HEARING THRESHOLDS OF OTOLOGICALLY HEALTHY 18-YEAR-OLDS

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Abstract

Objective: To determine mean hearing thresholds for 18-year-old, otologically healthy subjects.

Study design: Prospective historical cohort study.

Methods: As part of a follow-up study of a birth cohort, followed from age 2 to 18 years, meticulous otological examination including history-taking, otoscopy, and audiometry were available. At age 18, both air-conduction thresholds (0.25 kHz to 8 kHz and 8 kHz to 16 kHz) and bone-conduction thresholds (0.5 kHz to 4 kHz) were measured. Subjects of this cohort were defined as otologically healthy if they had not experienced substantial otitis media in childhood.

Results: On both ends of the frequency range of air-conduction testing, measured thresholds deviated statistically significantly from the ISO 389 reference zero. The air-conduction thresholds were comparable to data presented in the literature. Furthermore, a misfit with the ISO 389 reference was found at 2 and 3 kHz for bone-conduction testing. Only the mean bone-conduction thresholds at 0.5 kHz and 4 kHz were not significantly different from the ISO 389 reference zero. To explain the deviations at high frequencies, noise exposure was considered but thought unlikely.

Conclusions: This study cohort seems to be the best representative sample so far of otologically healthy subjects due to the longitudinal study of their otological status. Mean hearing thresholds at age 18 are different from the ISO 389 reference zero, suggesting once more the need to revise this ISO norm.

Key words: bone-conduction thresholds • air-conduction thresholds • norms • ISO 389 • adolescents • cohort study

СЛУХ ОТОЛОГИЧЕСКИ ЗДОРОВЫХ МОЛОДЫХ ЛЮДЕЙ В ВОЗРАСТЕ 18 ЛЕТ

Резюме

Цель: Определить средний порог слышимости для 18 летних отологически здоровых людей.

Проект исследования: Историческое когортное проспективное исследование

Методы: Тщательные отологические исследования, включая сбор анамнеза, отоскопию и аудиометрию, были доступны как часть дополнительного исследования когорты рождения, проведенное от 2 до 18 лет. В возрасте 18 лет были измерены оба порога воздушной (0.25 кГц до 8 кГц и 8 кГц до 16 кГц) и костной проводимости (0.5 кГц до 4 кГц). Субъекты этой когорты были определены отологически здоровыми, поскольку у нех не было существенного среднего отита в детстве.

Результаты: На обоих концах диапазона частот при тестировании воздушной проводимости измеренные пороги имели статистически значительные отклонения от стандартного относительного нуля ISO 389. Пороги воздушной проводимости были сопоставимы данным, представленным в литературе. Кроме того, несоответствие с эталоном ISO 389 было найдено на 2 и 3 кГц при тестировании костной проводимости. Только средние пороги костной проводимости на 0.5 кГц и 4 кГц значительно не отличались от стандартного относительного нуля ISO 389. При объяснении отклонений на высоких частотах были учтены шумовые загрязнения, которые скорее не имели сильного влияния.

Заключения: Данная когорта исследования правдоподобно до сих пор является самой лучшей репрезентативной пробой отологически здоровых субъектов благодаря продолжительному исследованию их отологического состояния. Средние пороги слышимости в возрасте 18 лет отличаются от стандартного относительного нуля ISO 389, поэтому еще раз предлагается пересмотреть данную норму ISO.

Ключевые слова: Пороги костной проводимости • пороги воздушной проводимости • нормы • ISO 389 • подростки • исследование когорты

AUDICIÓN DE LOS JÓVENES DE 18 AÑOS DE EDAD OTOLÓGICAMENTE SANOS

Abstracto

Objetivo: determinar los umbrales de audición medios de personas de 18 años de edad sanos desde el punto de vista otológico.

Diseño del estudio: Estudio de cohorte prospectivo histórico.

Métodos: Fueron disponibles los examenes meticulosos de otología incluyendo anamnesis, otoscopía y audiometría como la parte de un estudio complementario de una cohorte de nacimiento de 2 a 18 años. A la edad de 18 años, tanto los umbrales de conducción del aire (de 0.25 kHz a 8 kHz y de 8 kHz a 16 kHz) como los umbrales de conducción del hueso (de 0.5 kHz a 4 kHz) fueron medidos. Los sujetos de esta cohorte fueron definidos como otológicamente sanos, ya que no habían tenido otitis media sustancial en la infancia.

Resultados: En ambos extremos de la gama de frecuencia de las pruebas de conducción de aire los umbrales medidos mostraron desviación estadísticamente significativa de cero de referencia de ISO 389. Los umbrales de conducción de aire fueron comparables a los datos presentados en la literatura. Por otra parte, una disparidad con la referencia de ISO 389 fue encontrada en 2 y 3 kHz durante las pruebas de conducción del hueso. Sólo los umbrales de conducción del hueso medios en 0.5 kHz y 4 kHz no eran significamente diferentes de cero de referencia de ISO 389. Fue considerada la exposición del ruido para explicar las desviaciones en las frecuencias altas, pero no fue significativa.

Conclusiones: En este momento este estudio de cohorte parece ser la mejor muestra representativa de sujetos otológicamente sanos gracias a la continuación longitudinal de su estado otológico. Los umbrales de audición medios en la edad de 18 años son diferentes de cero de referencia de ISO 389, lo que sugiere una vez más la necesidad de revisar esta norma de ISO.

Palabras claves: umbrales de conducción del hueso • umbrales de conducción del aire • normas • ISO 389 • adolescentes • estudio de cohorte

Background

During the 1960s, the International Organization of Standardization (ISO) formulated a reference zero for the calibration of audiometric equipment (ISO 389R, 1964). The ISO norms for air-conduction audiometry were based on several studies of otologically healthy subjects from different countries. However, there was significant spread in the data (as discussed in Lutman and Davis (1994) and Buren et al. (1992). In the 1990s, several studies were published showing that mean air-conduction thresholds in young adults did not conform to the calibration guidelines, especially at 0.25 and 0.5 kHz, and at 6 and 8 kHz (Buren et al., 1992; Lutman and Davis, 1994; Axelsson et al., 1994; Smith et al., 1999; Rahko-Laitila et al., 2001). However, these studies also showed significant variability. Several causes have been suggested for the spread between studies: subject selection (did the included subjects constitute a representative sample?); small sample sizes; exclusion criteria (how was 'otologically healthy' defined?); as well as the precise audiometric procedures used in each case. Any study group that is assembled to make a proper evaluation of hearing thresholds is supposed to form a representative sample from which a subgroup with otologically healthy ears can be drawn. Otologically healthy ears might be defined as ears with a history of no signs or symptoms of middle ear disease and no exposure to excessive noise. Working along these lines, Lutman and Davis (1994) and Smith et al. (1999) used extensive questionnaires to select otologically healthy subjects from representative groups of young adults. Although retrospective snap-shot questionnaires might be helpful, the outcomes are not always reliable with respect to ear problems during childhood. For instance, Buren et al. (1992) excluded all patients with any sign of present or past ear disease; they were excluded only on the grounds of otoscopic findings. However, their study group of adolescents was comprised of subjects from a senior high school; thus, it was not necessarily a representative sample. Rahko-Laitila et al. (2001) did study a large representative subgroup. Since childhood, these subjects were followed up longitudinally with regard to their middle ear status. Their selection of otologically healthy subjects was based upon otoscopic and tympanometric findings. They did not take any history of noise exposure into account.

The cited studies all show that the mean hearing thresholds were poorer than the ISO 389 reference zero, especially at the low and high frequencies; the poorest results were recorded at 6 kHz. Variability in the published data might indeed be ascribed to subject selection and the definition of otological health. Thus, there is still a need for normative baseline data.

The aim of the present study is to test the validity of the reference zero formulated by ISO 389 for air- and bone-conduction thresholds at the conventional frequencies as well as to add data to establish (the still non-existing) norms for high-frequency thresholds (8 to 16 kHz). This aim was pursued by measuring hearing thresholds in a relatively large representative sample of young adults with a prospectively recorded otitis-free history.

Population and Methods

The adolescents enrolled in this study participated in OME (Otitis Media with Effusion) studies that were conducted in the 1980s and 1990s (Zielhuis et al., 1989; Schilder et al., 1995) All of the subjects were born between September 1, 1982 and August 31, 1984 in Nijmegen, The Netherlands. The ear-related morbidity of the subjects was recorded from birth onwards. They were examined otologically and audiometrically from age 2 to 4 years (every 3 months) and again when 8 years old. Their status prior to these examinations was assessed by means of extensive questionnaires on the occurrence and treatment of ear diseases and hearing disorders. On the basis of data on their previous status, an Otitis Media (OM) score was calculated (range 0 to 200). In the calculations, otalgia with fever or an occurrence of otorrhea was classified as acute otitis media, while a flat (type B) tympanogram was classified as otitis media with effusion. The calculation of this OM score has been described in a previous report (de Beer et al., 2003). More than half of the subjects selected for inclusion in the present analysis had an OM score of zero, while 90% had a score below 11. The maximum score in this subgroup was 21. In other words, the study group comprised 175 otologically healthy subjects, viz. 75 male and 100 female adolescents. They were re-evaluated at age 18 years. These adolescents also participated in a parallel study on the effect of noise exposure on their hearing thresholds (de Beer et al., 2003).

Otomicroscopy, tympanometry, and pure-tone audiometry were performed in every young adult enrolled in the study. Otomicroscopy was performed by the first author. Minor abnormalities in the appearance of the tympanic membrane did not constitute a reason for exclusion. Next, audiometric measurements were carried out according to the terms of ISO 8253 (ISO 8253-1, 1989) at the Audiological Center of the University Medical Center, Nijmegen. All subjects were examined in one of two identical double-walled soundproof booths that met all the requirements of the ISO 8253-1 norm. The persons who performed the audiometric measurements were qualified audiometricians.

Pure-tone audiometry was performed with the Interacoustic AC 40 audiometer (Interacoustics, Assens, Denmark), combined with the TDH 39P headphone (Telephonics, Huntington, New York) for air-conduction measurements, the B71 transducer for bone-conduction examinations, and the Koss HV/1a headphone (Koss Corp., Milwaukee, Wisconsin) for extended high-frequency testing. Prior to the start of the study, the audiometers were precisely calibrated according to ISO 389 standards (ISO 389-2, 1994; ISO 389-3, 1994; ISO 389-1, 1998; ISO/TR 389-5, 1998).

Air-conduction thresholds were determined in both ears for the frequencies 0.25 kHz to 8 kHz, including 3 and 6 kHz. In principle, assuming symmetric hearing thresholds, bone-conduction thresholds were determined in only one ear, at 0.5 kHz, 1, 2, 3, and 4 kHz. Thresholds at 6 and 8 kHz were measured but not included, because at these frequencies the sounds radiated by the B71 transducer might be audible via airborne stimulation (Lightfoot and Hughes, 1993). If at any frequency the air-conduction threshold exceeded the bone-conduction threshold by 10 dB hearing level (HL), bone-conduction thresholds were measured in both ears with standard masking techniques. Neither bone-conduction thresholds nor air-conduction thresholds were adapted when a negative air–bone gap was found (Barry, 1994). Finally, air-conduction thresholds in the high-frequency range (8, 12, and 16 kHz) were measured with the Koss HV/1a headphones and expressed in dB sound pressure level (SPL). Throughout the entire study, the right ear was examined first in all subjects.

Acoustic admittance measures of the middle ear were obtained with a Tymp87 Middle Ear Analyzer (Danplex, Copenhagen, Denmark) using a 226 Hz probe tone. The pump speed was 200 daPa/s, and the pressure was swept from +200 to −400 daPa. Acoustic reflex measurements were performed at the subject's peak middle ear pressure, usually at atmospheric pressure. The contralateral acoustic reflex threshold at 1 kHz was measured starting with an 80 dB SPL stimulus. If the reflex was not present, the presentation level was increased in steps of 5 dB up to 110 dB SPL. If the reflex was present at 80 dB SPL stimulation, the stimulus level was decreased.

Levels of noise exposure were determined by means of an extended questionnaire and an experiment with volume settings, described before (de Beer et al., 2003). In short, these data covered the duration of exposure to loud sounds. The participants were questioned about any exposure to (loud) occupational noise and various sources of music exposure: listening to a personal stereo device; going to discotheques, rock concerts, or dance parties; and working as a disc jockey or stage technician. Furthermore, they were asked about the volume settings they selected when listening to their personal stereo devices. These settings were measured in a trial run by attaching a volume detector to the devices. This study did not show any statistically significant relation between noise exposure and (frequency-specific) hearing thresholds (de Beer et al., 2003).

All computations were performed using SAS statistical software (version 6.12; SAS, Cary, North Carolina). The standard error was calculated where appropriate. In addition to the calculated means, medians, and standard deviations (SD), we also took the minimum and maximum values of both air-conduction and bone-conduction thresholds into account. All data presented here pertain to the right or left ear within an individual. Significance level was set at 0.05. Whenever more than one test was carried out, a Bonferroni correction was applied to adjust the significance level.

Results

Health status of the subjects

Only two subjects had two documented episodes of a bilaterally flat tympanogram before they were 8 years old. The rest had either not experienced (documented) OME or had had only one episode by that time. The parents of 35 subjects reported one (documented) event of otalgia with fever during the same period. All others reported no acute otitis media (AOM) episodes before the age of 8. No participant in this subpopulation had experienced OME or AOM between 8 and 18 years of age.

When assessed at 18 years of age, only four of the subjects showed tympanic membrane abnormalities. Slight myringosclerosis was found in five of their ears. The severity of the myringosclerosis was considered slight when the sclerotic plaque covered less than one quadrant of the tympanic membrane.

Tympanometry showed that over 98% (n=344) of the ears had a normal type A tympanogram. Three individuals had a one-sided negative middle ear pressure (type C tympanogram). In one individual, the pressure was negative on both sides. The mean static admittance was 0.82 cm^3, with 90% range values between 0.37 and 1.66 cm^3. The acoustic reflex measurements were carried out successfully in 174 right ears and 171 left ears. Any missing values were due to problems with the equipment. The mean acoustic reflex threshold was 86 dB SPL, with a standard deviation of ±8 dB. The reflex was considered absent when no reflex could be detected at the highest stimulation level used of 110 dB SPL. This happened in 2% of the ears.

Audiometry

Table 1 shows the mean air-conduction thresholds, standard deviations, median, minimum, and maximum values for the right and left ear separately. The data for both sexes has been combined, as there was hardly any difference between the outcomes for males and females. Only in the air-conduction thresholds at 3 and 4 kHz was there a statistically significant difference in favor of females (t-test). For the frequencies of 1 to 4 kHz, mean values for either ear were relatively close to zero; however, the mean hearing thresholds for 0.25 kHz, 6 kHz, and 8 kHz were not. Particularly at 6 kHz, the mean value was highly deviant from zero. Statistical analysis showed that the mean air-conduction thresholds (per frequency and per ear) were significantly different from the ISO 389 reference zero values, except at 1.0 and 3.0 kHz in both ears and at 4 kHz for the right ear (t-test). Figure 1 shows the mean value of air-conduction hearing thresholds, not only as observed in the present study but also as reported in comparable sources in the literature. To enable a proper comparison with the literature data, we had to average the hearing thresholds of the left and right ears.

Table 1 also presents the data of high-frequency audiometry (8 to 16 kHz). ISO norms for high-frequency audiometry are not yet available. Figure 2 shows the mean hearing thresholds, again after averaging the data of the right and left ear for purposes of comparison. The figure shows that our data fall well within the range of the data taken from the literature. Nevertheless, there is some variation between the studies.

Table 2 presents the bone-conduction threshold data for either ear. The mean bone-conduction thresholds at 2 kHz and 3 kHz for the left and right ear diverge from the ISO 389-3 norm (ISO 389-3, 1994) (t-test). The mean value after averaging the right and left ear is depicted in Figure 3, along with comparable data from the literature.

Discussion

The aim of the present study was to measure hearing thresholds for air- and bone-conduction, obtained from a unique representative group of young adults who were otologically healthy, as prospectively recorded. Exactly 175 subjects were followed from childhood to adulthood. This group was followed with respect to frequent history-taking, otomicroscopy, acoustic admittance measurements, and audiometric measurements. By age 18, the tympanic membrane in 99% of the ears of these subjects had a completely normal appearance. Their tympanograms showed maximum deflection at ambient pressure. A normally elicitable acoustic reflex was found in 98% of the subjects. A parallel study showed that an effect of noise exposure on hearing thresholds could not be established (de Beer et al., 2003). We cannot definitively rule out any effect of exposure to noise, but it is unlikely.

In short, these subjects have a practically otitis-free history, normal admittance and acoustic reflex measures, and no substantial noise exposure. Our evaluation of their status constitutes the maximum obtainable proof that they represent an otologically healthy population sample. Therefore, the present subjects form an excellent group for reevaluating the ISO389 reference zero norms and to add data to the literature to establish an ISO norm for high-frequency audiometry.

Audiometry

Table 1 and Figure 1 show that the air-conduction thresholds measured in otologically healthy 18-year-olds approach the ISO 389 reference zero values only for the mid-frequencies of the conventional frequency range. However, this does not hold true for the 0.25 and 0.5 kHz at one end of the spectrum and 6 and 8 kHz at the other end. This observation seems to corroborate the general picture presented in the literature (see Figure 1). That mismatch is undesirable, particularly since noise exposure might affect hearing in the high-frequency range. A dip at 6 kHz could easily be interpreted as a sign of noise-induced hearing loss (Axelsson et al., 1994). A dip at 6 kHz was not reported by Smith et al. (1999) (see Figure 1). Nor did it occur in the data of Buren et al. (1992). The hearing threshold at 6 kHz, found by Smith et al. (1999), was the lowest of all. As discussed in their publication, this finding was unexpected. It was not in agreement with earlier findings by the same group (Lutman and Davis, 1994). In that earlier report, Lutman and Davis reported a significant dip at 6 kHz. According to Smith et al., the discrepancy between the results of their two studies was caused by differences

Table 1A. Air conduction thresholds in otologically healthy subjects, right ear.

Frequency, kHz	Air Conduction dB HL				
	Mean	SD	Minimum	Median	Maximum
0.25	5.2	6.0	–10	5	30
0.50	2.5	4.8	–5	0	20
1.0	0.7	4.5	–10	0	15
2.0	1.2	5.6	–10	0	25
3.0	–0.5	6.0	–10	0	20
4.0	0.1	6.3	–10	0	15
6.0	7.3	7.8	–10	5	30
8.0	1.7	7.9	–10	5	35
	Air Conduction dB SPL				
8.0	20	8	–2	18	48
12.0	20	10	7	17	77
16.0	48	19	16	46	96

Table 1B. Air conduction thresholds in otologically healthy subjects, left ear.

Frequency, kHz	Air Conduction dB HL				
	Mean	SD	Minimum	Median	Maximum
0.25	6.9	6.4	–10	5	30
0.50	3.1	5.9	–10	5	30
1.0	0.3	5.0	–10	0	25
2.0	1.3	6.3	–10	0	20
3.0	0.5	6.2	–10	0	20
4.0	1.8	7.7	–10	0	20
6.0	9.6	8.6	–10	10	40
8.0	4.6	8.4	–10	5	30
	Air Conduction dB SPL				
8.0	22	8	3	23	48
12.0	13	9	–3	12	47
16.0	46	17	16	46	106

in the equipment they used (in the Smith et al. study they did not use the standard TDH headphone).

Figure 2 shows the mean hearing thresholds at extended high frequencies, compared to data in the literature. An obvious variation is found between the data of the cited studies, all of which comprised measurements in young 'normal' hearing subjects. Valente et al. (1992) found a similar spread when they compared eight studies of high-frequency hearing in adults. More studies are needed to elucidate these differences.

Figure 3 and Table 2 present our mean bone-conduction thresholds. Especially the 2 kHz and 3 kHz data seem out of the ordinary. However, they are close to the data of Smith et al. (1999). The other mean values are close to zero, as are all the mean thresholds of Rahko-Laitila et al. (2001). As indicated in the Population and Methods section, we allowed a negative air-bone gap as an outcome. In clinical practice, if a bone-conduction threshold is poorer than the air-conduction threshold, often the bone-conduction threshold is taken as being equal to the air-conduction threshold (Barry, 1994). Indeed, comparing the bone-conduction thresholds at 2 and 3 kHz with the air-conduction

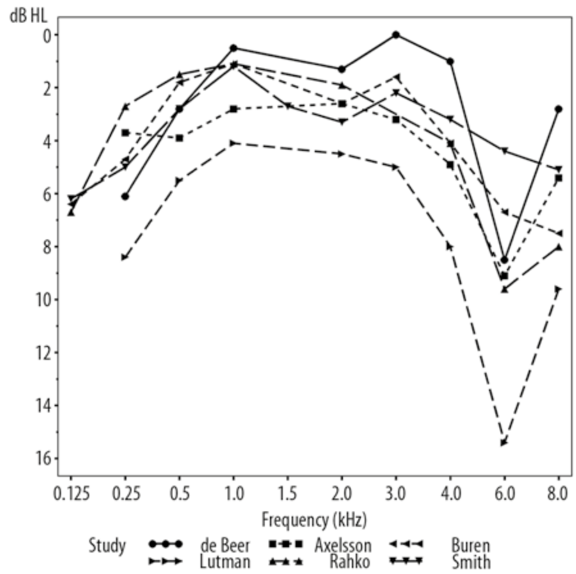

Figure 1. Mean air-conduction thresholds in dB HL of both ears and comparison with literature data. Smith et al. (1999) studied 93 otologically normal subjects, aged 18–25 years; Axelsson et al. (1994) studied 500 unscreened subjects, aged 18 years; Rahko-Laitila et al. (2001) studied 534 otologically normal subjects, aged 14 years; Lutman and Davis (1994) studied 241 screened subjects, aged 18–30 years; Buren et al. (1992) studied 69 otologically normal subjects, aged 17–22 years. Standard deviations are not presented but, across studies, they were around 5 dB at 0.25, 0.5, and 1 kHz (range 3.9–6.0 dB) and somewhat higher in the frequency range 4–8 kHz, namely 5.7–8.4 dB.

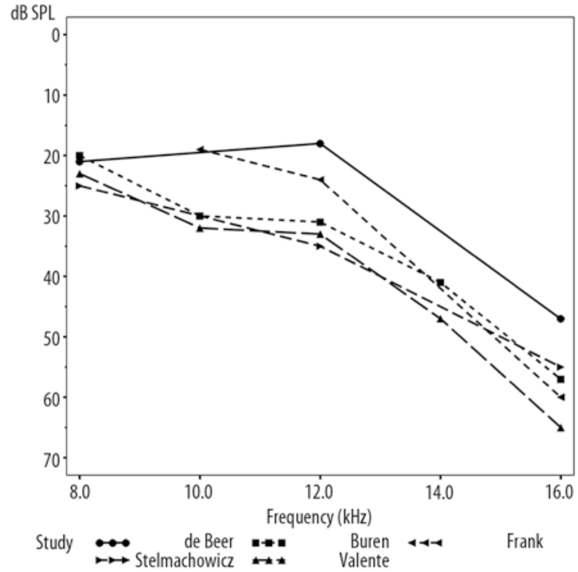

Figure 2. Mean extended high-frequency thresholds in dB SPL of both ears and comparison with literature data. Buren et al. (1992) studied 69 subjects, aged 17–22 years; Stelmachowicz et al. (1989) studied 10 subjects, aged 10–19 years; Frank (1990) studied 100 subjects, aged 18–28 years; Valente et al. (1992) studied 24 subjects, aged 21–25 years. All data pertain to otologically healthy subjects according to history-taking.

thresholds, a mean negative air–bone gap as large as 4.5 dB and 3.3 dB were found, respectively. If we had corrected the bone-conduction thresholds in the event of a negative air-bone gap, a good correspondence with the zero reference values would have been found. Smith et al. (1999) did not analyze their data in this respect. Nonetheless, an evaluation of their data reveals that the bone-conduction thresholds were worse than the air-conduction thresholds in the same frequency range as well. The reason for the negative air-bone gap might have been ambient noise in the sound booths. However, as stated before, the booths were double-walled and sound-treated and fulfilled the norms for acceptable ambient noise levels according to ISO 8523-1 (1989). This makes ambient noise as a disturbing factor unlikely.

In the present study, the two audiometers were calibrated yearly and, additionally, just before the start of the testing period (not during or directly after the tests). It was assumed that calibration was stable over time. At the following (current) regular calibration time, again no abnormalities were reported. Although calibration problems are not likely, they cannot be completely ruled out.

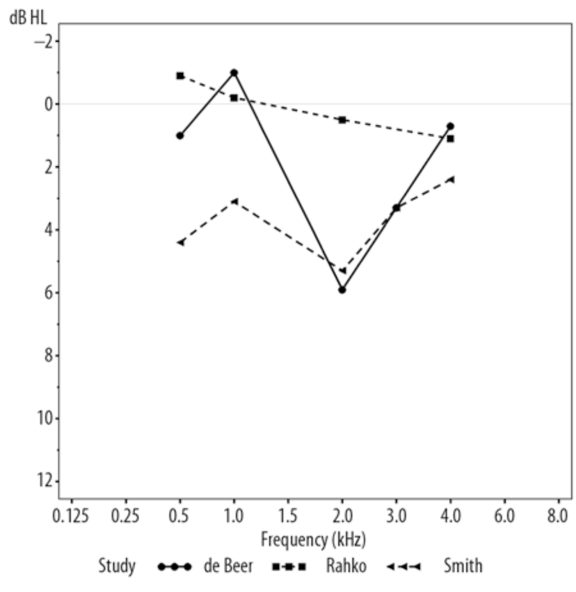

Figure 3. Mean bone-conduction thresholds in dB HL of both ears and comparison with literature data. Smith et al. (1999) studied 93 subjects aged 18–25 years; Rahko-Laitila et al. (2001) studied 534 subjects aged 14 years. All data pertain to otologically healthy subjects. Standard deviations are not presented but they were comparable across studies, between 4.5 dB and 8.0 dB.

Table 2B. Bone conduction thresholds in otologically healthy subjects, left ear.

Frequency, kHz	Left Ear Bone Conduction dB HL				
	Mean	SD	Minimum	Median	Maximum
0.5	0.9	6.8	–10	0	20
1.0	–0.9	5.6	–10	0	25
2.0	6.0	6.7	–10	5	30
3.0	3.6	6.4	–10	5	20
4.0	1.3	7.6	–10	0	20

Table 2A. Bone conduction thresholds in otologically healthy subjects, right ear.

Frequency, kHz	Right Ear Bone Conduction dB HL				
	Mean	SD	Minimum	Median	Maximum
0.5	1.1	6.9	–10	0	25
1.0	–1.1	5.5	–10	0	15
2.0	5.7	6.9	–10	5	30
3.0	3.0	7.0	–10	5	25
4.0	0.1	7.4	–10	0	20

In this cohort, the exposure to environmental noise and music was reported at age 18 years to be limited, and the noise exposure had not led to any significant hearing deficit (de Beer et al., 2003). An effect of noise exposure on hearing thresholds could also not be established by Buren et al. (1992), Axelsson et al. (1994), and Lutman and Davis (1994), who studied adolescents and young adults. The absent effect of noise exposure on hearing strongly suggests that the observed dip in hearing thresholds at 6 kHz is not caused by noise exposure but is more likely to result from not fully accurate ISO norms. This conclusion is in agreement with that of Smith et al. (1999).

Conclusion

In conclusion, previous studies have already shown that hearing thresholds obtained in otologically healthy adolescents does not match precisely the ISO 389 reference zero. According to our prospectively obtained data on otological history, based on longitudinal observations and measures, our group of subjects might qualify as the best representative sample of otologically healthy subjects that has been studied so far. Their measured mean hearing thresholds are closely comparable to those reported in the literature on hearing in adolescents and young adults, and the closest to the ISO 389 reference zero, but are systematically different for several frequencies. The present study suggests once more the need to revise ISO 389.

References:

1. Axelsson A, Rosenhall U, Zachau G: Hearing in 18-year-old Swedish males. Scand Audiol, 1994; 23: 129–34
2. Barry SJ: Can bone conduction thresholds really be poorer than air? Am J Audiol, 1994; 3: 21–22
3. Buren M, Solem BS, Laukli E: Threshold of hearing (0.125–20 kHz) in children and youngsters. Br J Audiol, 1992; 26: 23–31
4. de Beer BA, Graamans K, Snik AF et al: Hearing deficits in young adults who had a history of otitis media in childhood: use of personal stereos had no effect on hearing. Pediatrics, 2003; 111: e304–8
5. Frank T: High-frequency hearing thresholds in young adults using a commercially available audiometer. Ear Hear, 1990; 11: 450–54
6. ISO 389-1. Acoustics. Reference zero for the calibration of audiometric equipment. Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones. Geneva, Switzerland: International Organization of Standardization, 1998
7. ISO 389-2. Acoustics. Reference zero for the calibration of audiometric equipment. Part 2: Reference equivalent threshold sound pressure levels for pure tones and insert earphones. Geneva, Switzerland: International Organization of Standardization, 1994
8. ISO 389-3. Acoustics. Reference zero for the calibration of audiometric equipment. Part 3: Reference equivalent threshold force levels for pure tones and bone vibrators. Geneva, Switzerland: International Organization of Standardization, 1994

9. ISO 389R. Acoustics. Reference zero for the calibration of audiometric equipment. Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones. Geneva, Switzerland: International Organization of Standardization, 1964
10. ISO 8253-1. Acoustics. Audiometric test methods. Part 1: Basic pure tone air and bone conduction threshold audiometry. Geneva, Switzerland: International Organization of Standardization, 1989
11. ISO/TR 389-5. Acoustics. Reference zero for the calibration of audiometric equipment. Part 5: Reference equivalent threshold sound pressure levels for pure tones in the frequency range 8 kHz to 16 kHz. Geneva, Switzerland: International Organization of Standardization, 1998
12. Lightfoot GR, Hughes JB: Bone conduction errors at high frequencies: implications for clinical and medico-legal practice. J Laryngol Otol, 1993; 107: 305–8
13. Lutman ME, Davis AC: The distribution of hearing threshold levels in the general population aged 18–30 years. Audiology, 1994; 33: 327–50
14. Rahko-Laitila P, Karma P, Laippala P et al: The pure-tone hearing thresholds of otologically healthy 14-year-old children. Audiology, 2001; 40: 171–77
15. Schilder AGM, Zielhuis GA, Haggard MP, van den Broek P: Long-term effects of otitis media with effusion: otomicroscopic findings. Am J Otol, 1995; 16: 365–72
16. Smith P, Davis A, Ferguson M, Lutman M: Hearing in Young Adults: Report to ISO/TC43/WG1. Noise Health, 1999; 1: 1–10
17. Stelmachowicz PG, Beauchaine KA, Kalberer A et al: High-frequency audiometry: test reliability and procedural considerations. J Acoust Soc Am, 1989; 85: 879–87
18. Valente M, Potts LG, Valente M et al: High-frequency thresholds: sound suite versus hospital room. J Am Acad Audiol, 1992; 3: 287–94
19. Zielhuis GA, Rach GH, van den Broek P: Screening for otitis media with effusion in preschool children. Lancet, 1989; 1: 311–14