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Seasonal Effects on Transient Evoked Otoacoustic Emission Screening Outcomes in Infants versus 6-Year-Old Children

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Abstract

The purpose of this study was to compare transient evoked otoacoustic emission (TEOAE) screening outcomes (pass/fail) across the seasons (spring, autumn, and winter) between infants and schoolchildren. A total of 526 infants (275 boys, 251 girls) with a mean age of 2.0 months (SD = 0.38 months) and 975 schoolchildren (513 boys, 462 girls) with a mean age of 6.2 years (SD = 0.36 years) were screened using the ILO Otodynamics Quickscreen program. The same TEOAE pass/fail criterion was applied to the two groups. The results indicated a significant difference in pass rates between infants (91.2% of 1052 ears) and schoolchildren (86.0% of 1950 ears). A seasonal effect was found only for schoolchildren, with a significantly lower pass rate in winter than in spring or autumn. There was no difference in pass rates between spring and autumn. Implications for the seasonal effect on TEOAE screening outcomes for infants and schoolchildren are discussed.

Key Words: Infants, schoolchildren, screening outcomes, seasonal effects, transient evoked otoacoustic emission

Abbreviations: OAE = otoacoustic emission; OM = otitis media; SNR = signal-to-noise ratio; SNR3FA = average of SNRs across 2.4, 3.2, and 4.0 kHz; SNR16 = SNR at 1.6 kHz; TEOAE = transient evoked otoacoustic emission

Sumario

El propósito de este estudio fue el de comparar los resultados de un tamizaje (pasa/falla) con Emisiones Otoacústicas Evocadas por Transientes (TEOAE) en las diferentes estaciones (primavera, otoño e invierno) entre infantes y niños escolares. Un total de 526 infantes (275 niños y 251 niñas), con una edad promedio de 2.0 meses (DS = 0.38 meses) y 975 niños escolares (513 muchachos, 462 muchachas), con una edad promedio de 6.2 años (DS = 0.36 años), fueron tamizados utilizando el programa Quickscreen de ILO Otodynamics. Se aplicó a ambos grupos el mismo criterio pasa/falla para las TEOAE. Los resultados muestran una diferencia significativa en la tasa de aprobación entre los infantes (91.2% de 1052 oídos) y los escolares (86.0% de 1950 oídos). Un efecto de estación fue encontrado sólo para los escolares, con una tasa de aprobación significativamente menor en el invierno, que en primavera u otoño. No existió diferencia en la tasa de aprobación entre el otoño y la primavera. Se discuten las implicaciones para los efectos de estación en los resultados del tamizaje con TEOAE para infantes y escolares.

Palabras Clave: infantes, escolares, resultados del tamizaje, efecto de estación, emisiones otoacústicas evocados por transientes

Abreviaturas: OAE = emisión otoacústica; OM = otitis media; SNR = tasa de señal/ruido; SNR3FA = promedio de SNR entre 2.4, 3.2 y 4.0 kHz; SNR16 = SNR en 1.6 kHz; TEOAE = emisión otoacústica evocada por transiente

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Transient evoked otoacoustic emissions (TEOAEs) can be evoked by stimulation with broadband clicks of short duration and are present in nearly all normal-hearing ears (Stevens, 1988). TEOAEs are considered a rapid, objective, and noninvasive means of assessing the integrity and sensitivity of the preneural cochlear receptor mechanism (Kemp, 1997). The results from TEOAE testing provide information on the function of the cochlea in the presence of normal outer and middle ear function (Prieve, 1992). Therefore, it is widely accepted that TEOAEs are a valuable instrument for the hearing screening of young infants and children (White et al, 1993; Strickland and McPherson, 1998).

TEOAE screening alone does not discriminate between sensorineural and conductive hearing loss. TEOAEs have been found to be absent or reduced in ears with middle ear dysfunction (Proschel and Eysholdt, 1993; Choi et al, 1999) or compromised cochlear function (Kemp et al, 1986). Irrespective of whether the impairment is sensorineural or conductive in nature, TEOAEs are generally absent in ears with hearing impairment greater than 20 to 30 dB HL (Harris and Probst, 1991; Hussain et al, 1998).

The most common cause of conductive hearing impairment in the pediatric population is otitis media (OM) (Brooks, 1979; Maxon et al, 1993; Bennett and Haggard, 1998). In fact, OM is reported to be one of the most commonly diagnosed childhood diseases (Daly et al, 1999). High prevalence rates of OM occur in children at school entry (Haggard and Hughes, 1991; El-Sayed and Zakzouk, 1995). Yet, in many countries, this is a popular age group targeted for hearing screening (Nozza et al, 1997; Driscoll et al, 2000b). Many researchers report on a seasonal variation in the prevalence of OM, OM with effusion, acute OM, and/or type B tympanograms (defined as severely reduced or no change in compliance with variation in ear canal pressure), with the highest rates occurring in the winter months (Infante-Rivard and Fernandez, 1993; El-Sayed and Zakzouk, 1995). Because of its effect on the prevalence of OM, season can be a factor that may influence the pass/fail rates in a hearing screening program using TEOAEs.

Apart from hearing screening at school entry, other age groups have also been targeted for hearing screening. In Queensland (Australia), most 2-month-old infants attend a child health clinic for check-up and immunization, thus providing an opportunity for TEOAE screening (McPherson et al, 1998). Although the highest prevalence of OM and type B tympanograms occurs in the first 2 years of life (El-Sayed and Zakzouk, 1995; Hogan et al, 1997; Skull et al, 1999), the peak prevalence of OM occurs between 6 and 12 months (Haggard and Hughes, 1991; Engel et al, 1999). Two-month-old infants are usually not at risk for childhood diseases, which are often associated with attending child care centers—also a risk factor for OM (Bennett and Haggard, 1998; Rovers et al, 1999). Hence, 2-month-old infants may serve as a good reference to which other subject groups (such as schoolchildren) are compared. The aim of the present study was to compare TEOAE screening outcomes (pass/fail) across the seasons (spring, autumn, and winter) between 2-month-old infants and 6-year-old children.

METHOD

Participants

Two different groups, 526 infants (275 boys, 251 girls) with a mean age of 2.0 months (SD = 0.38 months) and 975 schoolchildren (513 boys, 462 girls) with a mean age of 6.2 years (SD = 0.36 years), participated in the present study. Infants were recruited from among those babies who attended child health clinics in the North Brisbane region for their first immunization at 2 months of age. Schoolchildren were recruited from among Grade 1 children who attended 23 primary schools in Brisbane. No selection criteria were used, and written consent was obtained from the parents or caregiver of every participant.

Procedure

An audiologist or a community health nurse, specifically trained in the use of TEOAE procedures, undertook all testing. Otoscopy was performed prior to TEOAE testing for both groups of participants to check for possible blockage of the ear canal and other abnormalities. For infants, TEOAE screening was conducted prior to immunization. If the infant was too restless for testing, he/she was tested after immunization and feeding. Infants were tested in a baby capsule (a portable crib for babies under 6 months of age) or their parents' arms in non–sound-treated rooms with an ambient noise level (measured near the participant's ear) ranging from 35 to 48 dBA (as measured with a RION NA-23 sound level meter). Schoolchildren were tested during school hours in the quietest room possible at their schools. The ambient noise level ranged from 34 to 51 dBA. Although a very quiet environment is always preferred, these ambient noise levels are considered acceptable for TEOAE testing (Rhoades et al, 1998; Smith et al, 2001).

TEOAE testing was carried out using the ILO88 Otodynamics Analyser (version 3.94H). The Quickscreen program was used in view of its resilience to background noise in nonideal acoustic environments (Vohr et al, 1993). Both ears were tested for each participant. For the infants, TEOAEs were initially collected in the ear most readily accessible to the tester. The probe fit was checked and the noise rejection level set before commencement of data collection. The noise rejection level was altered on a case-by-case basis (the default noise rejection being 47.3 dB) to allow efficient accumulation of data in the presence of ambient noise. The mean noise rejection levels for the infants and schoolchildren were 53.6 dB (SD = 0.4) and 51.3 dB (SD = 0.1), respectively. Wide-band, gaussian-shaped clicks of 80 μsec were presented to the test ear with an average stimulus level of 77.6 dB peak SPL (SD = 3.7) for infants and 79.9 dB peak SPL (SD = 2.0) for schoolchildren. For infants, at least 50 stimuli per ear were presented to evoke TEOAEs. If the resulting TEOAE spectrum did not meet the pass criterion (to be described), sampling was continued until 125 stimuli were presented and then the complete 260 stimuli if necessary. For the schoolchildren, the default number of 260 stimuli was presented to the test ear.

TEOAE measurement parameters included signal-to-noise ratios (SNRs) at center frequencies of 1.6, 2.4, 3.2, and 4.0 kHz. Although Driscoll et al (2001) suggested an alternative criterion for use with schoolchildren, the pass/fail criteria adopted by Kei et al (1997) were used for both groups for ease of comparison. Briefly, a pass was awarded if the TEOAE spectrum level was 3 dB or greater above the noise floor, and its width was at least halfway across the test frequency bands of 2 to 3 and 3 to 4 kHz. Otherwise, a fail was recorded.

Tympanometry (with a probe tone of 226 Hz) was performed only for schoolchildren using a Maden Zodiac 901 Middle Ear Analyzer. Apart from providing insight into the status of the middle ear system (Jerger, 1970), tympanometry results also provide important information regarding the possible source of reduced or obliterated TEOAEs. Failure of tympanometry was

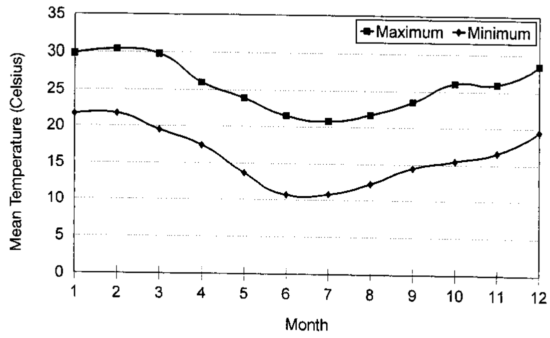

Figure 1 Mean daily maximum and minimum temperatures of Brisbane (Australia) by month, 1998 (Australian Bureau of Statistics, 1999). The seasons are spring (months 9, 10, 11), summer (months 12, 1, 2), autumn (months 3, 4, 5), and winter (months 6, 7, 8).

defined as any result that could be classified as a type B or C_2 tympanogram (refer to the Appendix for the classification of tympanograms). In the event of failure, participants were referred to their family doctors for follow-up medical consultation.

Climate in Brisbane and Period of Data Collection

Brisbane's climate is subtropical. It is warm to hot in summer (December, January, and February) and mild to warm in winter (June, July, and August). The mean daily maximum and minimum temperatures plotted against months for 1998 are shown in Figure 1 (Australian Bureau of Statistics, 1999). These temperatures were typical of Brisbane for the period from 1994 to 1998. TEOAE testing was performed from May 1994 to December 1996 for infants and from April 1998 to November 1998 for schoolchildren.

Data Analysis

Since schoolchildren were not screened in the summer months owing to summer vacation and logistic reasons, the data for only three seasons (spring, autumn, and winter) for the two groups of participants were included in the analyses for comparison purposes. Descriptive statistics on the mean SNR averaged across the frequencies of 2.4, 3.2, and 4.0 kHz (SNR3FA) and the SNR at 1.6 kHz (SNR16) for a total of 3002 ears (infants and 6-year-old children) were performed. The effects of group (age) and season on the SNR3FA and SNR16 were evaluated by applying an analysis of variance (ANOVA) to the SNR3FA and SNR16 data separately, with group

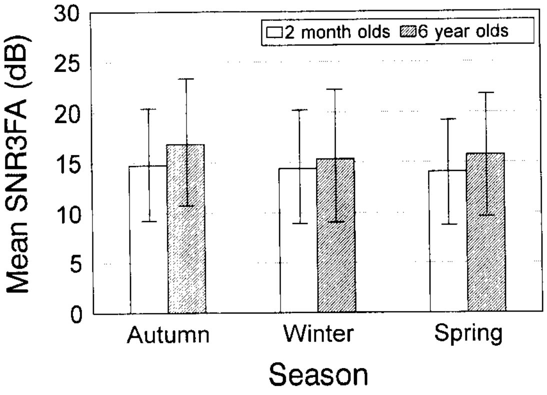

Figure 2 Mean average of signal-to-noise ratios averaged across 2.4, 3.2, and 4.0 kHz (SNR3FA) as a function of season for 1052 ears of 2-month-old babies and 1950 ears of 6-year-old schoolchildren. The *vertical bars* represent 1 SD from the mean.

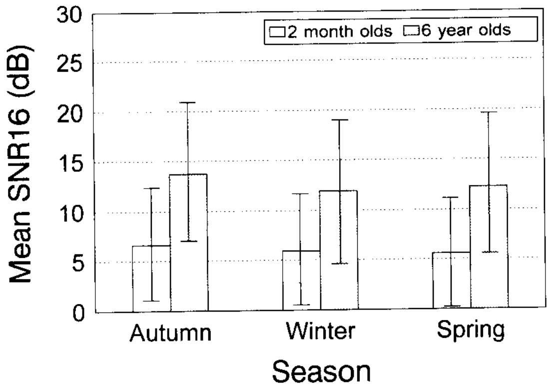

Figure 3 Mean signal-to-noise ratio at 1.6 kHz (SNR16) as a function of season for 1052 ears of 2-month-old babies and 1950 ears of 6-year-old schoolchildren. The *vertical bars* represent 1 SD from the mean.

and season as independent variables. Seasonal and group effects on TEOAE pass rate were analyzed with logistic regression analysis, with TEOAE outcome (pass/fail) being the dependent variable and age group and season the independent variables. The significance level was taken as .05.

RESULTS

Figure 2 shows the mean SNR3FA (SNR averaged across 2.4, 3.2, and 4.0 kHz) as a function of season. As shown in Figure 2, the mean SNR3FA for the 6-year-old children is higher than that for the 2-month-old infants for each season. The results from the ANOVA with SNR3FA as the dependent variable and group and season as independent variables showed a main effect for season ($F = 7.04$, df = 2, 2853, $p = .001$) and for group ($F = 41.80$, df = 1, 2853, $p = .000$). Post hoc analysis using the Tukey multiple comparison on the data for season revealed a significant difference between autumn and winter ($p = .007$) but not between winter and spring ($p = .456$) or between spring and autumn ($p = .105$). Hence, the SNR3FA for autumn was significantly greater than that for winter.

Figure 3 shows the mean SNR16 as a function of season. As shown in Figure 3, the mean SNR16 for the 6-year-old children is higher than that for the 2-month-old infants for each season. The results from the ANOVA with SNR16 as the dependent variable and group and season as the independent variables showed a main effect for season ($F = 9.77$, df = 2, 2826, $p = .000$) and for group ($F = 625.31$, df = 1, 2826, $p = .000$). Post hoc analysis using a one-way ANOVA on the data from 6-year-old children revealed a significant difference between winter and autumn ($p = .000$) and between autumn and spring ($p = .001$) but not between winter and spring ($p = .620$). Hence, the SNR16 for autumn was significantly greater than that for either winter or spring for schoolchildren (see Fig. 3).

To investigate if noise was a confounding variable in the comparison of SNRs between the two age groups, the noise contamination in the TEOAEs (as determined by the test parameter, A-B difference) was analyzed. The mean A-B differences averaged over 1950 ears of the 6-year-old children and 1052 ears of the 2-month-old infants were 4.52 dB (SD = 3.2) and 13.67 dB (SD = 3.0), respectively. The results as shown by the Student's t-test revealed a significantly greater mean A-B difference for 2-month-old infants than for 6-year-old children ($t = 77.87$, df = 3001, $p < .0001$).

An examination of the pass rates showed that 91.2 percent of 1052 ears of infants and 86.0 percent of 1950 ears of schoolchildren passed screening, respectively. Figure 4 shows the seasonal variation of the TEOAE pass rate for both age groups. As shown in Figure 4, the pass rates for 2-month-old infants are consistently higher than that for 6-year-old children across the seasons. The difference in pass rates between the two age groups was significant (logistic regression analysis, $N = 3002$, Wald = 16.35, df = 1, $p = .0001$). Hence, the likelihood of a 6-year-old child passing TEOAE screening was significantly lower than that of an infant.

To examine the seasonal variation in the pass/fail rates, the proportion of ears in each age group passing per season was analyzed. The

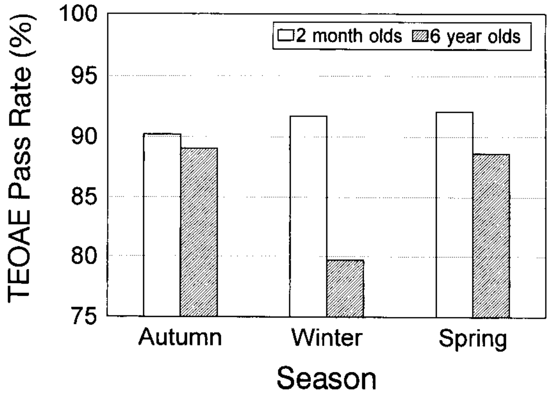

Figure 4 Transient evoked otoacoustic emission (TEOAE) pass rate (in percent) as a function of season for 1052 ears of 2-month-old babies and 1950 ears of 6-year-old schoolchildren.

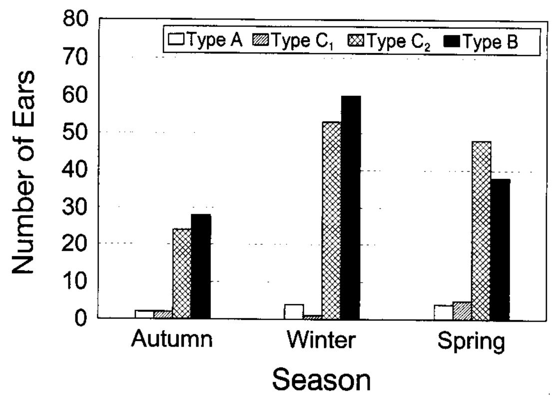

Figure 5 Histogram showing the types of tympanograms across the seasons for 273 ears of 6-year-old children who failed the transient evoked otoacoustic emission screen. Type A, B, C_1, and C_2 tympanograms were obtained in 10, 126, 8, and 125 ears, respectively. The results for 4 ears could not be obtained owing to existing medical conditions or poor probe seal.

results from logistic regression analysis showed no seasonal effect on the TEOAE outcomes for the 2-month-old infants. However, season had a significant effect on the likelihood of a schoolchild passing TEOAE screening (N = 3002, Wald = 19.362, df = 2, p = .0001). As shown in Figure 4, more children pass in spring and autumn than in winter. A post hoc analysis showed the difference in pass rates between winter and either spring or autumn to be statistically significant (logistic regression analysis, N = 3002, Wald = 18.965, df = 1, p = .0001). In addition, a post hoc analysis, comparing the pass rate for spring with that for autumn, showed that the effect of spring on the likelihood of passing TEOAE screening was not significantly different to the effect of autumn (N = 3002, Wald = 0.829, df = 1, p = .363). In summary, the results from the logistic regression and post hoc analyses showed that the TEOAE pass rate in winter for the 6-year-old children was significantly reduced.

To investigate if middle ear dysfunction was a possible source of reduced or obliterated TEOAEs, the tympanometric results for ears with a "fail" status in the TEOAE screen were analyzed. Figure 5 shows the types of tympanograms across the seasons for 273 ears of 6-year-old children who failed the TEOAE screen. Type A, B, C_1, and C_2 tympanograms were obtained in 10, 126, 8, and 125 ears, respectively. The results for 4 ears could not be obtained owing to existing medical conditions or poor probe seal. These results demonstrated that at least 92 percent of the 273 ears exhibited types B or C_2 tympanograms, consistent with middle ear dysfunction.

DISCUSSION

The results from the present study showed that schoolchildren had a significantly lower pass rate (86% of 1950 ears) than the 2-month-old infants (91.2% of 1052 ears). This may be attributable to an increase in late onset of auditory dysfunction, including conductive hearing impairment. Evidence from epidemiologic studies showed a prevalence of late-onset sensorineural hearing impairment of only approximately 1 case per 1000 children (Punch, 1983; Davis et al, 1997). Hence, the difference of 5.2 percent in the TEOAE pass rates between the two age groups found in the present study could not be solely accounted for by sensorineural hearing impairment of late onset. In fact, the tympanometric findings from the present study showed that type B and C_2 tympanograms were obtained in 92 percent of the 273 ears (of 6-year-old children) that failed the TEOAE screen. These results are consistent with the reported high prevalence of OM in this age group (Infante-Rivard and Fernandez, 1993). The results of the present study are also supported by Tos (1983), who reported a high prevalence rate of OM in 5- to 7-year-old children, and El-Sayed and Zakzouk (1995), who reported a peak in prevalence of type B tympanograms at age 2 to 3 years and again at age 6 to 7 years.

The results from the present study also showed a significantly higher mean SNR3FA for the 6-year-old group than for the 2-month-old group (see Fig. 2). In general, a high SNR3FA would result in a correspondingly high pass rate. However, the results from the present study found a lower pass rate for the 6-year-old children than for the 2-month-old infants. This apparent contradiction may be explained by the different TEOAE procedures used (different number of stimuli for the two groups). Such procedures led to a reduction in noise, as determined by the A-B difference, in the TEOAE response for the 6-year-old children (with more signal averaging using the default stimulus number of 260) than for the 2-month-old infants (with a stimulus number of about 50). As well, the greater variability (as shown by the standard deviation) of SNR3FA for the 6-year-old than for the 2-month-old group may have contributed to the above results.

The same apparent contradictory finding was also obtained for the SNR16 (SNR at 1.6 kHz), which showed a significantly higher mean SNR16 for 6-year-old children than for 2-month-old infants (see Fig. 3). Again, this can be accounted for by the greater variability of SNR16 for the 6-year-old group, as well as a reduction in noise contamination of the TEOAE responses. The large difference in SNR16 between the two groups could also be attributable to the presence of a higher level of physiologic noise for the 2-month-old infants (Kei et al, 1997, 2001) than for the 6-year-old children, given that the ranges of ambient noise levels measured for both groups were about the same.

The results from the present study showed a significant seasonal variation in TEOAE pass/fail rates for the schoolchildren, despite the relatively mild variation of temperatures across the seasons in subtropical Brisbane (see Fig. 1). The TEOAE pass rate for 6-year-old children for winter was significantly lower than that for both spring and autumn (see Fig. 4). This finding is supported by the results from SNR3FA and SNR16, which also showed significant seasonal variations, with the mean SNR3FA and SNR16 values for autumn being significantly higher than that for winter (see Figs. 2 and 3).

The decrease in the TEOAE pass rate for 6-year-old children in winter compared with spring and autumn may be attributable to an increase in *conductive* hearing impairment of schoolchildren in winter. The tympanometric results from the present study provide evidence that a large proportion (at least 92%) of these ears with a *fail* TEOAE status had tympanograms consistent with middle ear dysfunction. The seasonal variation in the TEOAE pass rate is consistent with the seasonal variation of OM, which has a higher prevalence in schoolchildren during the winter months (Owens et al, 1992; Proschel and Eysholdt, 1993). In contrast, the seasonal effect on TEOAE outcomes for 2-month-old infants was not found in the present study. The absence of a seasonal effect could be owing to the fact that 2-month-old infants are relatively free of OM.

CLINICAL IMPLICATIONS

The present study demonstrated that TEOAEs were effective at detecting OM with an associated hearing impairment. If coupled with tympanometry, the screening program could identify children with both hearing loss and OM. Although TEOAE screening at school entry is advantageous in that it can detect late-onset or progressive hearing impairment in children and has relatively lower running costs (Driscoll et al, 2000a), it results in a high failure rate, when compared with screening of infants, because of the higher prevalence of conductive hearing impairments in schoolchildren. If the aim of hearing screening at school entry is to detect permanent sensorineural hearing impairment, then the cost effectiveness of the screen is questioned in view of the higher prevalence of transient conductive pathology in this age group. Most importantly, there is no reason to delay screening for sensorineural hearing loss until 6 years of age owing to the known negative effects of speech and language delay (Yoshinaga-Itano et al, 1998). Hence, depending on the aim of hearing screening, careful consideration of the targeted age for screening is warranted to avoid costly over-referral and to achieve timely and appropriate medical and educational intervention.

If hearing screening at school entry is continued (as is happening in some countries), adequate personnel and infrastructure need to be in place to cope with the high proportion of conductive hearing impairments that will be identified during the winter months. Additional manpower should be provided for counseling children, parents, and teachers with regard to the management of transient conductive hearing loss.

CONCLUSION

There was a significantly lower TEOAE pass rate in 6-year-old children compared with 2-month-old infants in the present study. There was also a significantly lower TEOAE pass rate in winter for 6-year-old children compared with either autumn or spring. This is likely to reflect a higher prevalence of conductive pathology in 6-year-old children, particularly in winter, and implies a better use of resources if programs for universal screening for permanent hearing impairment target young infants rather than 6-year-old children.

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Appendix Classification of Tympanograms

Type	*Peak Compensated Static Compliance (mL)*	*Ear Canal Pressure (daPa)*
A	0.2 to 1.5	+50 to −100
B	No peak	
C_1	0.2 to 1.5	−101 to −200
C_2	0.2 to 1.5	< −200

Modified after Jerger (1970).