

Pure tone audiometry and impedance screening of school entrant children by nurses: evaluation in a practical setting

Ian Holtby, Donald P Forster, Udhaya Kumar

Abstract

Background—Screening for hearing loss in English children at entry to school (age 5–6 years) is usually by pure tone audiometry sweep undertaken by school nurses. This study aimed to compare the validity and screening rates of pure tone audiometry with impedance screening in these children.

Methods—Two stage pure tone audiometry and impedance methods of screening were compared in 610 school entry children from 19 infant schools in north east England. Both procedures were completed by school nurses. The results of screening were validated against subsequent clinical assessment, including otological examination and actions taken by an independent assessor.

Results—Both methods produced broadly similar validation indices after two stages of screening: sensitivity was 74.4% for both methods; specificity was 92.1% and 90.0%; and predicted values of a positive test 43.2% and 37.6% respectively for pure tone audiometry and impedance methods. Single stage screening in both methods produced higher sensitivity but lower specificity and predictive values of a positive test than two stage screening. Screening rates were appreciably higher with impedance methods than with pure tone audiometry.

Conclusions—In choosing the method to be used, it must be borne in mind that the impedance method is technically more efficient but takes longer than pure tone audiometry screening. However, the latter method allows opportunity for other health inquiries in these children.

(*J Epidemiol Community Health* 1997;51:711–715)

Hearing loss in children may influence their educational attainment both by compromising the development of perceptual and linguistic abilities and through reducing the input of aurally acquired information.¹ Early detection followed by appropriate intervention is therefore important to minimise the effects of hearing deficit on subsequent educational attainment.² A survey of district health authorities in Britain showed that screening for hearing loss through distraction testing by health visitors in babies aged 6–9 months and a

pure tone audiometry sweep shortly after entry to school were practised relatively uniformly.³ Otitis media with effusion is the principal cause of hearing loss in infant school children, however,⁴ and pure tone audiometry in children is ineffective in detecting early middle ear effusion that may proceed to hearing loss.⁵ This condition may be detected using otoadmittance tympanometry (impedance), which also takes less time to administer as a screening procedure.^{6,7}

A previous study comparing impedance screening with pure tone audiometry found that the sensitivity and predictive value of a positive test in two stage impedance screening were noticeably better than with pure tone audiometry.⁷ However, the impedance screen was carried out by a doctor, while school nurses undertook pure tone audiometry. The apparent superiority of impedance screening was further examined in a study of children entering infant school who were screened by nurses using both methods. The study aimed therefore to compare the processes and outcomes of pure tone audiometry and impedance investigations undertaken by school nurses in children entering school. An additional objective was to compare the costs of the two methods.

Methods

Children aged 5 and 6 years in 19 infant/primary schools in Redcar and Cleveland local authority area in north east England were the potential study subjects. The 19 schools used were those in which screening for hearing loss was already scheduled to take place in the study period. Children already known by the school nursing service to have middle ear or hearing disorders or previous ear surgery were, however, excluded from further study. The schools were randomly allocated into groups A and B. After permission from parents, children in group A were first screened at school by the pure tone audiometry method and then by the impedance technique. Children in group B schools were screened in reverse order (stage 1).

The pure tone audiometry tests were carried out by nine different nurses who adopted the usual district guidelines for assessment. Hence any child who was unable to hear pure tones of 20 dB intensity in either ear in the range of frequencies 0.25–4 kHz was considered to have screened positive (equivalent to failing the test). All impedance tests were carried out by

Tees Health Authority,
Poole House,
Stokesley Road,
Middlesbrough
TS7 0NJ
I Holtby

11 Ashdale, Ponteland,
Northumberland
NE20 9DR
D P Forster

Ear Nose and Throat
Department, North
Riding Infirmary,
Middlesbrough
TS1 5JE
U Kumar

Correspondence to:
Dr I Holtby.

Accepted for publication
January 1997

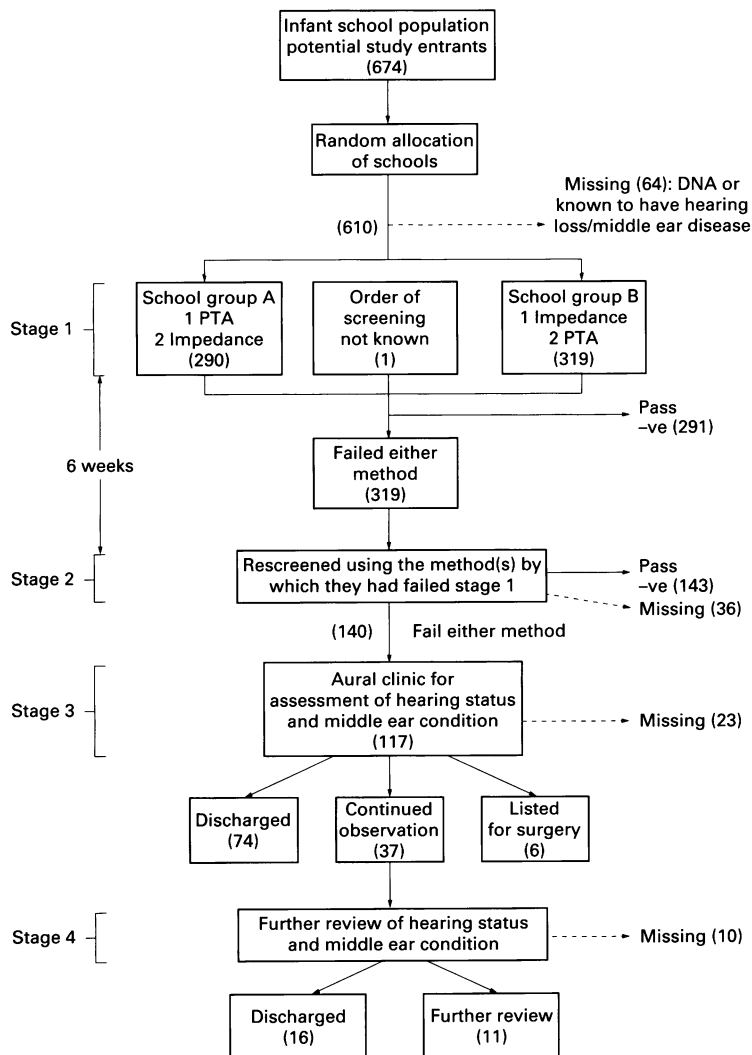


Figure 1 Four stage screening procedure comparing pure tone audiometry (PTA) and impedance testing methods in infant school children. DNA=data not available.

the same school nurses who had carried out the pure tone audiometry tests at the relevant school. It was possible for children to fail the impedance test on any one of three criteria, namely a tympanic pressure reading of -200 mm water or greater negative pressure; the inability to show a compliance or the achievement of a compliance volume with a low amplitude (<0.3 ml); or the inability to show a stapedial reflex at either 80 or 100 dB. The instrument used was a Kamplex AT 2 Tympanograph. The time taken for each of these screening sessions was recorded. All screening took place in 1992/93. All children in the same

Table 1 Comparability of methods of stage 1 screening (restricted to those children who received both screening methods at stage 1)

	Negative at impedance screening	Positive at impedance screening	
<i>Left ear</i>			
Negative at pure tone audiometry screening	347	80	427
Positive at pure tone audiometry screening	105	78	183
Total	452	158	610
Agreement between the methods = $\frac{\text{agreed positives} \times 100}{\text{those positive either time}} = \frac{78 \times 100}{78 + 105 + 80} = 29.7\%$			
<i>Right ear</i>			
Negative at pure tone audiometry screening	345	67	412
Positive at pure tone audiometry screening	113	85	198
Total	458	152	610
Agreement = $\frac{85 \times 100}{85 + 113 + 76} = 32.1\%$			

KEY POINTS

- Validity indices are similar for pure tone audiometry and impedance screening of deafness in children.
- Impedance screening is more efficient but pure tone audiometry is more conducive to a holistic approach.
- Two stage screening improves the specificity and predictive values of a positive test compared with one stage screening.
- About 25% of children have false negative results using two stage screening for either method so careful advice to parents is needed.
- Low parental awareness of hearing loss in children means that screening in school is important.

school were screened by the same nurse; trained in both screening methods, at stages 1 and 2.

Children who failed either of these stage 1 screening tests were rescreened. This stage 2 screening took place at the school after at least six weeks, thus allowing time for transient middle ear conditions to resolve. Children were only rescreened using the method by which they had failed at stage 1. If they had failed using both methods at stage 1, these were used in reverse order at stage 2 screening.

Those children who failed stage 2 screening on either method were referred to an aural clinic for examination under standardised conditions by an independent assessor (a senior clinical medical officer with special training in ENT and audiological techniques), who was unaware of the method(s) by which any child had failed stage 2 screening. This clinical assessment consisted of otoscopic examination, pure tone audiometry carried out in a soundproof room and, when considered appropriate, impedance measurements (stage 3). Some children in whom screening had been positive reached expert assessment via another route. They had, in the meantime, been referred by their general practitioner to the same independent assessor.

The results of the examinations by the independent assessor were used as the reference standard against which the prior screening tests were judged. Those children who had normal hearing on pure tone audiometry tests—that is, those who were able to hear pure tones of 20 dB or less in both ears at all frequencies—and who had normal otoscopic examination or an unimportant abnormality with no implications for treatment were discharged. Those with a hearing loss in either ear, an abnormality on otoscopy, evidence on impedance testing of a middle ear effusion, or other abnormalities which had implications for treatment were either designated for review (at stage 4) or listed for surgery.

Following the interim clinical judgements of normal, probably normal, and abnormal after these investigations the child was placed in one of three outcome categories: discharged as

Table 2 Validity of pure tone audiometry (PTA) screening

Screening result (either ear)	Discharge	Clinical action (at stage 3)		
		Continued observation	Surgery	Total
Negative at stage 1 PTA	373	6	0	379
Positive at stage 1 PTA and negative at stage 2 PTA	116	3	2	121
Positive at both stages 1 and 2 PTA	42	28	4	74
	531	37	6	574

Notes: (1) 36 of the 610 children screened by PTA at stage 1 have been omitted from this table since they missed later stages of screening; (2) children screened as negative at stages 1 and 2 were recorded as true negatives (discharges) in the table unless continuing to a later stage through a positive impedance result; (3) of those designated for continued observation (ie to be reviewed at stage 4), none was subsequently referred for surgery.

Table 3 Validity of impedance screening

Screening result (either ear)	Discharge	Clinical action (at stage 3)		
		Continued observation	Surgery	Total
Negative at stage 1 impedance	391	7	0	398
Positive at stage 1 impedance and negative at stage 2 impedance	87	3	1	91
Positive at both stages 1 and 2 impedance	53	27	5	85
	531	37	6	574

Notes: (1) 36 of the 610 children screened by PTA at stage 1 have been omitted from the above table since they missed later stages of screening; (2) children screened as negative at stages 1 and 2 were recorded as true negatives (discharges) in the table unless continuing to a later stage through a positive PTA result; (3) of those designated for continued observation (ie. to be reviewed at stage 4), none was subsequently referred for surgery.

Table 4 Validity indicators in one stage and two stage PTA and impedance screening (derived from tables 2 and 3)

	Sensitivity (%)	Specificity (%)	Predictive value of a positive test (%)	Predictive value of a negative test (%)
Stage 1 alone:				
PTA	86.0	70.2	19.0	98.4
Impedance	83.7	73.6	20.5	98.2
Two stage:				
PTA	74.4	92.1	43.2	97.8
Impedance	74.4	90.0	37.6	97.8

Note: a true positive is a child referred for surgery or designated for continued observation at stage 3.

negative; continued observation as a positive; or listed as a positive for surgery.

Results

A total of 674 school entrant children were potential study subjects. Of these, 610 (90.5%) were screened by both methods at stage 1—pure tone audiometry first in 290 cases and impedance first in 319 cases (data on order missing in one case). Altogether 319 were screened as positive by either method in the left or right ear and were rescreened at stage 2 using the method(s) of failure at stage 1. One hundred and forty children screened positive (left or right ear) at stage 2 and were referred to the specialist aural clinic (stage 3). Of the 117 children examined by the independent assessor at stage 3, six were listed for surgery and 37 were scheduled for further review at stage 4 (fig 1). Twenty three children who had been referred to the specialist aural clinic from the stage 2 screening failed to attend. Hospital outpatient records were checked and none of these 23 had been referred by their GP along this alternative specialist referral route.

At each stage the two methods of screening were carried out within two days of each other. The mean times between stages 1 and 2 were 51.7 days and 52.9 days respectively for pure tone audiometry and impedance tests. At stage

1, the pure tone audiometry positive screening rate in either ear ranged from 11.8%–70.7% (mean (SD) 35.6 (18.9)) between the nine nurses. This was greater than the variation in the stage 1 positive impedance screening rate which ranged from 28.4%–47.1% (mean (SD) 35.9 (5.0)). A similar pattern was noted at stage 2 screening.

The agreement between the screening methods at stage 1 was 29.7% for the left ear and 32.1% for the right ear (table 1). At stage 2, based on those 83 who were tested by both methods, the agreement between methods rose to 54.7% in the left ear and 54.8% in the right ear.

Those children found to be positive for first stage pure tone audiometry or impedance testing were retested using the same method after an interval of six weeks or more. The proportions of those who became negative at second stage screening were recorded in relation to the time intervals between the two stages of screening. No trend with time in the proportion becoming negative was found using either method.

Of the 117 children seen by the independent assessor at stage 3, 11 (9.4%) had been referred by their GP for specialist testing at the aural clinic in addition to being screened as positive. Altogether 115 (98.3%) had a pure tone audiometry test and 89 (76.1%) an impedance test at this third stage, in addition to otoscopy by the independent assessor.

A question about parental awareness of hearing loss in their child was asked by the independent assessor before examination at stage 3. In children who had been screened as positive at stage 2 using pure tone audiometry, 29.0% of parents had been suspicious of hearing loss compared with 26.7% of those who had passed stage 2 pure tone audiometry and who also attended the aural clinic as their child had failed second stage impedance. Similarly, 26.9% of parents of those children who failed the second stage impedance had noticed a hearing loss compared with 22.2% of those children who had passed the impedance test and who also attended the aural clinic because they had failed second stage pure tone audiometry. None of these differences was significant ($p > 0.05$).

We investigated, in part, the implications of changing the criteria for designating a test as positive at impedance screening by examining the stage 2 impedance measurements in those children whose hearing was subsequently defined as abnormal by the independent assessor at stage 3. That is, we were able to note those abnormal cases detected through the pure tone audiometry screening who would have been missed by less sensitive impedance criteria. In this study, a tympanic pressure reading of -200 mm or greater negative pressure was designated as a “fail” at screening. A potentially more sensitive negative pressure criterion of -150 mm would not have detected any additional abnormal cases at outcome. Using a compliance volume criterion of less than 0.2 ml of water instead of less than 0.3 ml would have missed one subsequently abnormal

case. The absence of a stapedia reflex at 80 dB alone would have detected 19 out of 40 (47.5%) of the abnormal cases at outcome whereas absence of the reflex at 100 dB alone would only have detected 4 (10.0%) abnormal cases.

Tables 2 and 3 show the passage of children through the screening pathway, separately for each screening method but based on results pertaining to the child (either ear). It should be noted particularly that these tables exclude children who were initially screened as positive but failed to attend for later screening or assessment. Table 4 shows validity indices based on the postulate that a true positive is a child who at stage 3 is referred for surgery or is designated for continued observation. On the basis of stage 1 screening alone and two stage screening there is little difference between the validity of the methods. At stage 1, the sensitivity lies around 85% with a specificity of about 70%. The addition of a second stage of screening reduces the sensitivity to about 74% with a rise in specificity to about 90%. The second stage also produces a rise in the predictive value of a positive test, as would be expected, since there is an effective increase in prevalence at stage 2.

Using the pure tone audiometry method, the mean screening rate per hour was 12.7 children, while 50.9 children per hour could be screened by the impedance method.

Discussion

The results of this investigation support previous work⁷ in that, whichever method is used, there are benefits in a two stage screening procedure with an interval of approximately six weeks since the specificity and predictive values are improved. Moreover, in this investigation there was relatively little loss in sensitivity when two stage screening was undertaken compared with stage 1 alone in either method. The study also showed that there is no advantage to be gained in increasing the time interval between the two stages of screening, since increased time between screenings was not associated with an increased proportion of negative results.

Comparing the two methods after two stage screening shows that the sensitivity was identical for both methods, as was the predictive value of a negative test, while the predictive value of a positive test was superior for pure tone audiometry compared with impedance testing. This contrasts with an earlier investigation in which impedance testing was carried out by a doctor and pure tone audiometry by nurses. This study showed that the sensitivity and predictive value of a positive test were better using the impedance method.⁷ In our investigation we once again defined as an abnormal finding the decision to continue clinical observation, as well as referral for surgery, on the grounds that this represented genuine clinical concern.

Using each method on its own in two stages misses 25.6% of true positive cases. It is possible that there may be additional false negative results since we do not know for certain

whether those excluded from the study because of negative screening at stages 1 or 2 subsequently develop into true positives. However, a previous study using similar methods with an extended follow up did not find any.⁷ The implications of a 25.6% false negative rate are that the parents of children screened negative should be advised that they must continue to be diligent about possible hearing loss since the test was negative on this occasion only.

Our results may also be compared with those obtained using an impedance method involving three sequential stages carried out on school entrant children by Lous.⁸ In that investigation a sensitivity of 80%, a specificity of 95%, and a predictive value of a positive test of 48% were obtained.⁸ However, the validation criterion used was the persistence of type B tympanograms (one in which the tympanogram curve is so flattened that no middle ear pressure can be determined) on subsequent occasions rather than other methods of examination. The same author also applied his data to American Speech and Hearing Association⁹ and Nashville¹⁰ models of impedance screening. He obtained sensitivities of 83% and 90%, specificities of 71% and 67%, and predictive values of a positive test of 15% and 14% respectively.

We noted greater variation in the positive screening rates between the nurses in pure tone audiometry compared with impedance techniques. Part of this variation may have been because of different levels of background noise in the schools. However, morbidity differences between schools was also a possibility. Since each school was visited by only one nurse, it was not possible to separate nurse effects from school effects.

The parameters for a child to fail—that is, to be found positive to impedance testing—were changed compared with the previous comparative study⁷ and illustrate the robustness of sensitivity in the individual criteria used with regard to compliance volume and negative pressure. For example, the results show that had the potentially more sensitive parameters of the previous study been adhered to, only one child would have been negative to impedance screening yet would have had abnormal findings on clinical examination. That is, one child with abnormal clinical findings had a compliance volume of > 0.2 ml but < 0.3 ml. The fall in the potential sensitivity of the tympanic pressure reading criterion in this study apparently resulted in the loss of no additional positive cases (assuming that such children would have screened positive by pure tone audiometry screening). However, our investigation of both of the above factors is only partial since we do not have the outcome results of those who were not seen at stage 3. On the basis of the results obtained in this investigation, the use of stapedia reflexes in the impedance screening process can only be as an adjunct to the other information obtained from the tympanogram.

There was no significant difference between the proportions of parents who suspected hearing loss in their children, irrespective of the

method by which their child had failed stage 2 screening. This was despite the fact that pure tone audiometry directly measures hearing ability whereas impedance measures mobility of the tympanic membrane, variations in which may be associated with conductive hearing loss. There were relatively low levels of parental awareness of hearing loss associated with both methods, which suggests the importance of continuing to screen for hearing loss in school entrant children, if such hearing loss is to be detected in its early stages.

The principal advantage of the impedance method in this study was the saving in terms of time spent in carrying out the procedure. However, this may have disadvantages in that it may also represent an opportunity lost in being able to establish a rapport with a child, in persuading him or her to undertake a performance test such as pure tone audiometry. Although parents were not usually present during screening, time spent with each child, for whatever reason, enables the health care worker to reach a greater understanding of that child's needs and any social/health problems he or she may have. Nevertheless, the higher screening rate for the impedance technique would mean that the school nurse had more time to deal with other aspects of the health care of school children (the opportunity cost). However, the cost advantages of this method do depend on acceptance by school nurses and the provision of a training programme on the effective use of the impedance technique combined with the efficient management of their time. In addition to the current study, nurses have previously been trained in the impedance method and have found it acceptable to both themselves and to the children involved.¹¹ An alternative might be to use technicians trained for this specific purpose.

Apart from the screening rate advantage, we have shown that impedance testing is a practical alternative to pure tone audiometry in

screening for hearing loss in school entrant children. If this screening is to continue, given the increasing restraint imposed on health service resources, then more cost effective methods such as the use of impedance testing may well need to be adopted by those responsible for providing preventive health care for schoolchildren. However, in policy making, the use of impedance screening perhaps favours a "one condition" approach whereas pure tone audiometry, as noted above, is a more holistic approach to hearing problems.

We are very grateful to all the school nurses who carried out the screening procedures, to Dr OM Aszkenasy for advice and to Ann-Marie Croft for secretarial assistance.

Funding: this research was funded by the NHS Locally Organised Research Scheme - Regional Research Committee of the Northern Regional Health Authority.
Conflicts of interest: none.

- 1 Haggard M, Hughes E. *Screening children's hearing*. London: HMSO, 1991;143-7.
- 2 Hall DMB, ed. *Health for all children: a programme for child health surveillance; the report of the Joint Working Party on Child Health Surveillance*. Oxford: Oxford University Press, 1989;60.
- 3 Stewart-Brown S, Haslum MN. Screening for hearing loss in childhood: a study of national practice. *BMJ* 1987;294:1386-8.
- 4 Ferrer HP. Use of impedance audiometry in school children. *Public Health* 1974;88:153-63.
- 5 Brooks DN. Impedance screening for school children. State of the art. In: Harford ER, Bess FH, Bluestone CD, Klein JO, eds. *Impedance screening for middle ear disease in children*. New York: Grune and Stratton, 1978;173-80.
- 6 Cooper JC, Gates GA, Owen JH, Dickson HD. An abbreviated impedance bridge technique for school screening. *J Speech Hear Disord* 1975;40:260-9.
- 7 Holtby I, Forster D P. Evaluation of pure tone audiometry and impedance screening in infant school children. *J Epidemiol Community Health* 1992;46:21-5.
- 8 Lous J. Three impedance screening programs on a cohort of seven-year-old children. Can serial impedance screening reveal chronic middle-ear disease? *Scand Audiol* 1983; **Suppl** 17:60-64.
- 9 ASHA Committee on Audiometric Evaluation. Guidelines for acoustic immittance screening of middle ear function. *American Speech and Hearing Association* 1979;21:283-88.
- 10 Harford ER, Bess FH, Bluestone CD, Klein JO, eds. *Impedance screening for middle ear disease in children*. New York: Grune and Stratton, 1978.
- 11 Bonny IC. Five years experience of combined impedance and audiometric screening at school entry. *Public Health* 1989;103:427-31.