

Report on the use of AutoAud in Broken Hill primary schools

Report prepared by: E Beach, L Carter

National Acoustic Laboratories

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Introduction

Aboriginal and Torres Strait Islander children are disproportionately affected by otitis media (OM) and associated hearing loss. The more persistent and severe the OM condition, the greater its effect upon hearing sensitivity and speech-language development. For this reason, regular surveillance of hearing health is recommended (Morris et al., 2010). Ideally, children suspected of OM should be referred for audiometric assessment by an audiologist. In rural and remote areas of Australia, this can be difficult to achieve in practice. Various screening methods have been developed, for example, Sound Scouts (Dillon et al., 2018). However, such screening techniques do not produce minimum hearing threshold levels (HTLs) and are lengthy to administer. Sound Scouts also requires access to tablet technology and internet connections in order to operate. The National Acoustic Laboratories (NAL) has developed an alternative hearing screening system, AutoAud, which has the ability to assess frequency-specific HTLs between 20 and 60 dB HL. AutoAud is a software program, which can be run on any stand-alone personal computer. The test can be administered and by a variety of practitioners with minimal training, such as nurses or health workers. Where hearing loss is identified by AutoAud, an appropriate referral can be made for audiological and/or medical management.

In 2018, NAL formed a partnership with the Royal Flying Doctor Service (RFDS), and, together with Hearing Australia and The Broken Hill University Department of Rural Health (UDRH), conducted a trial of AutoAud for hearing screening in a remote primary school setting. The aim of the trial was to assess the useability and appropriateness of AutoAud in this context. A secondary aim was to gather qualitative evidence from the health workers who used AutoAud with the students in the trial.

A direct comparison was made between HTLs obtained using standard manual audiometry methods (conducted by supervised audiology students from Flinders University), and HTLs obtained using the AutoAud system supplied by NAL. The AutoAud test was self-administered by the schoolchildren, with minimal assistance from a trained Aboriginal health practitioner who supervised the testing.

Method

Protocols were devised by NAL, in consultation with staff from Hearing Australia, RFDS and UDRH. Training in the use of AutoAud was provided to the supervising audiologist from Hearing Australia via Skype, who subsequently trained the audiology students and the health practitioner from RFDS, and oversaw all test procedures.

Participants

A total of 71 participants were tested, all primary school children from five schools in Broken Hill. The age range of participants was 4 years, 10 months – 11 years, 6 months; mean age = 7 years; 3 months. There was a relatively even gender distribution, with 33 females and 38 males. Thirty-seven students identified as Aboriginal or Torres Strait Islander. No participant had previous experience with AutoAud.

Parents and teachers of each child tested were asked to identify whether they had concerns about the child's speech, language or hearing. As shown in table 1, concerns were noted for around half the students.

Table 1. Pre-test concerns from parents, teachers and others.

Nature of concern	Number of students
Unspecified concern (from teacher or speech pathology student)	11
Unspecified concern (from parents)	4
Borderline result on other screening test (e.g., Sound Scouts)	8
Fail result on Sound Scouts	5
Reading / APD / Speech	3
No Concerns / No response	36 / 4
TOTAL	71

Equipment

AutoAud

AutoAud provides a screening test of hearing sensitivity via headphones at four pure tone frequencies: 500, 1000, 2000 and 4000 Hz. As noted, the range of test levels is limited to 20 - 60 dB HL. This covers the upper border of clinically 'normal' hearing through to 'moderate' hearing loss. The system automatically presents series of pure tones, first in one ear and then in the other. The patient responds when they hear the sounds by pressing the spacebar on the computer. The AutoAud software generates a *pass* or *refer* result for each ear and the actual threshold values (i.e., softest sound heard) at each frequency, for each ear, are also recorded in the software. The listener must respond within three seconds of the onset of the test tone, to be regarded as a valid result.

A *pass* result is assigned when all four thresholds are lower (better) than 40 dB HL, and indicates that the patient has no worse than mild hearing loss in the test ear. A *refer* result is assigned when at least one HTL is > 40 dB HL, or there is no response at 60 dB HL for at least one test frequency.

In addition to a laptop computer, the AutoAud system package included a pair of sound-attenuating 'Sync' headphones, headphone covers (for infection control purposes), and an audio dongle, as shown in Figure 1. An instruction booklet was also provided.



Figure 1. AutoAud equipment

Manual audiometry

Manual audiometry was performed using a MedRx Avant ARC clinical audiometer. Transducers were circumaural headphones, specifically, TDH 39P transducers inside 3M optime 101 Peltor H7A enclosure (TDH 39P- Peltor H7A). Audiometric equipment was calibrated in accordance with the requirements of ISO-389 (1994).

Procedure

AutoAud

Participants attended the health centre at their school. The rooms used for hearing assessments were not sound treated, but were solidly built with small windows facing away from the school, and with heavy doors which were closed during testing. The building stands apart from the classroom buildings at each school, which insulates it from noise and other distractions. External noise was minimised as much as possible and testing was usually halted during lunchbreaks.

Prior to each test, a noise measurement was taken using a handheld sound level meter (Tenma model 72-935). An otoscopic examination was performed to check for any obvious abnormality and to ensure the ear canal was not occluded.

Thirty-six children completed AutoAud first, followed by manual pure tone audiometry. The remaining 35 children completed AutoAud after manual audiometry was completed.

The health practitioner explained how to use AutoAud to each participant. The initial instruction was as follows:

“First we are going to do a practice test. We are going to put some headphones on you and you will hear some beeps in each ear. When you hear the beeps, you need to press the space bar. Each time you hear the beep press the space bar, even if the sounds are very soft.”

The number of valid responses during the practice run was recorded. The test proceeded according to the following rules:

1. If there were no valid responses, headphone connections were checked and the practice test was repeated.
2. If there was doubt the participant understood the instructions, the explanation was repeated before restarting the test.
3. If it was clear the participant could not hear any sounds, the test was terminated.
4. Ideally, if there were limited valid responses (< 4) in the practice test, the practice test was repeated once (to ensure the participant understood the test), before proceeding to the actual test. However, at the tester’s discretion, some children proceeded to test having only responded 3-4 times during the practice, for example, where the participant showed limited attention span.
5. If the participant responded to four or more sounds during the practice (total, both ears), the actual test was commenced. The patient was instructed again as follows:

“Now we are going to do the actual test. It is the same as we did before. You are going to hear some beeps in your ears. Press the space bar each time you hear the beeps even if they are really soft.”

Manual audiometry

As noted, manual audiometry was conducted at the school health centres by student audiologists from Flinders University. After a brief ear health history and otoscopic and tympanometric examination, manual pure tone audiometry was conducted using an ascending method, in accordance with ISO 8253-1 (2010). Older students completed pure tone audiometry using a push button response. For younger students, play audiometry techniques were used to keep the student engaged in responding to the stimuli where necessary. Options included a placing pegs on a peg board, placing monkeys in a barrel or putting plastic animals into a pen. The students were conditioned using a tone played through the headphones placed on the desk (at elevated levels) until reliable responses were obtained, before fitting the headphones for threshold testing. A warble tone was used if the student showed fatigue to task, poor attention or unreliable or slow responses. It was also used if the participant reported distraction from tinnitus.

Results and Discussion

Testing environment and duration

Background noise must be minimized during hearing testing to ensure accurate results. Noise level readings, taken pre-test, ranged from approximately 26–62 dBA, with an average level of 48 dBA. Although our noise measurements were A-weighted and fairly rudimentary, it is possible to estimate whether or not they were below the maximum permissible ambient noise levels for testing hearing to a minimum level of 20 dB HL. Using the procedure outlined in Williams (2010), which takes into account the attenuation provided by the ‘Sync’ headsets, we calculated that the maximum permissible noise levels were between 64 and 68 dB. Since all the recorded noise levels were below 64 dBA, we can conclude that the ambient noise levels were generally within the acceptable range for accurately testing hearing thresholds with AutoAud down to 20 dB HL.

Tympanometry and otoscopy results

Overall, otoscopic examination of the external ears revealed few abnormalities. No ear discharge or tympanic membrane perforation was noted. In only one case, a “red and retracted” tympanic membrane was observed. There were three notes of “dull” appearance of the tympanic membrane. Some ear wax was noted in five cases, but it was never fully occluding the ear canal.

Tympanometry results were obtained for 70 of the 71 participants. The majority of participants showed normal middle ear compliance and peak pressure values, which is consistent with normal middle ear function (see below). In one case, results were consistent with a functional grommet in each ear, which is also classified as “normal” function of the middle ear. Of the “abnormal” results, only two ears from two different participants showed a result consistent with OM (no peak pressure or compliance values). One child showed slightly reduced middle ear compliance in one ear only, and the remaining abnormal results were all consistent with eustachian tube dysfunction, not OM (i.e., they showed normal compliance with negative middle ear pressure).

Table 2. Tympanometry findings

Normal - both ears	Abnormal - one ear	Abnormal - both ears
59 (84%)	9 (13%)	2 (3%)

In 63 of the 71 cases (89%), no referral for further medical advice or audiometric follow up was made. In the remaining eight cases, medical advice was recommended for reasons including

abnormal tympanometric result, blocked grommet, expelled grommet in the ear canal, and wax - none of these cases required urgent medical attention. Of the referral cases, 3/8 identified as Aboriginal and Torres Strait Islander, and for 4/8 concerns had been noted by parents or teachers.

AutoAud results

All 71 participants completed AutoAud. Results from two participants were deemed invalid because the student responded inconsistently to the stimuli in both ears, and they missed the 3-second response window on more than 30 occasions. These data were not included in further analysis. The data output showed that a further 11 students were 'slow' but consistent responders, i.e., they pressed the space bar outside the 3-sec response window in at least 6 trials (range 8-35). As a result, they did not receive a system-generated *pass* or *refer* result onscreen, but their thresholds were recorded in the test software and were therefore included in the data analysis. A *pass* or *refer* result for each of these students was assigned on the basis of the thresholds recorded. For the 69 participants with either a valid system-generated *pass/fail* or an assigned *pass/fail*, 66 participants obtained a *pass* result for both ears tested, one obtained a *refer* result in both ears; and two obtained a *refer* result in one ear. The results from the better ear are shown in Figure 2.

For 45 participants, all HTLs in both ears were at the minimum screening level of 20 dB HL. For 14 participants, one ear had at least one threshold > 20 dB HL but ≤ 40 dB HL, and for seven participants, both ears had at least one threshold > 20 dB HL but ≤ 40 dB HL. Three participants had at least one threshold > 40 dB HL in one or both ears.

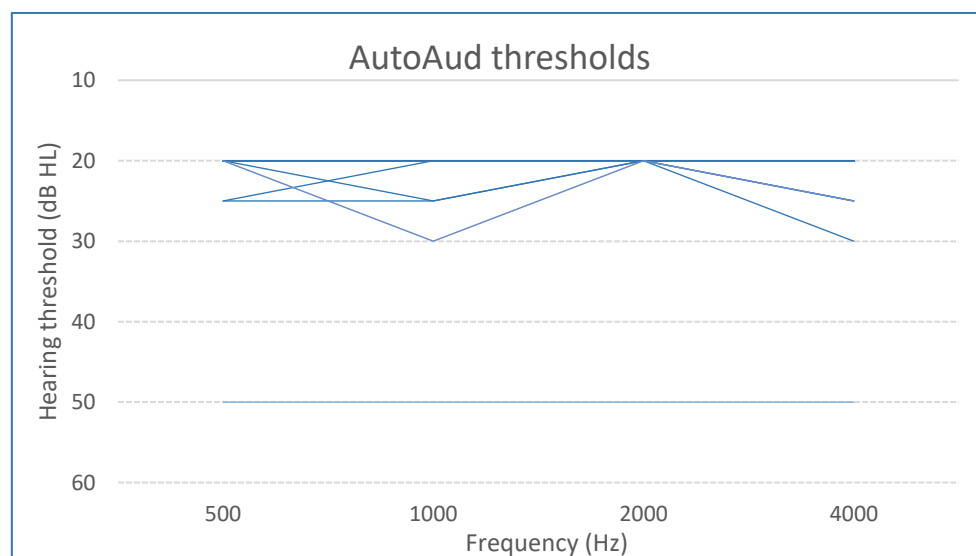


Figure 2. Better-ear hearing thresholds obtained with AutoAud

Manual audiometry results

Left- and right-ear HTLs were obtained from all 71 participants – 38 responded using play audiometry, 31 completed standard (button-press) audiometry (and for 2 cases, the method was not recorded). The audiometric data from one participant were misplaced, reducing the final dataset to 70. For 47 participants, all HTLs in both ears were at or below 20 dB HL. For 13 participants, one ear had at least one threshold > 20 dB HL but ≤ 40 dB HL, and for the remaining 10 participants, both

ears had at least one threshold > 20 dB HL but ≤ 40 dB HL. There were no thresholds > 40 dB HL. The results from the better ear are shown in Figure 3.

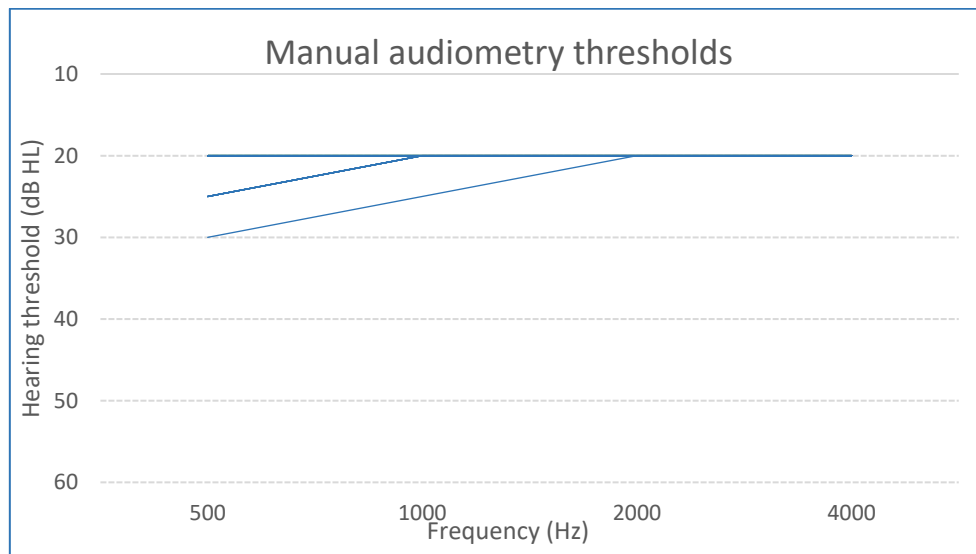


Figure 3. Better-ear hearing thresholds obtained with manual audiometry

There were no significant differences in average hearing loss thresholds for children who identified as Aboriginal or Torres Strait Islander and those students who did not. There were also no significant differences in average hearing loss thresholds for those children for whom there were concerns from parents, teachers or other professionals, and those for whom there were no concerns.

Validity of test results

Validity of the automated audiometry performed with AutoAud was assessed by comparing the results from 68 children for whom we had valid data using both test methods. In total, there were 544 HTLs obtained with AutoAud that were compared to the matched results obtained from manual audiometry. Before performing the analyses, all manual HTLs ≤ 20 dB HL were reclassified as 20 dB HL (i.e., normalised to the AutoAud minimum level) so that the range of HTLs of the manual and automated procedure were equivalent.

Following this reclassification, across all four test frequencies, 87.3% of HTLs agreed exactly. A further 6.7% were within 5 dB of each other. The differences between the HTLs collected via the two methods ranged from -40 to 10 dB HL, with a mean of -0.7 dB HL. Of the HTLs that differed from each other, about two-thirds of HTLs obtained from AutoAud were greater (poorer) than the manual HTLs, while one-third of the HTLs from AutoAud were lower (better) than the manual HTLs (8.1% and 4.6% respectively).

Pure tone audiometry is a psychometric procedure and, as such, human factors including listener alertness, concentration, and cooperation influence results. 'Perfect precision' is not achievable (p. 108, Schlauch & Carney, 2012). In general, clinical audiologists would expect discrepancies of 5 – 10 dB as 'normal' variation from test to test, and this is supported by previous reports of laboratory observations (e.g., Macrae, 1988; Schmuziger et al., 2004, Bell-Lehmkuhler et al., 2009).

To assess how well AutoAud performed as a hearing screening tool, the *pass/refer* result for each ear of each participant was compared with the result obtained from manual audiometry. In total, AutoAud classified 132 ears as *pass* (i.e., HTLs were essentially “normal” or in the range for mild hearing loss), and 4 ears as *refer* (i.e., at least one threshold was in the range for mild to moderate hearing loss). Using manual audio, all 136 ears were classified as *pass*, i.e., there was a discrepancy for 4 ears.

These discrepant data were reviewed and found to be from three participants. For the first participant, the discrepancy was in the left ear only. The AutoAud *refer* result was due to a 45 dB HL threshold at 4 kHz in the left ear. However, via manual audiometry, a threshold of 40 dB HL was obtained at 4 kHz in the left ear. The student audiologist noted wax in this ear, could not view the eardrum, and recorded a type C tympanogram in the right ear, and recommended that the case be reviewed by a general practitioner (GP) at the next appointment. In this case, both methods of audiometry indicated that a referral was necessary.

For the second participant, the AutoAud *refer* result was due to a 45 dB HL threshold at 4 kHz in the right ear. Although all thresholds were found to be better than 20 dB HL via manual audiometry, the student audiologist noted that the right eardrum was slightly retracted and recorded a Type C tympanogram in the right ear indicating significantly negative middle ear pressure, suggestive of eustachian tube dysfunction in the right ear, and recommended GP review if middle ear issues persist. Again, despite the discrepant results, both forms of audiometry led to a referral, although the reason for discrepant HTL at 4 KHz right is unclear.

For the third participant, both ears were classified *refer* by AutoAud, with all thresholds at 50 dB HL or worse. Using manual audiometry, thresholds were between 10 and 25 dB HL. However, the student audiologist recorded a Type B tympanogram in the right ear, noted that the right eardrum could not be viewed, and recommended GP review for middle ear dysfunction. Again, both forms of audiometry resulted in referral recommendation. However, if manual audiometry is considered the ‘gold standard’, then we must assume that the AutoAud system made an incorrect referral categorisation on the basis of unreliable HTLs. This case also highlights the limitation of a hearing screening system that does not include otoscopy and tympanometry, i.e., ear pathology not impacting on hearing sensitivity will be missed.

The sensitivity and specificity scores for AutoAud were calculated as detailed in Table 3. The specificity score for AutoAud was very high at 97%, indicating that the test successfully identifies those without hearing loss. However, because the sample had generally good hearing health, there was a lack of true positive results and sensitivity could therefore not be calculated. Further testing of AutoAud with a larger sample of participants with significant hearing loss is needed in order to conduct a more complete assessment of sensitivity and specificity.

Table 3. Comparison of results obtained with AutoAud and manual audiometry.

	Significant hearing loss (manual audiometry)	≤ Mild hearing loss (manual audiometry)
Positive (refer) result (AutoAud)	0 (true positives)	4 (false positives)
Negative (pass) result (AutoAud)	0 (false negatives)	132 (true negatives)
Sensitivity	= true positives divided by (true positives + false negatives) = $0/(0+4) = \text{N/A}$	
Specificity	= true negatives divided by (true negatives + false positives) = $132/(132+4) = 97\%$	

AutoAud useability

To obtain information about the useability of the system, the Aboriginal health practitioner who used AutoAud and the supervising audiologist were asked to provide feedback about the software and associated equipment. Both practitioners were positive about the use of AutoAud to screen hearing with children, and found that the software was easy to use and quick to administer with most children completing the task in under 10 minutes. AutoAud was presented to the children as a ‘game’ and most children ‘picked it up pretty quickly’, although some children struggled to maintain attention. Adding stickers or colourful icons to the laptop itself was suggested as a way of making the task seem more game-like and ‘less office-related’.

As noted previously, only two participants produced unreliable results and both were aged 5 years; 8 months – 6 years; 0 months. Similarly those who repeatedly missed the response window tended to be younger students. They were aged from 5 years; 7 months – 8 years; 11 months (with a mean age of 6 years; 7 months). The audiologist suggested that a separate response button could help with those children who struggled with using the space bar, but it was not necessary for the majority of children tested. Another option is to stop the stimulus playing as soon as a response is received.

Technical difficulties were encountered on the first day of testing, when testers reported an error message which coincided with a software ‘freeze’. However, securely reinserting the audio dongle into a new USB port solved the problem and there were no further problems.

Limitations

As noted earlier, testing was conducted in a non-sound treated environment, again because of the inherent constraints of assessing this population within a correctional setting. The room used, however, was considered fit for purpose and ambient noise levels were within acceptable limits. Furthermore, because both test methods were carried out in the same rooms, any effect of masking by background noise should have influenced both results to a similar degree.

Although the high incidence of normal middle ear findings and good hearing acuity is encouraging, the lack of abnormal results limited the comparison of the two test systems, as discussed above.

Summary

HTLs were successfully obtained using AutoAud and manual audiometry for 69 primary school students. For the majority of ears tested (97%) the same *pass* result was obtained using both AutoAud and manual audiometry. Of the 544 HTLs measured via both methods, 94% of the values obtained were within the 5 dB tolerance usually expected in clinical practice. AutoAud demonstrated excellent specificity, however sensitivity could not be determined due to the minimal number of true *refer* results obtained in the sample.

Interviews with the testers revealed that AutoAud is quick and simple to use, and is a viable clinical tool for screening hearing acuity in remote primary schools. Modifications to minimise responses made outside the response window or addition of a separate response button for younger children could further enhance the tool and improve its utility for the detection of hearing impairment in the remote school setting. Despite parents and teachers noting concerns in around half of the children tested, the study showed evidence of good hearing health indicators in the majority of children, and there was no evidence that those who identified as Aboriginal or Torres Strait Islander had poorer hearing than other children. These results may be, at least in part, attributable to the excellent school-based allied health support systems in place at Broken Hill - a model that could perhaps be adopted in other communities.

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