Reliability of auditory steady-state response to bone conduction stimuli in assessing hearing loss in children

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Objective
This study was designed to investigate BC/ASSR in children with normal hearing, together with various types of hearing loss, to find out an objective method to differentiate between different types of hearing loss.

Participants and methods
A total of 80 children (with ages ranging between 3 and 6 years) were subjected to history taking, otological examination, and basic audiological evaluation in the form of pure-tone audiometry (AC, BC). Single monotic ASSR (AC, BC) was tested at 0.5, 1, 2, and 4 kHz. They were classified on the basis of hearing status into three categories (20 children each): category I, normal hearing; category II, SNHL (subdivided into two groups: group 1, mild-to-moderate SNHL; and group 2, severe-to-profound SNHL), and category III, conductive hearing loss.

Results
BC thresholds were poorer for ASSR testing compared with thresholds obtained with behavioral testing in normal category using 9, 7.5, 5.5, and 10.5 dBHL at 0.5, 1, 2, and 4 kHz, respectively. In category II, in the mild-to-moderate SNHL group, it was poorer using 16.25, 5.75, 12.25, and 11.75 dBHL at the same measured frequencies. Minimum levels at which spurious BC/ASSR occurred were established in the group with severe-to-profound SNHL as 52, 66.5, 69, and 64 dBHL at 0.5, 1, 2, and 4 kHz, respectively (no BC/PTA could be measured). In CHL category, it was poorer using 12.5, 8.5, 9.5, and 9 dBHL at 0.5, 1, 2, and 4 kHz, respectively. Preliminary normal levels for BC/ASSR at 0.5, 1, 2, and 4 kHz were 23.5, 22.5, 20, and 25 dBHL, respectively. In children with conductive hearing loss, the average BC/ASSR thresholds corresponded closely to those in the normal-hearing group.

Conclusion
BC/ASSR thresholds could be recorded reliably in children with normal hearing and conductive hearing losses. Meanwhile, BC/ASSR may not provide a reliable measure in cases of SNHL, especially cases with moderate or greater loss due to the low levels at which spurious responses may occur.

Keywords:
AC/ASSR, BC/ASSR, children, hearing loss, play audiometry

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Introduction

Hearing loss is a relatively common sensory impairment. An undetected hearing loss in infants and young children compromises optimal language development and personal achievement [1]. It is recommended that hearing screening and intervention programs be carried out before 3 months of age and appropriate treatment be provided by 6 months of age. Accurate and early assessment of hearing sensitivity in children is critical in these programs [2].

ASSR is a physiological diagnostic tool for hearing evaluation that has increasingly gained research and clinical interest [3–5]. ASSR is a more objective measure of response presence or absence as it evaluates responses on the basis of statistical measures. An existing barrier to full clinical implementation of the ASSR is insufficient research. Research involving normal-hearing infants and young children can provide expected normal levels. Van Maanen and Stapells [6] posited normal AC multiple-ASSR levels for four frequencies – 500, 1000, 2000, and 4000 Hz.

Small and Stapells [7,8] have suggested normal levels for BC/ASSR for the same four frequencies. However,

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research must also involve participants with hearing loss to evaluate how well ASSR differentiates between varying types and degrees of hearing loss. Swanepoel *et al.* [9] were the first to study BC/ASSRs in children with hearing loss. However, they examined thresholds for a wide age range (from 3 months to 11.5 years) of children, and the accuracy of the ASSR results cannot be verified as hearing losses were not confirmed using a gold-standard tool.

Accordingly, this study was designed to investigate BC/ASSR in children with normal hearing and various types of hearing loss and to compare detected thresholds with thresholds measured with behavioral test battery (play audiometry) to find out the reliability of ASSR in assessing hearing loss in children.

Participants and methods

Participants

The study was conducted on 80 children. Their ages ranged between 3 and 6 years with a mean age of 4.5 years; there were 30 male and 50 female patients. The study group was classified into three categories on the basis of hearing status. This classification was based on behavioral audiometric measurements (play audiometry across frequencies 500, 1000, 2000, and 4000 Hz) and evoked potential measurements (ABR).

Category I included normal-hearing children with a mean threshold of 15 dBHL, normal AC click-evoked ABR thresholds, with a mean threshold of 30 dBnHL, and type A tympanogram with preserved acoustic reflexes at expected levels. Category II included SNHL children. This group was subdivided on the basis of degree of hearing loss into two groups: group 1 and group 2. Group 1 included mild-to-moderate SNHL with elevated AC and BC play audiometry between 30 and 50 dBHL with no air–bone gap, elevated AC click ABR threshold between 40 and 60 dBnHL, and bilateral type A tympanogram with elevated acoustic reflexes. Group 2 included severe-to-profound SNHL with elevated AC more than 70 dBHL and absent BC play audiometry, elevated AC click ABR threshold above 70 dBnHL, and bilateral type A tympanogram with elevated or absent acoustic reflexes. Finally, category III included CHL children with elevated air conduction play audiometry between 25 and 50 dBHL, together with normal bone conduction threshold play audiometry, elevated AC click ABR threshold with delayed AC click-evoked ABR waves, and bilateral type B tympanogram with absent ipsilateral acoustic reflexes.

Because of prolonged testing time as regards ASSR testing (120 min), most children needed a second session to complete testing of both ears. Of the 80 children, only 58 children returned to complete the tests. Thus, data were collected per ear with a total number of 138 ears (Table 1).

Procedure

Full history taking, including personal history, prenatal, natal, and postnatal history, family history, and otological examination, in addition to tympanometry and acoustic reflex threshold measurements using Acoustic Immittance Meter Interacoustics Model AZ26 (Assens, Denmark) with 220 Hz probe tone, calibrated according to ANSI S3.39-1987.

Behavioral hearing threshold estimation using play audiometry with play tone audiometer calibrated according to ANSI [10] with headphones TDH 39 and bone vibrator B-71. AC and BC testing were carried out with pure tones at 500, 1000, 2000, and 40000 Hz [11].

Evoked potential measurements included ABR and ASSR measurements using the evoked potential system GSI Audera device (Grason-Stadler, Eden Prairie, MN, USA). Chloral hydrate was used to sedate the children at a dose of 0.5 mg/kg. The participants were asleep comfortably during the test and the electrode site was cleaned with alcohol. Electrodes were placed on the high forehead (Fz)

Table 1 Number of children examined in first and second sessions with total number of examined ears for each category

	Number of patients attending first session	Number of patients attending second session	Number of ears examined
Category I	20	15	35
Category II			
Group 1	20	16	36
Group 2	20	12	32
Category III	20	15	35
Total number	80	58	138

Table 2 BC/PTA and BC/ASSR thresholds and the difference score in normal children (*n*=35 ears)

Frequencies (Hz)	BC/PTA (dBHL) (mean±SD)	BC/ASSR (dBHL) (mean ±SD)	Difference score±SD
500	13±2.5	23.5±12.26	9±9.76
1000	15±3.2	22.5±8.51	7.5±5.31
2000	14.5±2.24	20±6.49	5.5±4.29
4000	14.5±3.20	25±6.07	10.5±2.87

Table 3 BC/PTA and BC/ASSR thresholds and the difference score in children with mild-to-moderate SNHL (*n*=36 ears)

Frequencies (Hz)	BC/PTA (dBHL) (mean±SD)	BC/ASSR (dBHL) (mean ±SD)	Difference score±SD
500	36.25±4.5	52.5±6.39	16.25±1.89
1000	35.75±4.67	41.5±6.71	5.75±2.04
2000	42.75±4.99	55±5.13	12.25±1.14
4000	46.75±2.94	58.5±3.66	11.75±0.72

Table 4 BC/ASSR thresholds and detectability in children with severe-to-profound SNHL

Frequencies (Hz)	BC/ASSR thresholds (dBHL) (mean±SD)	Percentage
500	52±6.16	100
1000	66.50±4.8	90.6
2000	69±3.08	84.3
4000	64.5±5.10	93.75

for the noninverting position and on the ipsilateral mastoid for the inverting position. A third electrode placed on the contralateral mastoid served as a ground.

Stimulus parameters

The ASSR thresholds were recorded using the default settings of the GSI Audera evoked potential. The AC and BC/ASSR were evoked with tones modulated in amplitude and frequency with a relative AM/FM phase difference of 8. The tones were 10% frequency modulated and 100% amplitude modulated (0.5, 1, 2, and 4 kHz modulated at 74, 81, 88, and 95 Hz, respectively). High modulation rates were used to ensure that a satisfactory signal-to-noise ratio would exist for the detection of responses during sleep or sedation [12].

AC and BC/ASSR

For AC stimuli, a single modulated carrier frequency was presented per trial through EAR TIP-50 insert earphones calibrated in dBHL. The AC/ASSR initial stimulation intensity was determined by means of PTA threshold, starting from 10 dB above this threshold. If PTA threshold was absent at maximum intensities, the AC/ASSR stimulation commenced at the maximum intensities of Audera equipment. BC stimuli were presented through a Radioear B-71 bone oscillator that was held in place on the mastoid of each participant by a headband. The initial BC stimulation commenced at the level of the corresponding AC threshold. Contralateral AC masking was presented through insert earphones at a fixed value of 50 dBHL [13]. ASSR thresholds were established for each test frequency by increasing or decreasing the stimulus presentation level in 10 dB steps. Once an approximate minimum response level was established, threshold was defined as the softest level at which a statistically significant response could be obtained. The presence or absence of a response was determined automatically using a statistical measure known as phase coherence squared (PC^2). Each PC^2 value is evaluated to determine the probability that a given distribution of phases could have arisen for a trial in which no stimulus was present. If this probability was sufficiently small ($P<0.03$), a response was considered to be present ($P<0.03$ is the default criterion for the GSI Audera system). A noise criterion level of 1 mV (140.4 dBV) was used.

Statistical analysis

The collected data were coded, tabulated, and statistically analyzed using SPSS program software (version 18.0; SPSS Inc., Chicago, Illinois, USA).

Results

In children with normal hearing (category I), it was noticed that BC/ASSR thresholds were always higher than that of BC/PTA. The arithmetic difference score was calculated between the two values showing that the highest difference score was detected at 4000 Hz and the lowest detected was at 2000 Hz (Table 2).

In children with mild-to-moderate SNHL, group 1 of category II, a similar finding was noticed, and the highest difference score detected was at 500 Hz and the lowest detected was at 1000 Hz (Table 3).

In group 2 of the same category (children with severe-to-profound SNHL), BC/PTA thresholds could not be detected at maximum intensity (65 dBHL) at tested frequencies and thus only the results of BC/ASSR were presented (Table 4), showing the lowest threshold value of BC/ASSR detected at 500 Hz and the highest value detected at 2000 Hz and the response detectability of BC/ASSR.

In children with conductive hearing loss (category III), the highest difference score between BC/PTA and BC/ASSR was at 500 Hz and the lowest was at 1000 Hz.

Discussion

The ASSR has provided an accurate estimation of frequency-specific AC thresholds for varying degrees of hearing loss and has the added advantage of objective response detection using statistical tests [3]. More recently, the use of BC/ASSR has also become available on clinical systems, but few studies, especially on children, have been reported [9]. Hence, our study has been designed to provide possible data for the clinical use of BC/ASSR in estimating the degree and type of hearing loss in young children and to detect the possibility of enrolling BC/ASSR as a reliable tool in assessing hearing loss in children.

The study group was divided into three categories based on hearing status: category I, normal hearing; category II, SNHL, which was subdivided on the basis of degree of hearing loss into two groups: group 1 (mild-to-moderate SNHL) and group 2 (severe-to-profound SNHL); and category III, CHL. This classification was based on behavioral audiometric measurements (play audiometry) and evoked potential measurements (ABR).

In category I (normal hearing), BC/ASSR mean thresholds were 23.5±12.26, 22.5±8.51, 20±6.49, and 25±6.07 dBHL at 500, 1000, 2000, and 4000 Hz, respectively. The lowest mean threshold value was detected at 2000 Hz and the highest mean value was detected at 4000 Hz (Table 2). These results fall within the range reported by Small and Stapells [8], who proposed criteria for normal BC/ASSR thresholds in infants and adults, determined by the lowest level (in dBHL) at which at least 90% of their normal-hearing participants showed 'present' responses (50, 40, 30, and 30 dBHL for 500, 1000, 2000, and 4000 Hz, respectively). These 'normal' levels could then be used to determine whether BC thresholds are normal or elevated (i.e. no response at the 'normal' level indicates a SNHL).

Swanepoel *et al.* [9] examined a group of children with normal hearing with a mean age of 3.6 years. They found that BC/ASSR demonstrated frequency-dependent difference with better thresholds at low frequencies (0.25–1 kHz) compared with higher frequencies (2–4 kHz). The range of mean thresholds was 16–25.5 dBHL across frequencies 0.25–4 kHz, with 1 kHz presenting with the lowest (i.e. best) average threshold and 4 kHz with the highest average threshold. These results fall within the normal range as described in the study by Small and Stapells [8] and are nearly similar to our results due to the matching age group.

Our results demonstrated a better mean threshold at 2 kHz compared with other tested frequencies (23.5, 22.5, 20, and 25 dBHL) at 500, 1000, 2000, and 4000 Hz, respectively, indicating that children in our study were undergoing maturational changes.

Small and Stapells [7] were the first to report on BC ASSR thresholds obtained in infants (mean age: 4 months), and Casy and Small [14] in their study groups (infants and adults) together demonstrated an age and frequency-dependent difference in measuring BC/ASSR thresholds. Better thresholds for older infants and at low frequencies were observed. The implication appears to be that low-frequency BC thresholds worsen and high-frequency BC thresholds improve with maturation. Frequency 2 kHz may be the first frequency to show the maturational effect, as the mean threshold was elevated (worst) in infants in the study by Small and Stapells [7] and Casy and Small [14] with better thresholds detected in adults in the study by Casy and Small [14].

In category II group 1 (mild-to-moderate SNHL), the mean thresholds of BC/ASSR were 52.5±6.39, 41.5 ±6.71, 55±5.13, and 58.5±3.66 dBHL at 500, 1000, 2000, and 4000 Hz, respectively. BC/ASSR could be detected at all frequencies in all tested ears (Table 3). Our results are in agreement with the findings of Swanepoel *et al.* [9], who studied a group of children with the same level of hearing loss; they found that BC/ASSR mean thresholds were 36.5, 41.5, 56.5, and 55.4 at 0.5, 1, 2, and 4 kHz, respectively.

In category II group 2 (severe-to-profound SNHL), the mean thresholds of BC/ASSR were 52±6.16, 66.5 ±4.8, 69±3.08, and 64±5.10 dBHL at 500, 1000, 2000, and 4000 Hz, respectively. Detectability of BC/ASSR varied across frequencies (100% at 500 Hz, 90.6% at 1000 Hz, 84.3% at 2000 Hz, and 93.75% at 4000 Hz) (Table 4).

BC/ASSR response in children with severe-to-profound SNHL was reported by Swanepoel *et al.* [9] as well. They found that, in a sample of children with severe-to-profound SNHL, spurious (false response) BC/ASSRs, unrelated to audition, were recorded consistently in over 99% (112/113

Table 5 BC/PTA and BC/ASSR thresholds and the difference score in children with CHL

Frequencies (Hz)	BC/PTA (dBHL) (mean±SD)	BC/ASSR (dBHL) (mean ±SD)	Difference score±SD
500	11.5±2.3	24±6.4	12.5±4.1
1000	15±3.9	23.5±6.9	8.5±3
2000	14±4.6	23.5±8.2	9.5±3.6
4000	13.5±4	22.5±6.6	9±2.6

recordings) of frequencies assessed. The responses started to appear at 25 and 40 dB for 0.25 and 0.5 kHz, respectively, although the mean values were elevated (37.5 and 53.0 dB for 0.25 and 0.5 kHz). Spurious responses for the higher frequencies (1–4 kHz) only appeared at 60 dB and above.

In adults, Jeng *et al.* [13] and Small and Stapells [15] stated that the minimum levels of spurious BC/ASSR measured in frequencies 0.5, 1, 2, and 4 kHz were 45, 30, 50, and 50 dBHL and 40, 40, 50, and 50 dBHL, respectively.

As an explanation of this finding, Swanepoel *et al.* [9] suggested that this spurious BC/ASSR response in children with severe-to-profound SNHL is due to a possible stimulus artifact from the bone oscillator, or due to vestibular response in the lower frequencies. Two years earlier, Small and Stapells [7] suggested that spurious BC/ASSR responses to 0.5 kHz may be physiologic but nonauditory in origin, as the phases of the responses at this frequency did not invert with inversion of stimulus polarity.

In category III (CHL), the mean thresholds of BC/ASSR were 24±6.4, 23.5±6.9, 23.5±8.2, and 22.5±6.6 dBHL at 500, 1000, 2000, and 4000 Hz, respectively (Table 5). BC/ASSR could be detected at all frequencies in all tested ears. The overall average of BC/ASSR thresholds in category III indicated normal cochlear hearing in the presence of a typical conductive hearing loss configuration with elevated AC/ASSR thresholds sloping towards the lower frequencies.

Our study results are in agreement with those of Swanepoel *et al.* [9], who found that BC/ASSR thresholds in the group of children with conductive losses provided a useful measure of cochlear hearing status in the presence of a conductive pathology. Overall, average BC/ASSR thresholds indicated normal sensorineural hearing in the presence of a typical conductive hearing loss configuration with elevated AC/ASSR thresholds sloping towards the lower frequencies.

Notably, the mean thresholds of BC/PTA were better compared with the mean thresholds of BC/ASSR in included categories, with variable mean difference scores across studied categories, which were 9, 7.5, 5.5, and 10.5 dBHL at 500, 1000, 2000, and 4000 Hz, respectively, in category I (Table 2), 16.25, 5.75, 12.,25, and 11.75 dBHL at 500, 1000, 2000, and 4000 Hz, respectively, in category II group 1 (Table 3), and 12.5, 8.5, 9.5, and 9 dBHL at 500, 1000, 2000, and 4000 Hz, respectively, in category III (Table 4). Category II group 2 was excluded as BC/PTA could not be obtained at maximum intensity.

Casy and Small [14] found that mean BC difference scores for ASSRs and VRA in a group of normal-hearing infants ranged from 7 to 16 dB at 500–4000 Hz. Ishida *et al.* [16] found that the mean BC difference scores for ASSRs and PTA in a group of adults with mild-to-moderate SNHL were 18, 7, 4, and 0 dBHL at 500, 1000, 2000, and 4000 Hz, respectively. The variability in this relationship across studies suggests that there is a wide range of physiological results that correspond to normal behavioral responses.

Conclusion

BC/ASSR thresholds could be recorded reliably in children with normal hearing and conductive hearing losses. The levels at which spurious BC/ASSR thresholds occur, due to a possible stimulus artifact from the bone oscillator at high frequencies (1–4 kHz), or due to a vestibular response in the lower frequencies (0.5 kHz), limit the clinical utility of the technique. The most significant point with respect to the clinical use of BC/ASSR in children is that it must be performed and interpreted within the limitations posed by spurious response occurrence.

Recommendations

It is recommended that BC/ASSR be compared in future studies in young children using a frequency-specific objective method (e.g. tone burst evoked ABR for more accurate results). Multiple dichotic stimulation is recommended to minimize the duration of testing, and it is recommended to study BC/ASSR in other conductive pathologies (e.g. meatal atresia and CSOM).

Conflicts of interest

There are no conflicts of interest.

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