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Current perspectives on children's auditory perception and consequences of noise exposure effects

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ABSTRACT

Exposure to high sound pressure levels is well known to cause auditory damage, regardless of age. There is however limited knowledge of the effects on hearing due to noise exposure early in life. In addition, no well-established model is used to describe how children perceive and experience their sound environment compared to adults. New studies of children's hearing have revealed different directivity pattern especially at high frequencies given by the head-related transfer functions due to the anthropometric data of the children and also an ear canal resonance at considerable higher frequencies compared to adults. Recent studies also describe children feeling a great deal of discomfort when exposed to sounds with high frequency characteristics. Children today are exposed to high sound levels from an early age at preschool, school and during leisure time. Few studies have looked at general health effects or hearing in particular. It is being discussed whether age related hearing loss, regarded as an inevitable part of life, to a large extent may be caused by a lifetime of noise exposure starting early in life. This paper will review available studies on noise induced hearing damage among children and give suggestions for future studies within this field.

INTRODUCTION

Children today are exposed to high sound levels from an early age at preschool and later on in school and during leisure time when playing computer games and listening to portable music players. We see a lack of knowledge and research concerning the effects of this early exposure on the children. Moreover, there seems to be a lack of discussion regarding differences between children and adults concerning the current methods used to measure and assess e noise exposure as well as understanding of the possible differences in perception of the sound environment.

On the basis of a selection of studies on noise and young children' this paper will point to some knowledge gas that have hitherto been neglected We will try to describe aspects of acoustic transmission specifically for children and experiences reported by children. We will also try to discuss whether this has implications on risk of negative health effects of noise exposure on children that differs from the effects seen in adults. Finally we will give some suggestions for future studies needed within this field.

AUDITORY DEVELOPMENT

Anatomy and physiology of the auditory system gradually develops during the gestation period and after birth, both structurally and functionally. Prenatally the different parts of the auditory system develop simultaneously from different embryonic tissues. Around week 20 gestational age the system is developed to the point of being capable of yielding rudimentary hearing function. In week 34 gestational age the cochlea of the inner ear is considered to be developmentally complete. Unlike the structure of the inner ear the middle and outer ear continue to mature postnatally. For example the middle ear cavity will increase in volume until the late teenage years, which may influence the middle ear mechanics. The external ear canal will at birth be only about two thirds of the adult length and straight instead of the S-shape typically seen in adults. Maturation of ear-canal function probably extends at least to the onset of puberty. The neuromaturation of the auditory system also continues to develop postnatally. By the end of the first postnatal year the auditory brainstem neurons are approaching adult functioning, but auditory cortex will continue to develop gradually into the later teenage years. By then the progressive neural and cortical maturation probably explain the behavioral advances in auditory perception and integration. For example this maturation of the central auditory pathways results in an increasing ability to process speech under adverse listening conditions. Although it seems to be clear that infants and children undergo a developmental process in which proficiency in even basic psychoacoustic tasks improves as the child grows older, the underlying mechanisms and details in this process is still not entirely clear (Werner, Fey and Popper Ed., 2012).

HEAD-RELATED TRANSFER FUNCTION

As described in detail in Fels (2008), the growth dependency of head-related transfer functions (HRTFs) and ear canal impedances was investigated. The HRTFs play a major role when it comes to localize sound. Understanding speech in room under noisy conditions is coupled to the ear including the directivity pattern of the head. Previous investigations have shown a child as a receiver behaves and receives the sound different from adults. Figure 1 shows the magnitude of the HRTF of a typical adult head and child head, respectively, in the horizontal plane for the frequency range of 100 – 8000 Hz. The colorbar indicates the magnitude level in decibel. Figure 1 (right) shows an example of the differences in the spectral structure of the HRTFs of both heads. In the frequency range between 2 – 3.5 kHz and for frequencies above 5 kHz the differences exceed 10 dB. Interaural cues, such as Interaural Level and Time Difference (ILD and ITD) also differ accordingly.

Additionally, the ear canal impedance differs a lot from those of adults. The typical first resonance, which leads to the most sensitive frequencies of hearing, is at about 2.7 kHz for adults. For children, especially aged between 1.5 to 4 years of age the first resonance is shifted to higher frequencies due to the smaller ear canal.

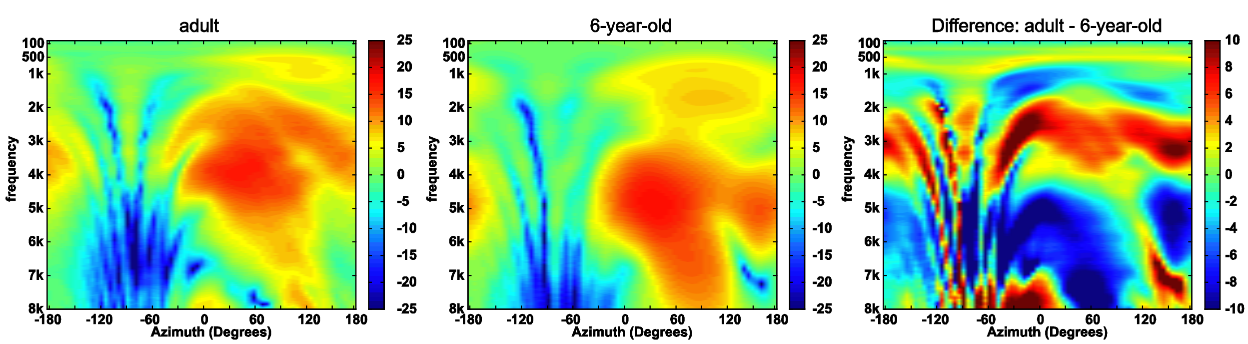

Figure 1. Magnitude of HRTFs in the horizontal plane for the adult and child head (cf. Fels 2008). The right plot shows the difference between the HRTFs of the adult and child head. The colorbars indicate the level in decibel.

In two previous studies Prodi et al. (2007) and Fels et al. (2007) understanding speech in a classroom was investigated using different receivers (microphones, children's dummy head, and adult dummy head). The effects on the speech perception are evaluated. It turned out that the Speech Transmission Index (STI) yields different results depending on the kind of receiver and situation. Thus, it is relevant to distinguish between children and adults when classroom acoustics need to be estimated.

NOISE EXPOSURE IN THE PRESCHOOL

Recent studies have shown that both children and personnel are exposed to high sound levels daily in the preschool. Many of the existing studies on noise measurements in schools have focused on noise from outdoor sources, such as traffic or aircraft noise (e.g. Hygge et al. 2002 & Stansfeld et al 2005) where cognitive effects of noise were studied. Measurements at pre-schools show typically that children and personnel are exposed to very high noise levels originating mainly from activity noise (e.g. children playing). Landström et al. (2003) reported average levels of 75-80dB LAeq from pre-schools in Sweden, Voss measured eight hour equivalent noise exposure levels of 80dB LAeq in daycare centers in Denmark, while Maxwell and Evans (2000) reported four hour LAeq levels of 76dB and peak levels of 96 dBC in pre-schools in the USA.Persson Waye et al. (2011) reported in addition to high noise levels from stationary measurements that children's exposure using portable dosimeters were 85 dB LAeq and 118dB LAFmax and significantly higher as compared to the personnel whose exposure on average was 77dB LAeq, and 108dB LAFmax. The reported measurements on children showed thus that the equivalent noise levels indoors in the preschool are at, or close to the permitted limit at 85 dBA Leq specified in the guidelines provided by the Swedish work environment authority (AFS 2005:16).

Due to the fact that the sound levels fluctuate a lot during the day in the preschool it is difficult to accurately assess the levels that children and personnel are exposed to. Figure 2 below demonstrates the sound levels during a typical day at the preschool. In accordance with this study Sjödin et al (2012) reported mean number of sound events with levels above 85 dB LAeq, to as many as over 100 events per hour in the afternoon in the preschool.

The work environment noise level regulations are designed to prevent hearing loss among the personnel after years of noise exposure. This regulation however does not to our knowledge in any country include the children in the preschool. The children might on one hand be considered more exposed, as they are often closer to the sound source (e.g. toys, their own and their pupil's activities). This might be reflected in the somewhat higher levels reported by Persson Waye et al. (2011) when measured on children, as opposed to Sjödin et al. (2012) where measurements where reported for the personnel.

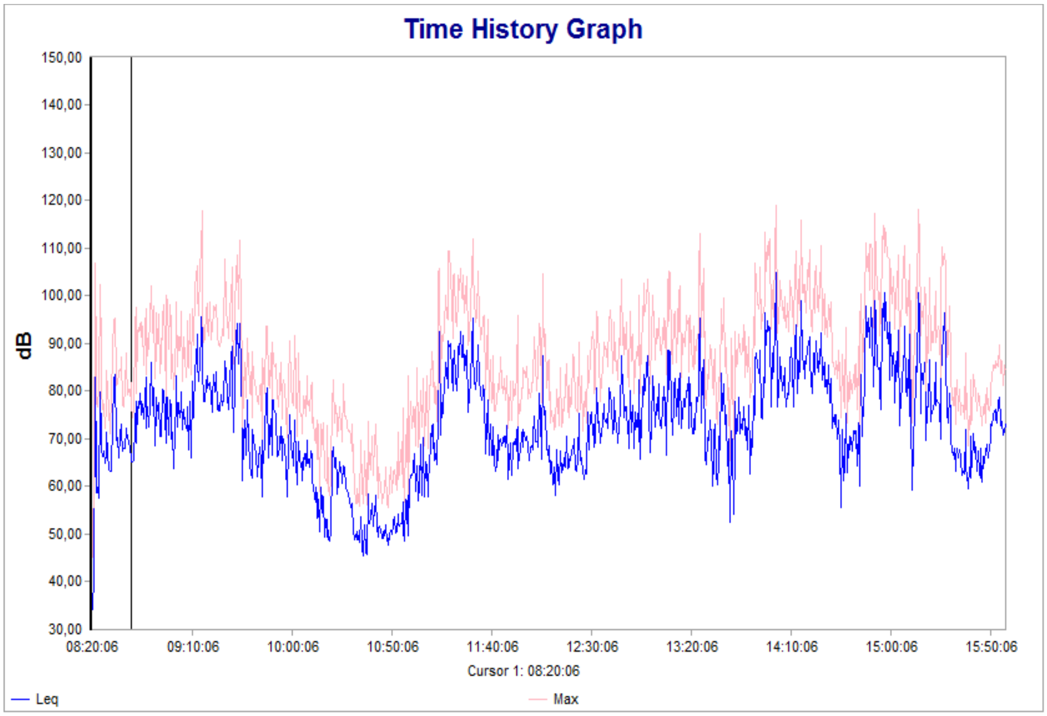

FIGURE 2. A typical day at the preschool. Sound level measurements (dBA) from dosimeters on a child wearing the microphone on a specially designed vest (Persson Waye et al. 2011).

PREVALENCE OF EFFECTS OF NOISE EXPOSURE

Exposure to high sound levels is well known to cause auditory damage, but most studies are focusing on adolescents and adults. There is no strong argument for why young children would not also be susceptible to auditory damage. The problem would rather be in the clinical assessment of hearing loss, since the standard psychoacoustic method used demands the participation of the child being tested.

Brookhouser et al. (1992) studied 114 children and adolescents (aged 19 and under) who were all referred to an otolaryngology/audiology clinic for evaluation after diagnosis of probable noise induced hearing loss (NIHL). The study thus does not represent a random sample of children. According to the authors, the diagnosis of NIHL in these cases were based on a history of noise exposure provided by the child, parents and other caregivers, as well as the absence of other plausible etiologies. Specific noise sources were identified and in almost half of the case histories impulse noises sources were reported. Audiometric results were analyzed for all the children; some showing a typical noise notch around 4 kHz. The authors also conclude, from a case report, that children as young as 14 months of age may suffer irreversible noise damage to their auditory acuity. It is not reported whether this particular case showed normal hearing prior to the incident reported, but the report may at least suggest that even very young children could also be affected by noise exposure.

There are also studies done on unselected groups of children. For example, Axelsson et al. (1987) reported the results of a longitudinal study among school children in Sweden born between the years 1968 - 1970. They found that hearing loss defined as a hearing threshold of 20 dB HL or worse measured by pure tone audiometry occurred among 12.8% of children at 7 years of age. Hearing loss increased with increasing age among boys from age 7 to 13, but not among girls. In a more recent cross-sectional study Niskar et al. (2001) studied data collected between the years 1988 – 1994 and reported that 12.5% of children between 6 - 19 years had noise-induced hearing loss in one or both ears, defined as a hearing loss at 3 - 6 kHz with a V-shaped audiometric configuration similar to a so-called "noise notch". Hearing loss was more common among boys than girls and more common in the ages 12 - 19 years compared to 6 - 11 years of age. In the younger age group the prevalence of hearing loss was still as high as 8.5%. Even more recently in a study from 2010, Shargorodsky et al. (2010) studied the same material as Niskar et al. (2001) compared to material collected in 2005-2006 and concluded that hearing in teens measured in 2005-2006 had poorer hearing than in 1988-1994. They showed an alarmingly high prevalence of hearing loss of 20%. Noise was considered as a possible etiology because of the fact that high-frequency loss dominated the sample. This result has been criticized by Schlauch and Carney (2012), who re-analyzed the material and propose that the prevalence of sensorineural high-frequency loss reported both by Niskar et al. and Shargorodsky et al. are probably much lower.

Among adults exposed to noise, temporary or permanent hearing loss is often accompanied by tinnitus. In a recent study Juul et al. (2012) a representative cross-sectional sample of 756 children 7 years old were interviewed and screened with pure-tone audiometry. The results shows that even young school-aged children experience both tinnitus ant impaired hearing after noise exposure. Since tinnitus is common among individuals with hearing loss, it is interesting to note that noise induced tinnitus among the children in this study was not affected by hearing loss.

PRE-SCHOOL CHILDREN’S EXPERIENCE AND UNDERSTANDING OF THEIR SOUND ENVIRONMENT

Population studies in Sweden among 4 and 12-year-old children highlight environmental noise as a main source for environmental stress (National board of health and welfare, 2005). Noise from other children’s activities at school or around home was experienced as most distressing. Previous studies have mainly focused on the effects of transportation noise on annoyance and school performance (e.g. Stansfeld, 2005; van Kempen et al, 2009), while reactions to noise from other children are studied to a lesser degree (Shield & Dockrell, 2008). Furthermore, only a handful of studies have dealt with how younger (preschool) children react and respond to noise (Voss, 2012; Maxwell & Evans, 2000). In order to learn more, we carried out a study where children described their experience, understanding and coping with sounds at pre-schools, applying focus group interviews (Dellve et al., 2013). Children related to their sound environment as uncontrollable. The uncontrollability was linked to the children being non-disturbed or distressed. Distressing sounds were experienced as physically and emotionally painful and examples of such sounds were screams or scraping and screeching sounds. In a subsequent study, we also found that a large proportion of the children, over 70%, used various coping strategies to avoid those sounds by occluding the ears (Persson Waye et al., submitted). Compared to adults, children seem to describe their reaction to noise in a somatic way; they literary feel the noise in their body, especially in the head, heart and tummy, with a prevalence varying between 15-20%. There were also some tendencies for the children to react strongly to sounds that were of predominantly high frequency characteristics.

DISCUSSION

Studies have shown that children’s daily environment in the preschool is comprised of high sound levels. Epidemiological studies indicate that children may suffer from auditory damage from noise exposure in the same way or similarly to adults. There is however no existing studies on auditory effects due to noise in children specifically looking at the preschool sound environment. Generally though, children in the preschool are regarded as more at risk than the adults since they play close together, sometimes with toys generating sudden high levels of noise. In addition to this, children often do not understand that they should avoid high sound levels or noise (Passchier-Vermeer, 2009; Evans et al., 1993; Segal et al., 2003). Evidence of an increased prevalence of noise related effects among children is not determined, but suggested as the view by many today is that children are exposed to larger extent today, especially when considering amount of time exposed. There is a lack of knowledge of whether exposure to high sound levels at an early age increases the risk of hearing loss in adulthood. But it is in fact being discussed whether age related hearing loss (presbyacusis), previously regarded as an inevitable part of life, to a large extent may be caused by a lifetime of noise exposure starting early in life.

And as can be seen from Fels studies, an increase of more than 10 dB is present in the average children's ear compared to the average adult. We do not know how much "more" physiological injury we should expected in children, but with this background in mind, children might be able to perceive higher sound levels compared to adults. Recent studies by Dellve et al. show that children do perceive distress due to the sound environment in the preschool and the results indicate that high-frequency sounds might be of particular interest. To what extent this distress causes an effect of general well being for the children should also be addressed more in detail.

When assessing noise levels the A-weighting is often used, which reflects human hearing not being equally sensitive to all frequencies. However the A-weighting is related to the equal loudness curve for sinoid tones and is only valid for adults. Since adults have a lower resonance frequency compared to children, the methods currently used in noise assessment might not correctly reflect the perception and the risk of children. It can be assumed that the equal loudness curves for children (especially for very young children 2-4 years of age) are different from those of adults. For higher SPL the dB(C) should be applied, or even better the whole spectrum should be considered. It would be interesting, although extremely difficult, to establish equal loudness curves for children.

To conclude, we want to stress the importance of looking at the sound environment, noise exposure assessment and its possible effects and implications from the children's point of view. Since there are some documented differences between children and adults both from a perceptual as well as an acoustic point of view, we should not simply assume that the theories and methods we use or the results we have seen in studies on adults are directly transferable to assessments regarding children. Research specifically looking at noise and children is therefore crucial.

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