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Main Article

Screening for hearing loss and middle-ear effusion in school-age children, using transient evoked otoacoustic emissions: a feasibility study

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Abstract

Introduction: The characteristics of otoacoustic emissions that make them ideally suited for universal newborn hearing loss screening could potentially be useful for the screening of older children. This study was performed in order to assess the role of otoacoustic emissions in a screening programme for middle-ear disorders and hearing loss in school-age children.

Methods: Cross-sectional, preliminary screening study.

Setting: Primary schools of Argolida municipality, south-east Greece, between December 2004 and March 2005.

Patient selection and recruitment: All the primary school students of Argolida were invited, by press releases and individually by their teachers, to attend a session of otological and audiological screening.

Results: One hundred and ninety-six children were evaluated using transient evoked otoacoustic emissions. Twenty per cent failed in both ears, while in 32 per cent otoacoustic emissions could not be produced in at least one ear. Younger children had higher rates of absent transient evoked otoacoustic emissions. The absence of otoacoustic emissions was highly correlated with tympanic membrane changes seen on otoscopy and the presence of a type B tympanogram. As a single screening modality, otoacoustic emissions had a 100 per cent sensitivity in diagnosing hearing loss worse than 30 dB, and a 90 per cent sensitivity and 64 per cent specificity in diagnosing hearing loss worse than 25 dB, which did not improve by adding tympanometry to the screening protocol.

Conclusion: These results strongly suggest the potential usefulness of otoacoustic emission testing in screening school-age children for hearing loss. Further studies, taking into account cost-effectiveness issues, are indicated.

Key words: Otitis Media With Effusion; Otoacoustic Emissions; Mass Screening; Child; Deafness

Introduction

Otoacoustic emissions (OAEs) were first described by Kemp, from the Royal National Throat, Nose and Ear Hospital in London, in 1978.[1] They combine several very useful characteristics: they provide an objective measure of hearing, and their recording and interpretation is not time-consuming and does not require significant expertise or expensive equipment. These features have proven extremely valuable in universal neonatal screening programmes.[2] These same features could potentially render OAEs useful in screening school-age children. To date, few countries have adopted universal neonatal hearing screening. In those that have, a large cohort of school-age children who have not undergone neonatal screening still exists. Even when neonatal screening programmes are implemented, some infants will not be available for testing due to medical considerations, lack of caregiver consent, or home or community birthing.[3,4] Also, neonatal screening does not enable detection of progressive and late-onset pathologies, which may account for up to 20 per cent of all cases of childhood hearing impairment.[5,6] Therefore, hearing screening throughout childhood is useful, and it is recommended by some authorities[5] in older children, including those of school age.

Screening for otitis media with effusion (OME) is more controversial. Otitis media with effusion is a common, simply diagnosed condition. However, there is no evidence that otherwise asymptomatic children under four years of age, identified through screening, gain any benefit from earlier detection, specifically in terms of receptive or expressive language or improved intelligence.[7,8] However, it is

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recognised that children with OME and more than 25 dB hearing loss are a different subset. These children are at a higher risk of persistence of OME[9,10] and would probably benefit more from ventilation tubes.[11] Transient evoked otoacoustic emissions (TEOAEs) could bye useful in targeting this specific subgroup of children, as TEOAEs tend to be absent in children with middle-ear pathology and more than 25 dB hearing loss.

Following on from our preliminary study of screening for OME in rural Argolida,[12] we conducted the current study in order to assess the feasibility of a community- and school-based screening programme using TEOAEs in children between the ages of six and 12 years. We also aimed to assess the correlation between TEOAEs and clinical history, tympanometry and audiometry in a population of asymptomatic, school-age children, as well as to determine the diagnostic properties (i.e. sensitivity, specificity, and negative and positive predictive values) of TEOAEs in this context.

Methods

Type of study

We designed a cross-sectional, preliminary screening study.

Setting

The study was conducted in primary schools within the Argolida municipality of south-east Greece, between December 2004 and March 2005.

Patient selection and recruitment

All Argolida primary school students were invited, by press releases and individually by their teachers, to attend a session of otological and audiological screening.

Parents of children taking part in the screening programme were asked to complete a questionnaire about their child's otological history, including previous infections and the presence of hearing problems. This parental account was subsequently validated using the child's health logbook.

All testing was performed on the primary school premises, in specially configured, partially soundproofed rooms. Residents and consultant otolaryngologists from the Hippocration academic department of otolaryngology performed all examinations.

Otoscopy was performed following the removal of earwax, and the presence of liquid, opacity, retraction, perforation or erythema was noted.

Tympanometry was performed using the Interacoustics AT −235 impedance audiometer (William Demant Group, Interacoustics A/S, Assens, Denmark). A frequency of 226 Hz was used, at 85 dB SPL with pressure recording from −400 to 200 daPa. The Jerger modified classification for type A, B and C tympanograms was used.[13]

A Maico MA 40 portable audiometer (Bosch, Berlin, Germany) was used to record hearing thresholds at the frequencies 500, 1000, 2000 and 4000 Hz. Based on these frequencies, average hearing thresholds were calculated.

An ILO 92 recorder (Otodynamics, London, UK) was used to assess transient evoked otoacoustic emissions (TEOAEs), in Quickscreen mode. In this mode, the stimulus was a non-linear click at 83.5 dB, corresponding to a 2 ml external auditory meatus. This non-linear click was derived from the combination of four stimuli, three of which had the same intensity, while the fourth had an intensity equal to the sum of the previous three, with inverted polarity. The response was discarded if the noise recorded in the external auditory meatus was louder than 47.3 dB. We used Kei and colleagues' modified Rhode Island pass–fail criterion.[14] Results were considered a 'pass' if the TEOAE spectrum was recorded at least 3 dB above the noise floor and halfway across the frequency bands of 2–3 and 3–4 kHz.

Statistical analysis

All data were entered into an Excel spreadsheet, where they were initially assessed for completeness and accuracy. Subsequently, they were transferred to a Statistical Package for the Social Sciences (SPSS) file where the main analysis was performed with the help of SPSS version 13.0 software (SPSS Inc, Chicago, Illinois, USA). All continuous variables were assessed for normality by visual inspection, normality plots and Kolmogorov–Smirnov testing. Continuous variables with a distribution which approximated the normal were compared using the independent samples *t*-test and analysis of variance (ANOVA), while the remainder were tested using the Wilcoxon sign rank test and the Kruskall–Wallis test. The chi-square and Fisher exact tests were used to compare proportions, as appropriate. For all comparisons, the limit for statistical significance was set at 0.05, in two-tailed testing. Logistical regression testing was performed using the backward eliminating method, with 0.05 thresholds both ways.

Ethical considerations

The study was approved by the Hippocration University ethics committee. Consent was sought and obtained from the guardians of participating children. The study was also explained to the children and their verbal consent obtained.

Results

Patients

A total of 196 children were examined. Their ages ranged from six to 12 years, with a mean age of 8.7 years (standard deviation (SD), two years). One hundred and one (52 per cent) subjects were boys and 95 (48 per cent) were girls. The perinatal history was negative for almost all children, with the exception of two pregnancies complicated by pre-eclampsia and insulin-dependent diabetes mellitus, variously. In 54 per cent of households, there was at least one smoking parent. Fifty children (25 per cent) had a history of ear problems: 16 (8 per cent) had suffered otitis media with effusion (OME) and 32 (17 per cent) recurrent acute otitis media. One child had undergone tonsillectomy for recurrent tonsillitis and one had undergone myringotomy for acute otitis media.

Otoscopy

Otoscopy was attempted in all 196 children. However, nine left ears and seven right ears could not be examined because of impacted wax that could not be removed. In 70 per cent of the ears examined, the tympanic membrane and external ear canal was normal. Retraction of the tympanic membrane was noted in 74 ears (19 per cent), opacity or bubbles in 24 (6 per cent), erythema in five, and a perforated tympanic membrane in two.

Tympanometry

Tympanometry showed a type A pattern in 185 ears (48 per cent), type B in 49 (13 per cent) and type C in 152 (39 per cent). In total, 9 per cent of children had bilateral type B tympanograms and 27 per cent had type C tympanograms.

Audiometry

Due to financial and time constraints, audiometry was only performed in the first 86 presenting children. Average thresholds for the right and left ear were 13.5 and 12.9 dB, respectively, ranging from 10 to 42.5 dB, SDs 7.4 and 6.4 dB. In all 172 ears examined, the average threshold was 13.1 dB (SD 6.9 dB).

Children with a history of otological problems had higher thresholds. Specifically, the average threshold for children with no history of ear problems was 11.9 dB (95 per cent confidence interval (CI) −10.8 to 13.0 dB), that for children with a history of acute otitis media was 14.3 dB (95 per cent CI 9.4 to 19.1 dB), and that for children with a history of OME was 19.8 dB (95 per cent CI 3.8 to 35.8 dB). On ANOVA testing, this difference was highly statistically significant ($p = 0.01$).

Boys had slightly worse hearing than girls (14.2 dB compared with 12.2 dB, respectively), but the difference was not statistically significant ($p = 0.12$). Hearing was slightly worse in children whose parents smoked (13.4 dB compared with 12.7 dB), but, again, the difference was not statistically significant ($p = 0.63$). The group with perinatal problems was too small to attempt any comparisons.

In summary, 10 out of 86 children tested with audiometry (11 per cent) had thresholds higher than 25 dB in at least one ear. In six of these children, this hearing loss was bilateral. None of these children had thresholds worse than 55 dB, while all children with bilateral hearing loss had thresholds better than 40 dB (i.e. mild hearing loss).

Transient evoked otoacoustic emission testing

Assessment of transient evoked otoacoustic emissions (TEOAEs) was performed in all 196 children, i.e. 392 ears. Using our predefined criteria, TEOAEs were absent in at least one ear in 63 children (32 per cent), and were absent bilaterally in 39 children (20 per cent). Otoacoustic emissions were absent in at least one ear in 34 per cent of boys and 30 per cent of girls screened. A past history of OME or acute otitis media did not correlate with OAE presence. On univariate analysis, the absence of OAEs did not correlate with gender ($p = 0.65$), parental smoking ($p = 0.16$), or a history of otological problems ($p = 0.95$) or interventions ($p = 0.43$). However, an absence of recordable TEOAEs was strongly associated with age. On backward conditional logistic regression, the only factor associated with OAE absence was age ($p = 0.017$), with younger children having higher rates of TEOAE absence; however, this association explained only a small proportion of the total variance ($R^2 = 0.03$) (Figure 1).

Correlation between otoacoustic emissions and otoscopy, tympanometry and audiometry

Otoacoustic emissions were absent in 46 per cent of ears in which otoscopy revealed dullness or bubbles, compared with 20 per cent of ears with normal otoscopy ($p = 0.007$). In addition, OAEs were absent in 69 per cent of ears with type B tympanometry and 30 per cent of ears with type C tympanometry, but only in 10 per cent of ears with type A tympanometry ($p < 0.001$) (Figure 2). The average hearing threshold of children with present OAEs was 11.2 dB (SD 10.3, 95 per cent CI 10.6–11.8 dB); in children with absent OAEs, the average threshold was 16.18 dB (SD 9.51, 95 per cent CI 13.7–18.6 dB). The difference was highly statistically significant ($p < 0.0001$). More importantly, OAEs were not recorded in any child with a hearing threshold worse than 30 dB (Figure 3).

Role of transient evoked otoacoustic emissions in middle-ear disease screening

Otoacoustic emissions were 2.26 times more likely to be absent if the tympanic membrane was otoscopically

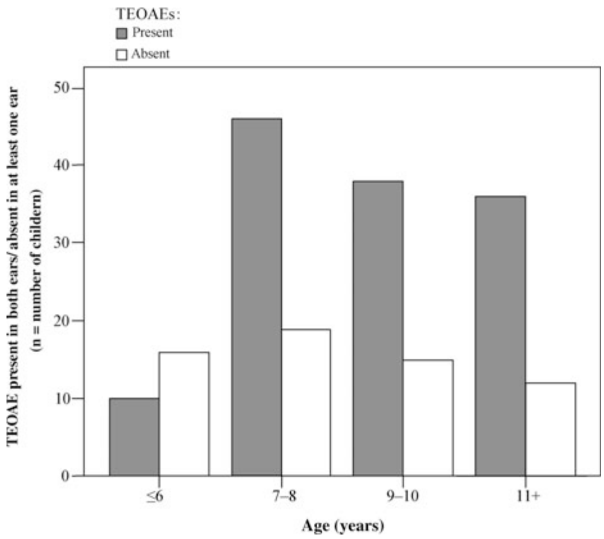

FIG. 1

Correlation between subjects' ages and transient evoked otoacoustic emission (TEOAE) results.

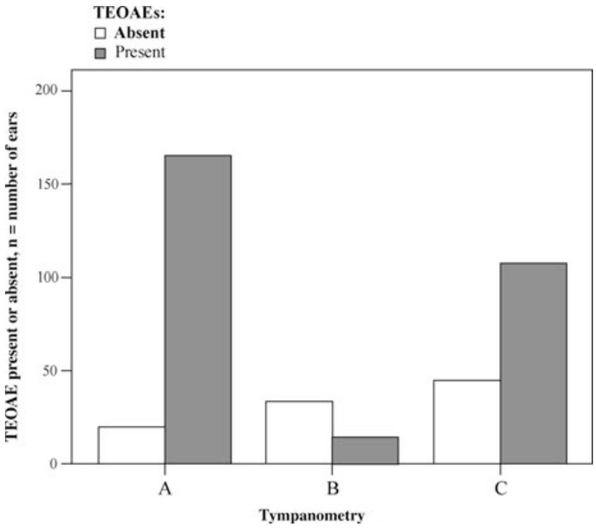

FIG. 2

Correlation between subjects' tympanometry patterns and transient evoked otoacoustic emission (TEOAE) results.

abnormal (odds ratio 2.26, 95 per cent CI 1.4–3.7, $p = 0.0008$). However, the OAE sensitivity was relatively low (38 per cent), as TEOAEs were present in 65 out of 104 children with abnormal otoscopy, despite the fact that the OAE specificity was relatively high (79 per cent).

Regarding the diagnosis of OME, (in this case defined as the presence of type B tympanometry in at least one ear), OAEs displayed better screening characteristics. Transient evoked otoacoustic emissions were absent in 22 out of 32 children with type B tympanometry, being absent 6.6 times more often than in children with type A or C tympanometry (odds ratio 6.6, 95 per cent CI 2.9–14.8, $p < 0.0001$). The specificity of absent TEOAEs in identifying children with type B tympanometry was 75 per cent, (95 per cent CI 72–77 per cent) and the sensitivity was 69 per cent (95 per cent CI 53–81 per cent).

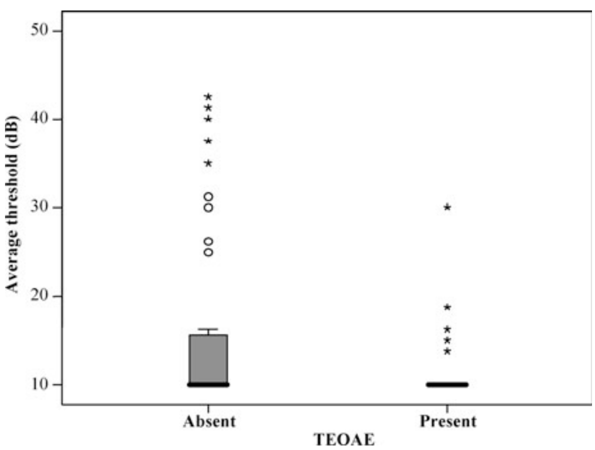

FIG. 3

Boxplot of average hearing thresholds in children with present and absent transient evoked otoacoustic emissions (TEOAEs) (including outliers).

Role of otoacoustic emissions in hearing loss screening

All children with audiometric thresholds higher than 30 dB failed to produce OAEs. Nine out of 10 children with hearing worse than 25 dB had absent OAEs. Consequently, by using just OAEs, we were able to identify virtually all children with significant hearing loss. Transient evoked otoacoustic emissions demonstrated 100 per cent sensitivity in identifying children with thresholds worse than 30 dB, and 90 per cent sensitivity (95 per cent CI 61–98 per cent) and 64 per cent specificity (95 per cent CI 60–65 per cent) in identifying hearing thresholds higher than 25 dB. Transient evoked otoacoustic emissions had a negative predictive value of 98 per cent and a positive predictive value of 25 per cent. Agreement (as defined by kappa statistic) was 0.25.

Combining tympanometry and otoacoustic emissions in hearing loss screening

From these findings, the next logical step would be to combine tympanometry and OAEs in a screening model for hearing loss in school-age children. Using type B tympanogram and absent TEAOEs as a criterion for failure, 37 children would be classified as 'fail'. However, this combination does not offer any advantage over the use of OAEs exclusively, as the results are exactly the same – the identification of nine out of 10 children with hearing worse than 25 dB – while the specificity and sensitivity are not improved.

Discussion

During the last few years, a preliminary screening programme for hearing loss and otitis media with effusion (OME) has been implemented in schools within the Argolida municipality in south-east Greece, based on tympanometry and audiometry.[15,16] We performed the present study in order to assess the feasibility of a screening programme based on the use of transient evoked otoacoustic emissions (TEOAEs), as well as to compare the efficacy of this parameter with that of tympanometry and audiometry.

As this was a 'one-off' screening test, we decided to focus on sensitivity at the expense of specificity – in other words, we felt it was important to identify all children with hearing loss, even at the risk of increased false positive results. This was the reason we used type C tympanogram pattern (and not C_1 or C_2) in tympanometry testing. We found that 52 per cent of children had type B or C tympanometry, while 12 per cent had type B tympanometry. These results are slightly higher than those found in similar populations[17] (7 per cent type B and 27 per cent type B + C_1/C_2), and significantly higher than those found in the same population in a previous study.[15] This discrepancy can be explained in part by the time of the year the test was performed – i.e. February and March, when one would expect a higher incidence of OME. Otoscopy was abnormal (i.e. retraction, dullness, bubbles, erythema or perforation) in 26 per cent of ears, a relatively high incidence that corresponds with the tympanometry results. Eleven per cent of children failed audiometry testing – an incidence marginally higher than that found in Driscoll's study (8.9 per cent)[17]; however, it is important to note that we found bilateral hearing loss in only six out of 10 of these children.

We feel that this study shows that mass screening using TEOAEs in schools is feasible. The test time did not exceed 10 minutes per child, and we were able to test all children, despite the absence of a fully soundproof room. Transient evoked otoacoustic emissions were not recorded in one-quarter of ears (26 per cent), while they were absent in at least one ear in 32 per cent of all children tested. Consequently, if we were to test only children with absent TEOAEs, we would have to assess only 63 out of 196 children.

Studies performed previously in children of the same age[18] showed a smaller rate of absent TEOAEs (10 per cent). Driscoll *et al.*[17] found absent TEOAEs in 20.3 per cent of children. In children studying in special schools, the same authors found absent OAEs in 40 per cent.[19]

In our study, the factor most closely associated with absent OAEs was age, with younger children showing a higher incidence of TEOAE absence. This accords with our general knowledge of OME. However, other studies found absent TEOAEs to be associated with a history of previous ear infections or perinatal problems and with paediatric intensive care treatment.[20]

We found that 69 per cent of children with type B tympanometry had absent TEOAEs, compared with 10 per cent of children with type A tympanogram. This result lies between the 90 per cent found in Van Cauwenberge and colleagues' study[21] and the 52 per cent found in Amedee's study,[22] both of which confirmed the presence of a strong association between absent TEOAEs and OME. Even stronger, however, was the association between hearing loss and absent TEOAEs; TEOAEs were absent in all children with hearing worse than 30 dB, and were present in only one in nine children with hearing worse than 25 dB.

The importance of the current study lies in assessing to what extent OAEs, as a sole test, can replace otoscopy, tympanometry and audiometry in screening for hearing loss and OME. It seems that TEOAE assessment can be used as a screening test for hearing loss in school-age children; however, it cannot take the place of either otoscopy or tympanometry. More specifically, by using OAEs we can identify virtually all children with hearing worse than 30 dB, and nine out of 10 children with hearing worse that 25 dB (sensitivity, 100 per cent and 90 per cent, accordingly, specificity 64 per cent), by testing only 36 out of 86 children, while being sure that we will not miss any child with hearing worse than 30 dB. Our results are not improved if we integrate tympanometry findings into our screening protocol. However, when using TEOAEs to assess middle-ear function, our sensitivity is much lower – 38 per cent for otoscopy and 69 per cent for type B tympanometry; therefore, their use would result in a significant number of children with potential middle-ear pathology being missed.

- **The characteristics of otoacoustic emissions (OAEs) that make them ideally suited for universal newborn hearing loss screening could potentially be useful for screening older children**
- **This study assessed the role of OAE testing in a screening programme for middle-ear disorders and hearing loss in school-age children**
- **As a single screening modality, OAEs had 100 per cent sensitivity in diagnosing hearing loss worse than 30 dB, and 90 per cent sensitivity and 64 per cent specificity in diagnosing hearing loss worse than 25 dB (which did not improve by adding tympanometry into the screening protocol)**
- **These results strongly suggest the potential usefulness of OAE testing in screening school-age children for hearing loss**

It is debatable whether screening for hearing loss and/or OME is indicated in all school-age children. Regarding OME, there is a good argument against screening for a condition which, in the vast majority of cases, is self-limiting and has no lasting sequelae. However, the same cannot be said for hearing loss, especially sensorineural hearing loss, which may go undetected in children not undergoing universal neonatal screening. However, our study could not conclusively answer these questions, due to lack of power, cost-effectiveness analysis and an appropriate time frame. Our study was mainly designed (as the title suggests) as a feasibility study, i.e. as preliminary research which could guide more extensive assessment of TEOAEs in school-age children. What we have shown is that it is possible to screen a large number of school-age children, within their school setting, in a relatively short period of time, and still maintain sufficient sensitivity to prevent us from missing any child with significant hearing loss.

Further studies with greater power and an analysis of cost-effectiveness are required, in order to answer the question of whether a universal screening programme for hearing loss is cost-effective and should be implemented in school-age children.

Conclusion

This preliminary study confirms the feasibility of using transient evoked otoacoustic emissions in a primary school based screening programme for hearing loss. Further studies, taking into account cost-effectiveness issues, are indicated.

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