwelling.

Statistical analyses

The associations between exposure to residential road traffic and railway noise and risk for behavioral problems at 7 year of age were analyzed by logistic regression. Exposure to road traffic noise was modelled linearly as time-weighted mean per 10 dB increase during two different exposure windows: a) *pregnancy period* and b) *from birth to 7 year of age*, taking all present and historical addresses into account. Exposure to railway noise was modelled at the residential address at: a) *time of birth* and b) *time of filling in SDQ (7 years)* and analyzed linearly among exposed (per 10 dB). We calculated crude odds ratios (OR) and OR's adjusted for potential confounders: sex, age at filling in the SDQ, gestational age, birth weight, maternal age at delivery, parity smoking during 1st trimester of pregnancy, alcohol consumption during 1st trimester of pregnancy, level of education, disposable income and maternal mental health problems during 1st trimester.

Results

Of the study base of 57,281 mother and child pairs, we included only the first enrolled pregnancy to avoid non-independent observations (54,103) and excluded 2,272 mothers with multiple pregnancies, 1,833 without information on behavioral problems, 170 without noise exposure and 2,888 with incomplete confounders information, leaving a study cohort of 46,940 children.

Characteristics of the study population and abnormal cases (on the total difficulties score) are summarized in Table 1.

Table 1
Characteristics of the study population by case status using the total difficulties score

Confounders		Cohort *N = 46,940*	Abnormal cases *N = 3,770*
Sex	Boy	51 %	52 %
	Girl	49 %	48 %
Gestational age, birth	< 37 weeks	4 %	6 %
	≥ 37 weeks	96 %	94 %
Birth weight	< 2500 grams	3 %	5 %
	≥ 2500 grams	97 %	95 %
Parity (%)	Nulliparous	50 %	56 %
	Uniparous	35 %	33 %
	Multiparous	16 %	11 %
Maternal smoking, 1st trimester	No	76 %	66 %
	Yes	24 %	34 %
Maternal alcohol intake, 1st trimester	< 1 drinks per week	88 %	90 %
	≥ 1 drinks per week	12 %	10 %
Highest attained education	Basic (7-12 years)	13 %	27 %
	Vocational (10-12 years)	53 %	54 %
	Higher (≥13 years)	34 %	19 %
Disposable income	Low	18 %	21 %
	Medium	31 %	32 %
	High	51 %	47 %

Maternal age among children scored as abnormal was slightly lower (29.1 years) than age of mother of the total study population (30.3 years). Of the 46,940 included children, 11 % were classified as borderline and 8 % were classified as abnormal. The correlation (Rs) between L_{den} road during pregnancy and childhood was 0.74, and between L_{den} road and L_{den} railway among the participants exposed to railway noise (13.1 % at 7-years of age) the correlation was very weak (0.03).

For time-weighted mean exposure from birth to 7 year of age, we found a 10 dB higher exposure to road traffic noise to be associated with a 7 % higher risk for scoring abnormal (95 % CI: 1.00-1.14) on the total difficulties score (Table 2). Similarly, railway noise at 7-y was also associated with a higher risk for scoring abnormal on the total difficulties score (Table 2). We found no associations between pregnancy exposure to traffic noise and risk for scoring abnormal on the total difficulties score.

Table 2
Associations between residential traffic exposure during childhood and risk for scoring abnormal on the total difficulties score

Total difficulties score	N exposed	OR (95% CI)
Road traffic noise (per 10 dB)		
Normal	37,861	1.00
Borderline	5,309	1.00 (0.95-1.06)
Abnormal	3,770	1.07 (1.00-1.14)
Railway noise (per 10 dB)		
Normal/ Borderline	5,649	1.00
Abnormal	500	1.13 (1.02-1.25)

Adjusted for sex, age at SDQ, gestational age, birth weight, maternal age, parity, education, income, smoking and alcohol consumption (1st trimester), and maternal mental health problems (1st trimester).

On the hyperactivity/inattention subscale a 10 dB higher road traffic noise exposure was associated with a 5 % higher risk for scoring borderline (95 % CI: 1.00-1.10) and a 10 % higher risk for scoring abnormal (95 % CI: 1.03-1.18) as compared with normal scores (Table 3). Similar tendency was seen for railway noise, with a 9 % higher risk for scoring abnormal (95 % CI: 0.97-1.22; Table 3). We found no associations between pregnancy exposure to traffic noise and risk for scoring abnormal on the hyperactivity/inattention score.

For the peer relationship score there also seemed to be associations between both noise exposures during childhood and risk for scoring abnormal: OR's were 1.06 (95 % CI: 0.99-1.12) per 10 dB road traffic noise and 1.13 (1.03-1.25) per 10 dB railway noise. Again, no

associations were found for pregnancy exposure. There was no associations between neither pregnancy nor childhood exposure to traffic noise and risk for scoring abnormal on the emotional symptoms scale or the conduct problems scale.

Table 3
Associations between residential traffic exposure during childhood and risk for scoring abnormal on the hyperactivity/inattention score

Hyperactivity/inattention score	N exposed	OR (95% CI)
Road traffic noise (per 10 dB)		
Normal	37,799	1.00
Borderline	6,097	1.05 (1.00-1.10)
Abnormal	3,044	1.10 (1.03-1.18)
Railway noise (per 10 dB)		
Normal/ Borderline	5,648	1.00
Abnormal	501	1.09 (0.97-1.22)

Adjusted for sex, age at SDQ, gestational age, birth weight, maternal age, parity, education, income, smoking and alcohol consumption (1st trimester), and maternal mental health problems (1st trimester).

Discussion

Our study suggested that exposure to residential traffic noise during childhood increases the risk for having hyperactivity/inattention symptoms at the age of 7 years. Hyperactive children are normally more easily distracted by background noise [11], and it is possible that traffic noise may exacerbate these children's difficulties, thereby making an already existing tendency towards hyperactivity worse or more obvious. Our results are similar to most of the few previous studies investigating associations between exposure to traffic noise either at home and in schools and risk for behavioral problems [4, 12, 13].

Our study also suggested that childhood exposure to traffic noise may result in peer relationship problems. Peer relationships are thought to play an important role in children's development, as they stimulates learning of social norms and learning new social skills. A previous German study on traffic noise at the home address and behavioral problems did not observed similar trends [4], and more studies investigating this is clearly needed.

We found no associations between exposure to traffic noise during pregnancy and any of the investigated behavioral problems in children aged 7-y, suggesting that prenatal stress and sleep disturbance from traffic noise is not relevant for the development of behavioral problems.

Strengths of our study include the large study population, with information on various confounders, together with access to residential address histories from conception to 7 years of age, which makes it possible to investigate different exposure time-windows. Limitations include the cross-sectional design, with no follow-up information on outcome, which prevents us from making any causal conclusions regarding the effect of noise on the development of behavioral problems. Furthermore, behavioral problems were based on the parent-reported version of the SDQ and recalling the child's behavior in the past 6 month, which may be associated with recall bias. However, we do not expect recall to be associated with exposure to residential traffic exposure and therefore not be associated with systematic bias.

In conclusion, this study provides further insight to the relationship between traffic noise and behavior in children. The results indicate that exposure to residential road traffic noise from birth until 7 years of age is associated with behavioral symptoms, especially hyperactivity/inattention symptoms, whereas exposure to noise during pregnancy showed no associations. More studies are needed to understand the mechanism through which traffic noise may affect children's behavior.

For further information on this study: Hjortebjerg et al, 2016, Environ Health Perspec, 124: 228-234; https://ehp.niehs.nih.gov/1409430/

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Implications of being in a preschool noise environment, a qualitative analysis of children's behaviour from a personnel perspective

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Abstract

Exposure to noise at an early age may have health implications of which we today have very little knowledge. Mechanisms such as age specific hearing, adoption of inadequate behavioural strategies which may result in manifest coping patterns and alterations in biological stress regulatory responses could be of concern. In Sweden about half a million preschool children attend preschool. The noise exposure is intermittent and unpredictable and the noise levels reach up to 84LAeq (time indoors) with maximum levels of 118 LA_{Fmax}. To increase the overall understanding of the possible implications of being in a preschool noise environment, the paper aim to describe children's experience, understanding, and coping with their every day sound environment given from a personnel perspective. The analyses are based on qualitative content analyses.

Introduction

In Sweden more than 80% of 1-5 year old children spend most of their day in preschool. They are exposed to high levels of intermittent and often high frequency sounds. Our measurements show that preschool children are on average exposed to of 84 dB $LAeq_{\text{Time indoors}}$, with maximum noise levels reaching LAFmax 118 dB (Persson Waye et al 2011). These levels correspond to noise levels not to be exceeded to comply with the Swedish Work Authorities limits (AFS 2005: 16) for adults. Teachers report stress, fatigue, hearing problems and voice problems (Fredriksson et al 2017) but little is known on how children are affected.

From earlier qualitative studies among 4-5 year old preschool children we learned that children communicated their sound environment in a varied way (Dellve et al 2013). They talked about trustful sounds (everyday sounds from known trusted individuals), neutral sounds (i.e washing machines), unknown frustrating sounds (i.e sounds from the radiator) and distressing sounds. Distressing sounds were described as painful (high frequency and sudden sounds like screeching sounds from the swing, and rakes, screaming from smaller children), and threatening (situations involving screaming of specific children who often initiated violent situations). The concluding model was formulated "Living with own uncontrollability of sounds and noise". We further found that children described coping with their sound environment by going away, hiding, cover their ears, but also sometimes expressing "not knowing what to do". The coping strategies were later confirmed in an intervention study where more than 70% of the children adopted some coping strategy when exposed to loud or unpleasant preschool noise (Persson Waye et al 2013).

To increase the overall understanding of the possible implications of being in a preschool noise environment, this paper describes the personnel perspective on how high noise levels at preschool may affect children's behaviour. The data is analysed using qualitative content analyses of manifest contents of the personnel report.

Method

The qualitative content analyses were done of one question of a 56 item questionnaires sent to 11 276 females with a preschool exam. The aim of the total questionnaire was to evaluate how the current and previous occupational sound environment affected hearing and health among this study population in comparison to a randomly selected population of females (Fredriksson et al 2017). Response from the preschool population was obtained from 5 475 respondents giving a response rate of 49%. Among those currently working as a preschool teacher (around 4000), 3986 had answered the question: "Do you find that preschool noise affects the behaviour of the children?" (Q52). The response alternatives were four: not at all, somewhat, rather much and very much. If responding at least somewhat they were encouraged to describe how in free text. The free text was analysed in a qualitative content analysis using the software Open Code 4.03 (OpenCode 3.4. Umeå University 2013). In performing qualitative analyses, one may focus on the manifest content or the latent content. A manifest analysis describes the visible, obvious components, what the text says, while a latent analysis tries to analyse the underlying meaning of the text (Kondraki et al 2002). They both involve an interpretation but varies with regard to depth and level of abstraction (Graneheim and Lundman 2004). This article focus on a manifest analyses of the free text given by the personnel. The unit of analysis for the coding included the whole text given by each personnel, usually comprising around 10-20 words. The procedure was initiated by reading through all the text to achieve an overall picture of the context. Frequently occurring words or concepts were written down, and word stems i.e "focus" was searched. The word stem would then identify words with the stem included such as unfocussed, out of focus, and the number of words with the stem included was recorded. The words were added to categories or themes and codes were used to label a condensed common meaning. The categories are derived to share an internally homogeneous and external heterogeneous commonality.

Results

The distribution of the personnel answers of whether noise affected children's behaviour (Q52) is given in figure 1.

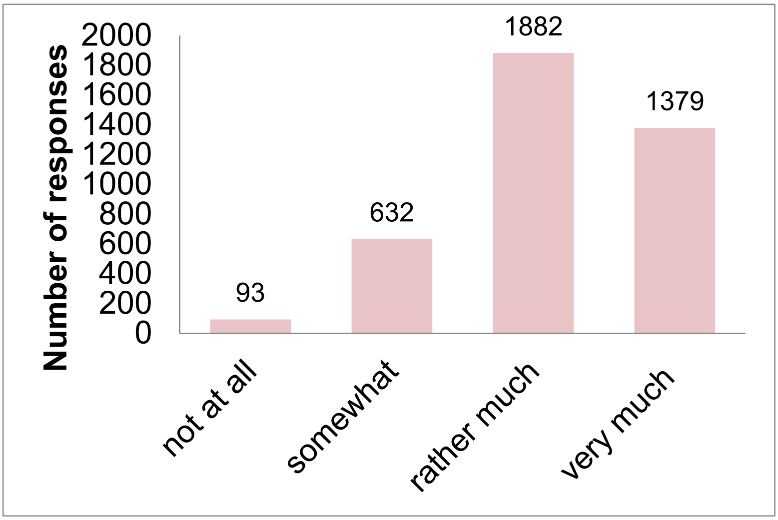

Figure 1.
Distribution of personnel answers to the question: Do you find that preschool noise affects the behaviour of the children?

As can be seen only a small proportion or 2.3 % reported that preschool noise had no effect on children's behaviour, while more than 81.8 % reported that preschool noise affected children's behaviour rather much or very much.

Table 1 reports on the number of word stems that were found among the free text given as a response to the question on whether preschool noise affected children's behaviour. It should be noted that both positive and negative answers could have been given, however only a handful of the answers indicated words that related to joyful behaviour and being so few they were not considered as a category of its own.

Table 1.
Identified word stems, number identified and the coded categories of the free text to the answers of the question: Do you find that preschool noise affects the behaviour of the children?

Identified word stems	Number	Coded categories
loud	3271	To be heard /vocal behaviour
voice	1534	
scream	1157	
to be heard	412	
overheard	353	
increase	768	
yell	159	
unfocus	990	Distracted behaviour
unconcentration	926	
stress	728	
worry, insecure	528	Unsafe feeling
sad	77	
several	129	Beeing in a crowd
many	114	
busy (rörigt)	175	
noisy (stimmigt)	63	
conflict	181	Agressive behaviour/acting out
fight	51	
acting out	32	
angry	25	
slow down	59	Withdrawal behaviour
go away, go quiet	58	
to be left alone	14	
restore	131	
tired	434	Being exhausted/fatigued

It can be seen that the word stem "loud" was the most frequently reported word stem, and was given by more than 3000 personnel. The category including "loud" describes vocal behaviour to be heard, such as scream, yell, use of voice, to be overheard and is the category reported by most personnel. Many personnel also report about unfocussed or unconcentrated behaviour and stress. Personnel also report with quite a variety of words how noise seem to be related to children being more busy, noisy and that children tend to crowd or be many at the same place. Emotional behaviour include both feeling unsafe, with most frequent word stems of worry, insecure, and sad, withdrawal behaviour with left alone, go away, go quiet, and aggressive behaviour with seeking of conflicts, acting out, aggressive behaviour. Finally there was a category of fatigue or exhaustion.

Discussion

The personnel perspective on how children's behaviour are affected by preschool noise displayed some clear and interesting patterns. First it is apparent that a vast majority of the personnel included in this study considers that preschool noise affects children's behaviour rather or very much. Being a cross sectional study, the direction or causality cannot be determined, and it is possible that children's behaviour per se drives the noise, as indicated by the free text describing noise being associated with children crowding and being noisy. Nevertheless, the majority of answers indicating that noise affects children and the descriptions reported, displays a more complex picture.

Vocal behaviour leading to loud sounds, screams, yelling with the intention to be heard seems to be the most often used or by the personnel most often noticed way of behaving when there is noise. Given the very high noise levels measured, in the range of 80-85 dB LAeq, this behaviour is understandable. The level of a relaxed speaking person would be in the range of 55-60 dBA at one meters distance, with increasing background level a person and most probably also a child tends to increase the voice, the so called Lombard effect (Lombard 1913). If the surrounding noise is in the range of 80-85 dBLAeq, a child would have to scream with more or less full effort to make itself heard and that is also what is being noted by the personnel under noisy conditions. It is possible that after a longer time in noisy settings children maintain this way of coping, also when the background noise level decreases. Accordingly, about 40% of parents, who were asked whether they experienced that their preschool children talked with a loud voice also at home reported this often or always (Persson Waye et al 2011).

The vocal behaviour, the acting out and aggressive behaviour may also be a way of gaining control over a situation that is experienced by the child as being out of control or chaotic. The personnel describes that noise makes children more unfocussed and less concentrated which could also add to this perceived chaos. The theory formulated in the model: "Living with own uncontrollability of sounds and noise" based on the child perspective was put forward in the earlier study (Dellve et al 2013). In such situations it may be natural to try and cope.

According to Wadsworth 2015, children during the toddler and preschool age progress from the infant coping behaviour including crying and seeking physical comfort to seeking help and avoidance of sources of stress. Interestingly seeking help is not mentioned by the personnel, but avoidance behaviour, with withdrawal and wanting to be left alone is reported. As children have less ability to anticipate, and understand stressors in general (Bistrup 2003) there is a risk that children functionally adapt to noise by maladaptive coping behaviour. We have today very little knowledge of how small children cope and its long term consequences for health and healthy coping behaviour, and longitudinal studies are urgently needed.

Conclusion

More than 80% of the preschool teachers regard that noise affects children's behaviour. The most dominant behaviour reported include vocal behaviour to be heard. Children are observed to loose concentration and become unfocussed, and seem to adopt several coping strategies involving both aggressive and withdrawal behaviour.

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The effects of noise on pupils in primary and secondary schools

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Introduction

Problems caused by noise and poor acoustic design of educational establishments have been recognised for well over 100 years, and guidance on how to prevent such problems have been published in book, articles and guidance documents since the 1930s [1].

The early recommendations were based upon the need to provide good speaking and listening conditions through control of background noise and reverberation, rather than concern about more direct effects of noise on pupils and teachers. However, since the early 1970s there has been an increasing body of research into the detrimental effects of noise and poor acoustic design on children's cognition and academic performance, as well as annoyance and distraction caused by noise in the classroom.

This article briefly summarises the findings of previous research investigating the impact of noise on pupils, and presents some summary results of a programme of research carried out in the UK. Further information about the research and more detailed results can be found in the cited papers.

Previous research

A comprehensive review of research published between 1968 and 2009, into the impact of noise on children at school, was published in 2010 [2]. This updated information presented in two earlier reviews of the 1990s [3,4].

The research shows that noise interferes directly with pupils' ability to hear and understand their teachers, distracts them from the task in hand, and also has a direct impact upon their academic performance. Types of noise which can cause problems in the classroom include external noise (for example, noise from road traffic or construction noise), internal noise from building services (for example from ventilation and heating systems), and noise from pupils and teaching activities, both within the classroom and from adjacent spaces.

The early research was largely focussed on the effects of environmental noise, particularly aircraft noise, on pupils. Noise from aircraft, road traffic and trains has been found to cause difficulties with hearing and understanding the teacher, and annoyance to pupils and teachers.

Children's attainments and performance in literacy and mathematics, as well as attention and memory, have been shown to be affected by environmental noise. Much of the research has involved studies in schools around airports, which have demonstrated that exposure to high levels of aircraft noise affect reading development and long term memory. Recent studies around airports in Europe have provided further evidence of the detrimental impact of aircraft noise on reading [5,6].

Thus there is comprehensive and consistent evidence of the impact of environmental noise, particularly aircraft noise, on children's academic performance but much less attention has been paid in the past to possible effects of internal noise in the classroom, especially the noise of irrelevant speech among pupils (general classroom 'babble'). Furthermore, past research concentrated mainly on the effects of noise on children in primary schools; there was little evidence concerning the response of pupils in secondary schools to noise and its impact on their performance. The research described in the following sections aimed to address those areas where there was less evidence of effects.

Effects of noise on pupils in primary and secondary schools in england

Since 1999 a programme of research has been carried out by acousticians at London South Bank University and Salford University, and psychologists at London University's Institute of Education, to investigate in detail pupils' perceptions of their acoustic environment in primary and secondary schools, and the effects of both environmental and classroom noise on their academic performance. Detailed noise and acoustic surveys were carried out of all the schools involved, and pupils' attitudes to noise and poor acoustics examined by questionnaire surveys. The effects of noise on children's attainments and academic performance were examined in two ways: by comparing noise levels with results of standardised testing (primary schools only) and by experimental testing of pupils in various subjects in different noise conditions (primary and secondary schools). The acoustic and noise data were compared with questionnaire responses and also used to inform the noise conditions that were used in the experimental testing of pupils.

Effects of noise on pupils in primary schools

External noise surveys were carried out at 142 primary schools in three London boroughs, and internal noise surveys were conducted in 16 of the schools [7]. The external surveys consisted of the measurement of five minute samples of noise outside each school during a typical period of the school day. Results of the external noise survey, with levels normalised to a distance of 4 metres from the school façade, are shown in Figure 1. Road traffic noise was present at over 85% of the schools surveyed, as would be expected of most school sites in London. At 65% of the schools external levels exceeded 55 dBA, the World Health Organisation guideline for noise outside schools.

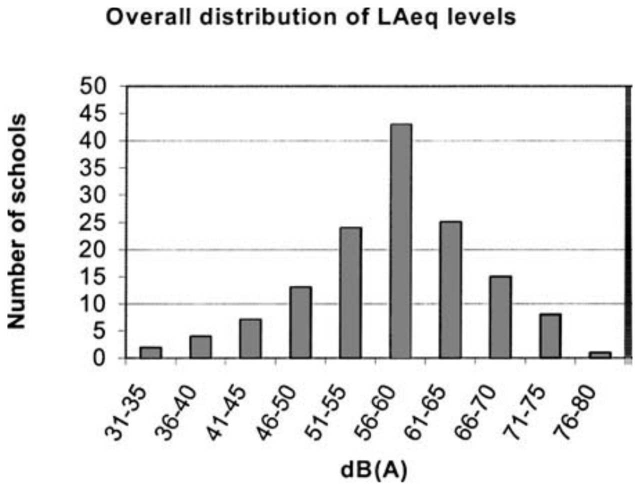


Figure 1.
Noise levels (L_{Aeq}) measured outside 142 primary schools in London

The internal noise surveys included measurements of noise during lessons in over 100 classrooms. Averaged internal levels in occupied classrooms ranged from 56 dB L_{Aeq} when children were engaged in a quiet activity, such as working in silence, doing a test or silent reading, to 77 dB L_{Aeq} when children were working in groups and moving around the classroom. The average level for the most typical activity, children sitting in groups working individually, was 65 dB L_{Aeq}.

Questionnaire survey

Over 2000 pupils aged 7 (Year 2) and 11 (Year 7) years of age, in 43 primary schools in_one of the London boroughs surveyed, responded to a questionnaire on noise. Questions concerned what noises the children heard while in the classroom; what noises annoyed them; and how easy it was to hear and understand their teacher in different classroom situations [8].

The results of the questionnaire survey were consistent with the noise survey in that the sound most commonly heard was that of road traffic (cars 71%; trucks 58%; motorbikes 56%). The sounds found most annoying, when heard by the children, were trains (60% of those who heard them were annoyed), motorbikes (60%), trucks (59%) and sirens (59%).

In general, the older children were more aware of external noise but were less annoyed by it than the younger children. The hearing of external sources was related to external background noise (L_{A90}) levels, whereas annoyance was related to external maximum (L_{Amax}) levels.

When asked how easy they found it to hear the teacher in different classroom situations, the younger children reported finding it more difficult than the older age group to hear what the teacher says in most situations. The ability to hear the teacher was related to external noise levels, the higher the level the less likely the children were to hear the teacher easily. The situation in which both age groups found it most difficult to hear was when other children were making noise outside their classroom.

Effects of noise on attainments and performance of primary school children

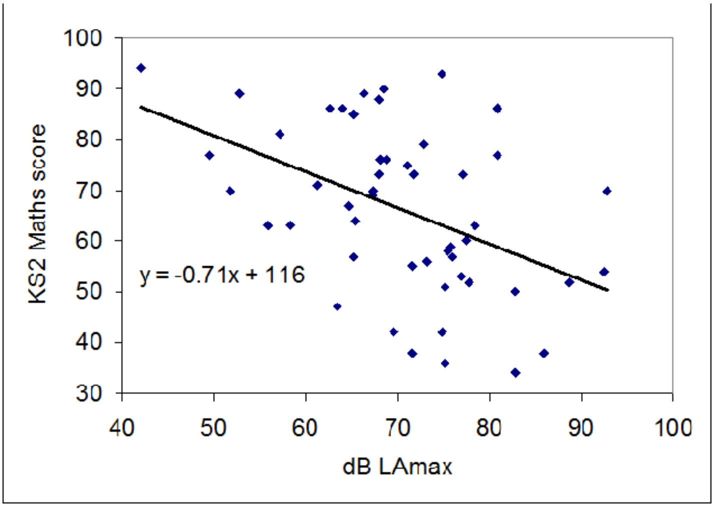
As discussed above, the effects of noise on primary school children's performance in various subjects was examined by comparing overall school results in national standardised assessment tests (SATs) with noise levels, and by experimental testing in two different noise conditions [9,10]

SATs

Primary school children in the UK take standardised national assessment tests (SATs) in literacy and numeracy at the ages of 7 ('Key Stage 1', KS1) and 11 ('Key Stage 2', KS2) Results for all schools are published annually by the Department for Education as, for each school, the percentages of pupils achieving a certain standard in each test. The noise levels measured inside and outside schools were compared with the SATs results for the relevant year.

Significant negative relationships were found between internal and external noise levels and all test scores, the relationships being stronger for the older pupils [9]. Test scores were related both to external maximum levels, which suggests that pupils are distracted by individual loud external events, and to background noise levels during lessons, suggesting that general classroom 'babble' affects a child's performance. To illustrate the relationship between SATs scores and noise, Figure 2 shows the relationship between external maximum noise levels (L_{Amax}) and KS2 mathematics scores, and background classroom noise levels (L_{A90}) and KS2 English scores.

a)



b)

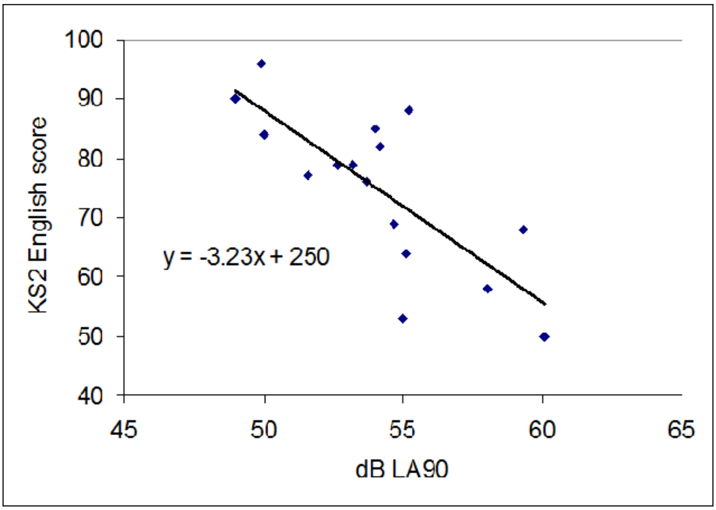


Figure 2.
Effects of noise on standardised test results: a) KS2 Mathematics scores v external maximum noise levels (L_{Amax}) b) KS2 English scores v background noise levels in occupied classrooms (L_{A90}).

Experimental testing

The above results were complemented by the results of experimental testing of children in different noise conditions [10]. Altogether, 158 Year 3 (8 years old) children from six classes in four schools, matched for external noise levels, were selected to participate in the tests. The children were tested in reading, spelling, arithmetic and speed of processing tests in quiet conditions and in simulated classroom babble. The babble was played at a level of 65 dB L_{Aeq}, which was the average level measured in occupied classrooms when children were sitting and working individually. Statistically significant differences were found between the pupils' performance in the quiet condition and in classroom babble, with the children performing less well in the babble condition in all tests.

Figure 3 illustrates the decreases in test scores in the babble condition, compared with the quiet condition, for the reading, spelling, arithmetic and speed of processing (score is number of correct items) tests. These support the findings of the SATs analysis above, showing that classroom noise has a detrimental impact upon the academic performance and attainments of children in primary schools [10].

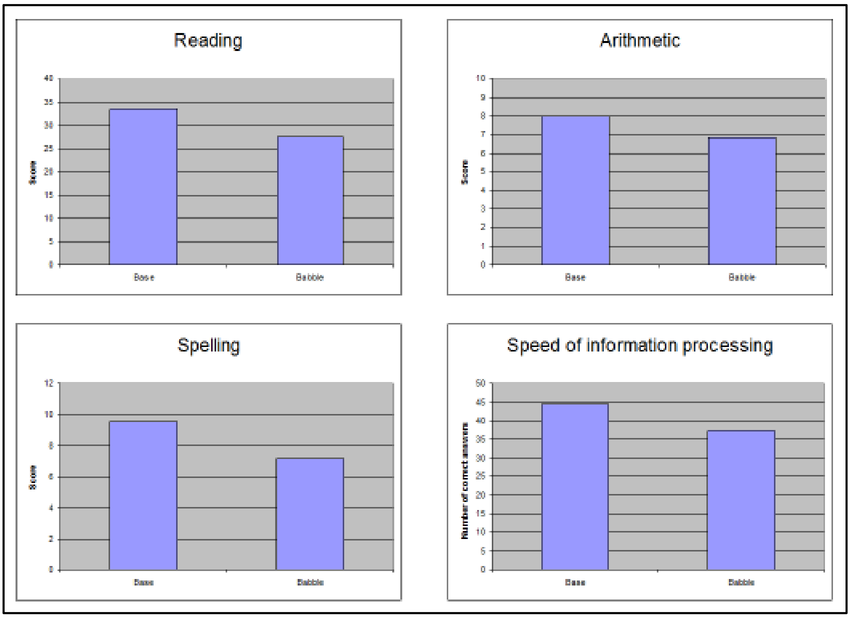


Figure 3.
Results of experimental testing: effects of classroom babble on performance of primary school children

Effects of noise on children with additional learning needs

The experimental testing provided an opportunity to study directly the impact of noise on children with additional learning needs. Around a quarter of the children who were tested had a recognised special educational need. It was found that those children were particularly affected by classroom babble in the spelling and reading tests. Figure 4 shows the scores of the children with special needs compared with the typically developing children in these two tests. It can be seen that the decrease in performance in noise, compared with the quiet condition, is much more marked for the children with special needs than it is for the other children. These results suggest that the children with special needs are differentially affected by noise, being less able to process language in the babble condition.

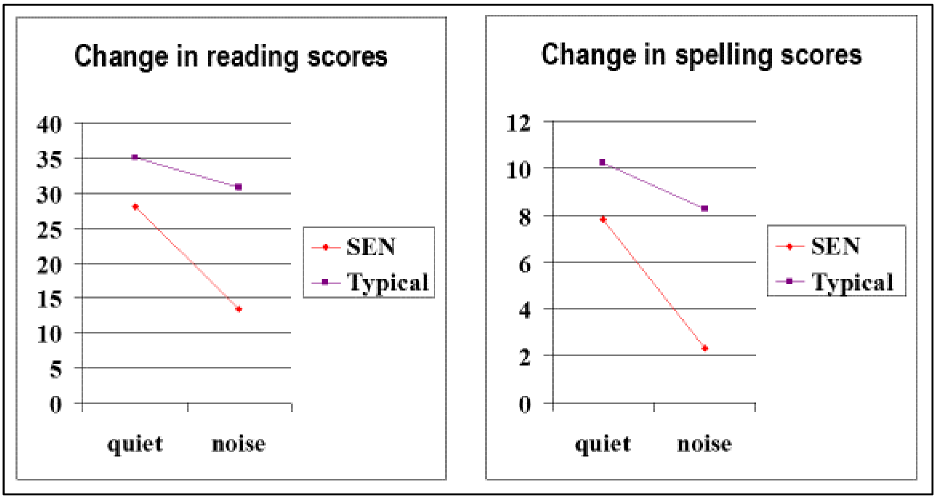


Figure 4.
Effects of classroom babble on primary school children with special needs

Secondary schools

Similar work to that in primary schools has been carried out in secondary schools in England, with noise and questionnaire surveys, and experimental testing of pupils in different noise conditions. Thirteen schools were selected to represent a range of locations (rural, suburban and urban) and sizes (from 500 to 1600 pupils). External noise levels were in general considerably lower than those at the

London primary schools, as would be expected, the only school exceeding the WHO guideline of 55 dBA for noise outside schools being the one urban school that was included. Noise levels were measured throughout 274 lessons in five core subjects (Mathematics, English, Science, Modern Foreign Languages, and Humanities). The average levels were very similar between subjects and, interestingly, the average level over all lessons and classrooms of 64 dBA L_{Aeq} agreed closely with the average level of 65 dBA measured in primary schools when pupils were working individually.

Questionnaire survey

A questionnaire on attitudes to noise was completed online by over 2500 pupils aged 11 to 16 in six of the selected schools. Questions related to four different aspects of noise: ease of hearing in different school spaces; annoyance caused by noise from different sources; consequences of noise during lessons; and sensitivity to noise. In general, the older pupils reported being more affected by noise than the younger students. Pupils in schools that were exposed to higher levels of external noise or that had open plan spaces, causing noise from students in other areas, reported more effects from noise [11].

The impact of noise on pupils with additional learning needs or other factors that might compromise hearing and learning in the classroom was examined separately, and compared with the responses of the other pupils. Of the respondents to the survey, 19% reported such factors including having English as an additional language, learning support or hearing impairment. The pupils who reported no challenges to hearing and learning were the least affected by noise in all four categories of effect, while those with a combination of two or more challenges were the most affected [11].

Experimental testing of pupils

Nearly 1000 pupils completed mathematics and reading tasks on laptops with classroom noise played at different levels (50 dBA, 64 dBA and 70 dBA) through headphones. Figures 5 and 6 show the results of different aspects of the mathematics and reading comprehension tests for the younger and older pupils, and overall, in noise at 50 and 70 dBA. It can be seen that, for all pupils, performance decreases in the higher noise level (although not all differences are statistically significant) and the noise tends to have more of an impact upon the older age group. In general noise at 64 dBA had less of an impact upon performance, but the older pupils were again more seriously affected than the younger age group. It therefore appears that noise at levels above 64 dBA affects students' academic performance with older (14-16 year old) students being more affected than younger (11-13 year old) ones [12, 13].

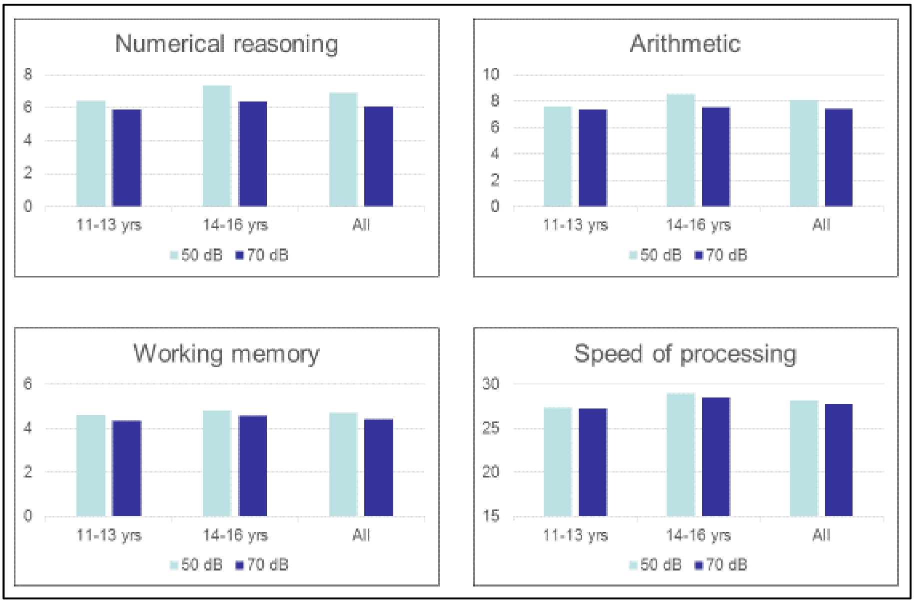


Figure 5.
Experimental testing of secondary school pupils: comparison of performance in mathematics test in noise at 50 dBA and 70 dBA

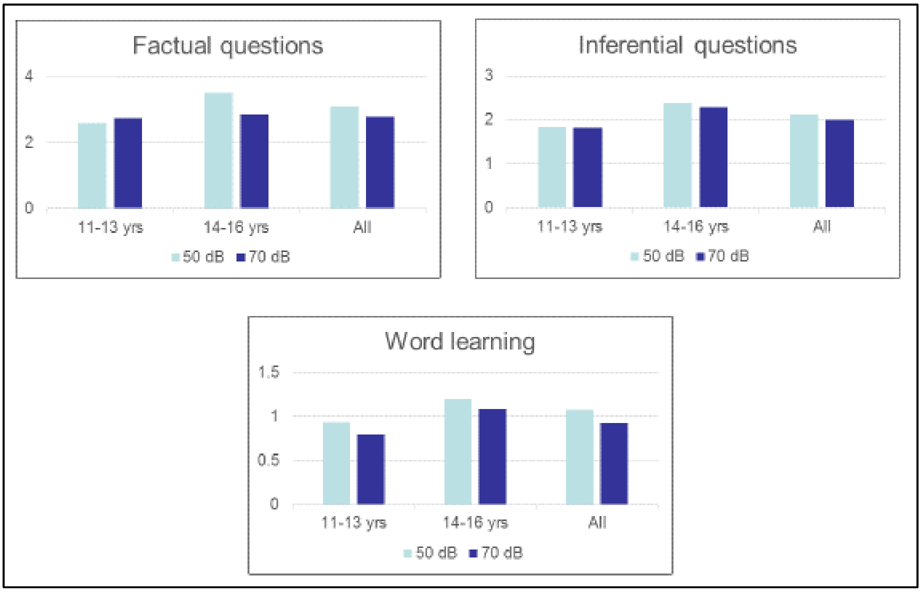


Figure 6.
Experimental testing of secondary school pupils: comparison of performance in English test in noise at 50 dBA and 70 dBA

Prevention of adverse effects of noise at school

Previous research plus the results described above show that noise in the classroom affects pupils of all ages, causing annoyance, distraction, and difficulty in hearing and understanding the teacher. Furthermore, it affects the academic performance and attainments of pupils.

These adverse effects of noise can be mitigated or prevented by attention to the acoustic design of school buildings. Many countries have introduced legislation, standards or guidelines relating to the acoustic design of schools. For example, in the UK good acoustic design of schools is now mandatory under the Building Regulations. Both new and refurbished school buildings must meet specifications for noise levels, reverberation and sound insulation. The specifications vary from space to space and are designed to ensure low levels of noise and good speech intelligibility, particularly in classrooms, to enable pupils to hear and understand their teachers and to reduce the detrimental effects of noise.

Conclusions

High levels of noise in schools can result from both external environmental noise sources, and from internally generated noise including general classroom activities and pupils' 'babble'. Research carried out since the 1960s now provides a large body of evidence which demonstrates the many adverse effects of high levels of noise in schools on pupils of all ages, and the particular vulnerability of children with additional learning needs. It is therefore essential to ensure that school buildings are designed, and measures introduced, to reduce noise in schools and to provide an optimal acoustic environment for teaching and learning.

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Room acoustics affects students and teachers

Jonas Christensson & Saint-Gobain Ecophon

Summary

For thousands of years we have lived outdoors and developed our senses in the outdoor environment. Hearing works very well outdoors where natural sounds from singing birds, gurgling sound from small streams, wind sound from the trees and human voices are common. The problem is that we spend the major part of our time indoors today, in an environment with very few natural sounds. This affects us a lot, especially pupils in the learning situation. Outdoors there are no hard flat parallel surfaces that reflect sounds. In the classrooms however, reflected sound is very common and this raises sound levels and deteriorates speech intelligibility. The effect is problems for students to understand what the teacher is saying and voice problems for teachers. Being able to listen without effort is important for good learning and we know that poor room acoustics is a burden that impedes learning. Therefore it's important that teaching spaces provide good speech intelligibility and good speech comfort. A good example is forests where we can talk to each other over long distances without having to raise our voice. I have made several listening tests in Swedish forests and also measured the sound reflections from trees and other reflecting surfaces. I have then compared the sound reflections in the forest with reflections in Swedish classrooms. The results are interesting and I mean that "forest acoustics" can be a source of inspiration for good classroom acoustics. When we talk and communicate we use consonants and vowels. Consonants carry a lot of information in most languages, therefore it is important that the room-reflections support consonants. Vowels, on the other hand, don´t carry information and need no support. My measurements show that "forest-rooms" support consonants but not vowels.

Introduction

Hearing works very well in the forest where natural sounds from singing birds, gurgling sound from small streams, wind sound from the trees and human voices are common. The problem is that we spend very little time in forests today. Instead we live in cities with many artificial sounds such as traffic noise and other manufactured sound. Another problem is that we spend the major part of our time indoors, in an environment with very few natural sounds. Spending so much time indoors affects us a lot, especially pupils in the learning situation. In Sweden we can very often read articles in newspapers about how bad the acoustic environment is in our educational premises. Many classrooms have poor room acoustics for modern teaching. Most rooms have a lot of sound reflections that raises the sound level and deteriorates the speech intelligibility. In recent years there have been several studies, reports and papers showing how the acoustic environment in Swedish schools affects students and teachers. HRF (Swedish association for hard of hearing people), published 2010 the report "Kakofonien"[1]. This report shows that 67% of the teachers say that the sound environment is a problem. 44% say they often find it difficult to talk and communicate in the classroom. Fredrik Sjödin shows in his thesis, "Noise in the preschool, Health and preventive measures" [2], that the acoustic environments in Swedish preschools are the most troublesome safety factor. A poor acoustic environment that masks speech impedes the educational work, and this is a big reason for illness among preschool staff. Teacher's voices are an important tool in teaching and Viveka Lyberg Åhlander thesis, "Voice use in teaching environments Speaker's comfort" [3], shows that Swedish teachers, more than others professionals, have voice problems. This leads to increased sickness absence with human suffering and huge costs. Robert Ljung shows in his thesis, "Room Acoustics and Cognitive Load When Listening to Speech" [4], what classroom acoustics affects student's ability to remember what they heard. This shows that ambitious teachers and motivated students' performance may be degraded by the acoustical properties in the classroom. My father, who worked as a teacher, in math and physics, all his life, got a hearing loss in old age. It gave him great trouble to hear and communicate, especially indoors. One summer my father and I were walking in a forest, and suddenly I noticed that he did not hear that badly. He told me that in forests, he could often hear and communicate quite well, but almost never indoors. – The only things I can hear indoors are vowels, and they carry very little information, he said. The information in speech is carried by the consonants. Rooms with poor room acoustics often reflect vowels, and this masks consonants and deteriorates the speech intelligibility. But in the forest, consonants are easy to hear because the masking vowels are not reflected. In the autumn same year, I was in a forest and tried to find mushrooms with my son, and then I noticed that he could hear what I said at long distance, even though I deliberately spoke with a low voice level. Swedish teachers often complain about the acoustic environment in classrooms, canteens and corridors. Instead of continuing to examine how bad the acoustic environment is in Swedish schools, I have tried to find schools with good acoustics for teaching and learning. I have asked Swedish teachers if they know any room or place with a good sound environment. Certainly there are Swedish schools with good acoustic environment, but the interesting response from teachers is that they often experience the best acoustic environment outdoors, in the forest. Therefore I have investigated how good the acoustic environment is in Swedish forests by making listening tests, and also measure the "room acoustics" in different forests.

Method

Since my son could hear my voice over long distances, I did a test to experience the speech intelligibility in the forest myself. I live in south Sweden were we have some nice forests far away from traffic roads, airports and railways, the only sounds that occur there are natural. I placed a loudspeaker on a stand in the forest. With an mp3-player, I played an audio book and checked that the sound level 1 meter in front of the loudspeaker was 60 dBA. This corresponds to normal speech level.

Picture 1.
Measuring sound level at 1 meter.

Then I took a chair and sat down 10 meters away from the loudspeaker and listened, I could easily hear and understand all words.

Picture 2.
Listening test in the forest, near the loudspeaker.

It turned out that I could sit up to 20 meters away from the loudspeaker and still understand what was said. Background sound level, created by natural sounds like bird songs and wind from trees varied between 30-35 dBA. I have done the same test with different people, and all of them are astonished about how easy it is to hear and understand a voice in the forest even when the loudspeaker is quite far away. Sweden have a sound classification standard for schools, SS 25268 [5], the verification of room acoustics is made by measuring the reverberation time according to EN ISO 3382-2 [6]. I have therefore made room acoustic measurements in some Swedish forests, and compared the result to the required values in SS 25268.

Picture 3.
Measuring impulse response in pine forest.

Picture 4.
Measuring impulse response in fir forest.

Picture 5.
Measuring impulse response in beech forest.

Result

I have measured the reverberation time (T_{20}) in different forest types like; pine, fir and beech. And I can see a pattern in the results. The typcal result is shown in figure 1.

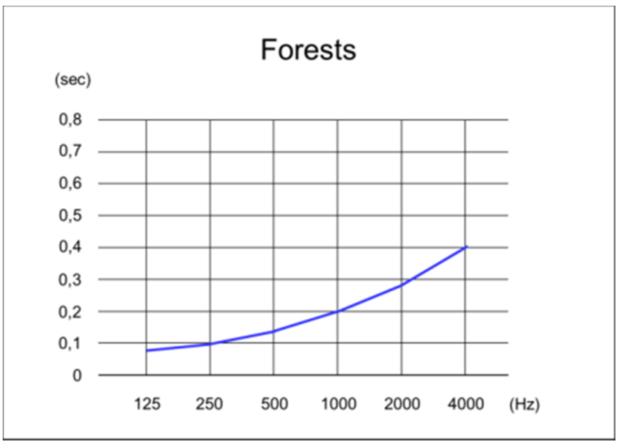


Figure 1.
Common RT in forests.

In forests there is a reverberance in the higher frequencies, but in the lower frequencies, especially at 125 Hz, there is almost no reverberance at all. In this environment the speech intelligibility is very good. Unfortunately this result is very unusual in Swedish classrooms. Very often the reverberation time in regular classrooms turns out to be like the red line in figure 2.

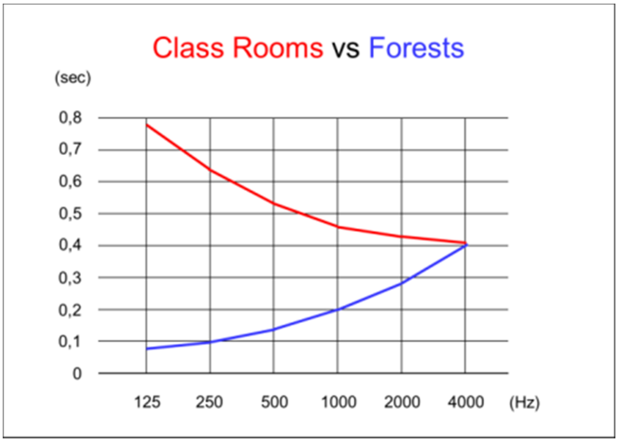


Figure 2.
Common RT in Classrooms and Forests.

In typical Swedish classrooms the reverberation time is longer in the lower frequencies compared to the higher. The "reverberation time-curve" in classrooms is reversed to the "reverberation time-curve" in the forest.

The Swedish sound classification standard for schools, SS 25268 put requirement on reverberation time at different sound classes, class A, B, C and D. Class A is the best and class C is the Swedish authority's requirement. The requirement in class C is shown with the dashed line in figure 3.

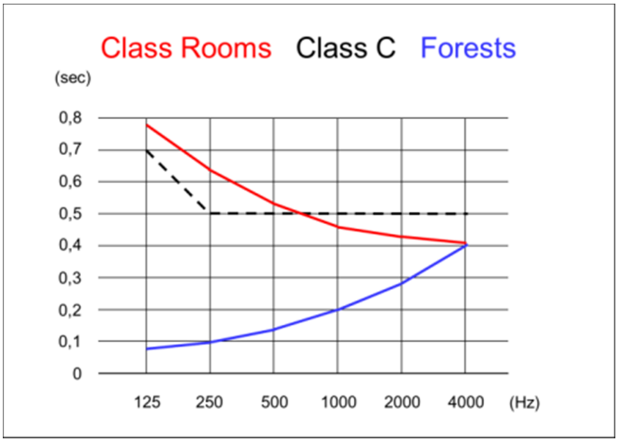
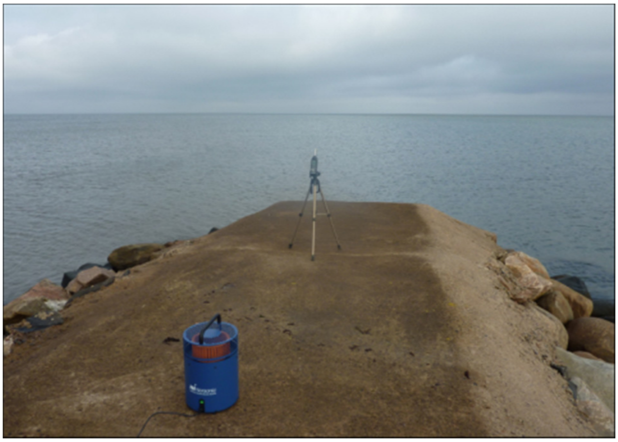


Figure 3.
Classroom, Sound class C and Forest.

Comparing the results in the forest (blue line), the classroom (red line), with the standard requirement (dashed line) there are some interesting differences. A typical Swedish classroom often fulfills the requirement in the standard above 1000 Hz, but in the lower frequencies the reverberation time is too long. One interesting thing about sound problems in Swedish classrooms is that very often teachers and pupils complain about high sound levels. A teacher explained it very good when she said: "*Outdoors the children talk with normal voice levels, but when we come indoors they start to shout because they need to hear themselves among all the sound. And since the room amplifies the sounds from active children, they start to shout."* This gave me the idea to measure how many decibels different rooms amplify the sound level. I took a sound source, with known sound effect, and placed it outdoors on a pier and measured the sound level at different distances (3-7 meters).



Picture 6.
Measuring the sound level on a pier.

Then I took the same sound source in to different rooms and measured the sound level.

Picture 7.
Measuring the sound level in a room.

By comparing the result between the room and the pier one could see how the reflections from the room (walls and celings) amplifies the sound level. This is a pedagogic way to explain for teachers and architects how different building materials and furniture affect the sound level. And all teachers know that when we put children in a room with a lot of sound, the pupils will raise their voices (the Lombard effect). The expected connection between a short RT and low sound level (low amplification) is not always fulfilled. I have compared 22 rooms and there is a strong connection between the amount of sound absorption in the room and the room amplification, where absorption lowers the amplification. This connection is not always found between sound absorption and reverberation time. One example is 2 rooms with the same measured T_{20}, but the room amplification was not the same. At the distance of 5 meters from the sound source, the sound pressure level was 3 dBA lower in one of the rooms. Despite that these rooms had the same reverberation time.

Conclusion

In a classroom with good acoustics it´s easy to hear what the teacher is saying. Poor room acoustics makes it difficult for the students to hear, listen, understand and remember what the teacher said. Having bad room acoustics in classrooms is an unnecessary cognitive burden and requires a lot of energy from the pupils just to listen, understand and remember. Being able to listen without effort is therefore a prerequisite for good learning. Speech intelligibility in the forest is very good, despite sound reflections in the higher frequencies. In almost all languages, the information in speech is carried by the consonants. Consonants are in the high frequencies, and vowels are in the low frequency range. Indoors, it is often a lot of reflections in the low frequencies, so the room amplifies the low frequency vowels which then mask the consonants, and this degrades speech intelligibility. In the forest however, there are no reflected vowels and therefore no masking of consonants. My experience is when people complain of poor acoustics in classrooms, it is very often because the room has too little absorption in the low frequencies. I mean that it´s the lack of reflected vowels that creates the excellent speech intelligibility in Swedish forests. I have studied some national European standards (guidelines) and notes that most of them allow a longer reverberation time in the lower frequencies in classrooms. Shouldn't it be the opposite in rooms where speech intelligibility is important? The problem in preschools is often high sound levels. How different rooms affects the sound level can be measured with G according to EN ISO 3382-1:2009 [7]. G is not easy to explain because the reference level for G is "10 meters away from the sound source in free field conditions". This reference level is hard to understand for a person with "normal" acoustic knowledge. To describe how different acoustic treatments in rooms affect the sound level I suggest that we use *room amplification*. Room amplification is a version of G but it is easier to understand for teachers and architects. My suggestion is to show how many dB the room amplifies at a distance of 5 meters from the sound source.

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Child & Noise

– How does the child percieve the sound environment?

An interdisciplinary symposium was held at Lund University in Sweden in march 2017 arranged by the Sound Environment Center aimed at shedding light on how sound environment affects children, spanning all the way from the prenatal stage to the young person enjoying loud music or engaging in other loud activities. Too seldom the question is asked of how the child percieves the surrounding sound environment.

This report from the Child & Noise symposium brings forward answers to this question as well as presents state-of-the-art knowledge of children and the world of sound, music and noise from top researchers in the field.

CHILD & NOISE – CONTRIBUTIONS

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