WHAT IS NORMAL HEARING' IN PAEDIATRIC AUDIOLOGY

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Introduction

There is increasing awareness of the need for new reference data for paediatric audiometry against which disease states, and in particular ototoxic medications can be compared. International standards for hearing thresholds for air conduction (AC) audiometry in the conventional range of 0.125-8 kHz as a function of age and sex for otologically healthy persons have been published [1]. However, for age groups below 18 years no standard exists. In the extended high frequencies (EHF) (8- to 20-kHz), an official normative reference has yet to emerge, despite numerous studies demonstrating the benefits of monitoring EHF sensitivity in patients receiving ototoxic medications [2, 3]. The aim of the present study was to determine the normative response to air-conduction audiometry in the frequency range of 0.25 to 20 kHz and to compare thresholds between age groups and across gender.

Material and Methods

Subjects

Subjects were 90 children (39 male, 51 females) aged 4 to 17 years (median age 10 years). All subjects underwent a clinical interview to obtain relevant information and otoscopy to exclude visual evidence of ear disease. Ethical Committee approval was obtained for the study with informed consent obtained from each subject.

Procedures

Conventional Pure Tone Audiometry (CF) Air conduction thresholds for 0.25, 0.5, 1, 2, 4, and 8 kHz were measured using standard clinical pure tone audiometry [4].

Extended high frequency audiometry (EHF) EHF thresholds were established at intermediate frequencies between 9 and 20 kHz (9, 10, 11.2, 12.5, 14, 16, 18 and 20 kHz) using a modified Hughson-Westlake procedure [3].

Tympanometry A GSI-33 Middle Ear Analyser (Guymark, UK) was used for admittance screening with a single probe frequency of 226 Hz for both ears.

Statistical Analysis CF and EHF data were combined and analysed using a repeated measure ANOVA. Within subject factors were frequency (levels: 0.25, 0.5, 1, 2, 4, 8, 9, 10, 11.2, 12.5, 14, 16, 18, 20 kHz) and ear (levels: left, right). Between subject factors were gender and age (levels: 4-10 years, n=50; 11-17 years, n=40). Significance tests on within factors and interactions were made using the Greenhouse-Geissler correction for effects with significant Mauchly test for sphericity**.**

Results

All 90 subjects had normal middle ear function as determined by tympanometry on the day of testing and completed threshold tests at all frequencies for each ear. To obtain a rough estimate of the reliability of the threshold data, standard deviations of threshold were computed across subjects within two age groups (4-10 years, 11-17 year) at each frequency (0.25-20kHz). The results from each ear were pooled. As seen from Figure 1B, there was a systematic increase in standard deviation with frequency, from about 5 to 10 dB. This variability compares favourably, if not better, than previous reports [2]. Interestingly, the younger group performed no worse than the older group. Indeed we could find no evidence that 4-5 year-olds had more variability than 16-17 year-olds.

Conventional Pure Tone Audiometry All subjects completed threshold tests at all frequencies. Overall mean thresholds (ie. across ear and gender) are plotted in dB HL for the two age groups in Figure 2A. Thresholds were significantly elevated over standard hearing thresholds ($p<0.001$). Mean levels were 6.0 dB HL (95CI= 5.2-6.8) in the 4-10 age group and 6.2 dB HL (95CI = 5.3-7.2) for the 11-17 group; there was no significant difference between the age groups ($p=0.73$). These elevated thresholds also depended significantly on frequency ($p<0.001$), with a clear U-shaped function. For comparison, the means from the data published by Buren et al., (1992) [2] for the age range 10-18 are also plotted in Figure 2. As can be seen, there is a similar departure from 0 dB HL. We conclude, therefore, that children from 4-17 have thresholds that are significantly elevated above the assumed standard [2]. There was no significant main effect for age, gender, or ear. However, there was a strong statistical interaction between frequency and ear ($p<0.002$), which was due to an elevated threshold of the right ear over the left ear at 4 kHz. There were no other significant interactions.

Extended High Frequency Audiometry For EHF analysis was carried out in SPL for frequencies 9-20 kHz. Fig.1A shows the significant increase in threshold with frequency ($p<0.001$); error bars show the 95% confidence interval of the mean at each frequency. The standard deviation across all subjects at each frequency is plotted in figure 1B.There was a significant effect of age ($p<0.001$), with an interaction with frequency ($p<0.025$). To further explore the role of age, subjects were grouped into two-year categories (4-5, 6-7, … 16-17 years). A contrast to compare thresholds between adjacent age groups showed a significant increase between the age groups 12-13 and 14-15 years (~10 dB HL , $p<0.001$), but not between any other adjacent groups (see Fig.3). Interestingly, plotting gender separately revealed a distinct qualitative trend, with males showing an increase between the ages of 14/15 to 16/17, and females showing an earlier increase between 12/13 to 14/15 years, but followed by a decline in the 16/17 group (see Figure 3). However, the 3-way interaction between age, frequency and gender was not significant. The main effect of ear was also significant ($p<0.026$), with the right ear having higher threshold than the left. Overall, males had higher thresholds than females, but this effect did not reach significance ($p=0.1$). It was also clear that this gender difference tended to be more pronounced with increase in frequency, but this interaction was of borderline significance ($p<0.08$).

Discussion

In this paper we have clearly shown that in normal hearing children, audiometric thresholds significantly deviate from a reference normal of 0 dB HL over conventional frequencies (CF). This theoretical construct of a ‘normal hearing’ individual was originally based upon an adult population in whom the data was obtained over several centres with differing selection criteria, measuring conditions and differing references for normal hearing [2]. Therefore the value for comparative purposes is inherently limited when using such data in children. There was a strong statistical interaction between frequency and ear, which is due to an elevated threshold of the right ear over the left. Moreover, this interaction is particularly evident at high frequencies. Our data suggests that auditory thresholds should be analysed to account for potential ear differences.

At extended frequencies, age, ear, and possible gender effects become apparent. The results are not unlike those obtained by previous investigators who have shown that audiometric thresholds increased gradually as a function on frequency with the EHF threshold loss begins as early as around the 10 year stage [3]. Overall, males had higher thresholds than females, but this effect did not reach significance. It was also clear that this gender difference was most evident at high frequencies, but not significant. Interestingly, plotting gender separately revealed a distinct qualitative trend, with males showing an increase in threshold between the ages of 14/15 to 16/17, and females showing an earlier increase between 12/13 to 14/15 years, but followed by a decline in the 16/17 groups. This could be related to dissimilar noise exposure of the two sexes.

In summary, the significance of such behavioural data reported in this study suggests that in younger children, responses in conventional and high frequency audiometry are significantly influenced by age, gender and ear. As such, audiometric results should always be considered in relation to all these factors. These extended data should permit more enlightened interpretation of audiometric test results in children. In addition, international standards for audiometry need to be re-examined to include age, gender and ear effects in a population younger than 18 years old.

References

[1] International Organization for Standardization ISO 7029-1984. Acoustics – thresholds of hearing by air conduction as a function of age and sex for otologically normal persons.

[2] Buren M, Solem BS, Laukli E (1992) Threshold of hearing (0.125-20 kHz) in children and youngsters. British Journal of Audiology, 26: 23-31.

[3] Stelmacowicz PG, Beauchaine KA, Kalberer A, Jesteadt W (1989) Normative thresholds in the 8-to 20-kHz range as a function of age. JASA, 86: 1384-1391.

[4] British Society of Audiology (2004). Recommended procedure for pure tone audiometry using a manually operated instrument. British Society of Audiology.

Figures mentioned aboved:

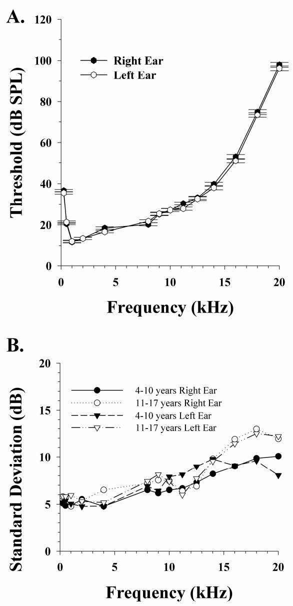

Figure 1. A. Mean (±SEM) air conduction hearing thresholds for the right and left ears in the conventional and extended high frequency range for the normal group (n=90) in dB SPL; error bars show the 95% confidence interval of the mean at each frequency.

B. The standard deviation across all subjects in two age groups (4-10 years; 11-17) at each frequency is plotted. Note the dB SPL calibration in this frequency range.

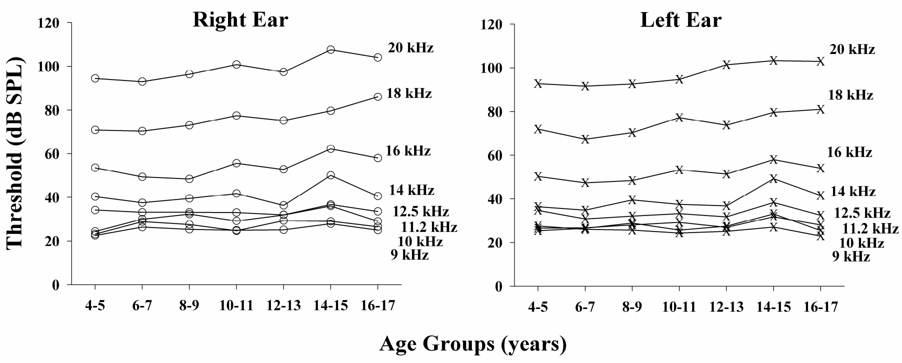

Figure 2. *Conventional air conduction thresholds (0.25-8 kHz) in two age groups (4-10 years; 11-17 years) are compared with earlier data published by Buren et al., (1992). A similar comparison is shown at the extended high frequencies (in dB SPL). In both sets of data, thresholds are significantly elevated above the assumed reference standard (ISO 389, 1985).*

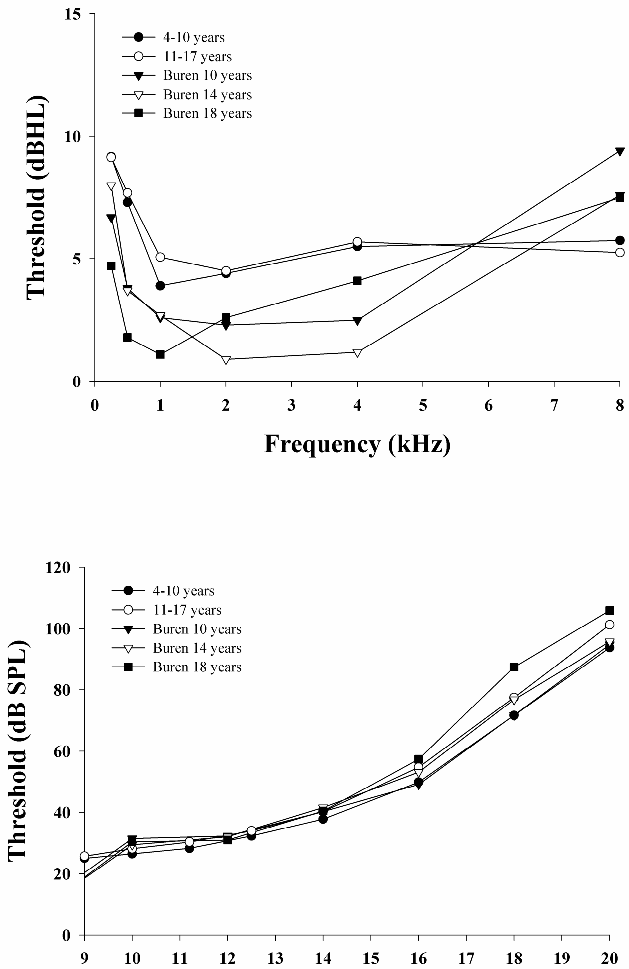

Figure 3. *Mean thresholds for the seven age groups for both males (top panel) and females (bottom panel). Overall, males had higher thresholds than females, this gender difference was most evident at high frequencies, but this effect did not reach significance.*