AUDITORY STEADY-STATE RESPONSES FOR ESTIMATING MODERATE HEARING LOSS

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ABSTRACT

The Auditory Steady-State Response (ASSR) has gained popularity as an alternative technique for objective audiometry but its use in less severe degrees of hearing loss has been questioned. The aim of this study was to investigate the usefulness of the ASSR in estimating moderate degrees of hearing loss. Seven subjects (12 ears) with moderate sensorineural hearing loss between 15 and 18 years of ages were enrolled in the study. 48 behavioural and ASSR thresholds were obtained across the frequencies of 0.5, 1, 2, and 4 kHz. ASSR thresholds were determined using a dichotic multiple frequency recording technique. Mean threshold differences varied between 2 and 8 dB (±7-10 dB SD) across frequencies. The highest difference and variability was recorded at 0.5 kHz. The frequencies 1 – 4 kHz also revealed significantly better correlations (0.74 – 0.88) compared to 0.5 kHz (0.31). Comparing correlation coefficients for behavioural thresholds less than 60 dB and 60 dB and higher revealed a significant difference. 86% of ASSR thresholds corresponded within 5 dB of moderate to severe behavioural thresholds compared to only 29% for mild to moderate thresholds in this study. The results confirm that the ASSR can reliably estimated behavioural thresholds of 60 dB and higher, but due to increased variability caution is recommended when estimating behavioural thresholds of less than 60 dB, especially at 0.5 kHz.

INTRODUCTION

Accurate determination of the degree and configuration of hearing loss can be challenging and even impossible in difficult-to-test populations such as infants and malingerers. In such cases, clinicians resort to objective audiometry to determine a patients hearing status. The goal of objective audiometry is therefore to accurately estimate behavioural thresholds from physiological measurements when behavioural thresholds are unavailable [7]. A number of Auditory Evoked Potential (AEP) techniques have been implemented for this purpose over the past three decades. The most widely used of these techniques has been the Auditory Brainstem Response (ABR). Its widespread popularity was as a result of the robust and highly replicable characteristics of the response irrespective of the patient state of consciousness. More recently another AEP, the Auditory Steady-State Response (ASSR), has also gained popularity as an alternative technique for objective audiometry [15].

In contrast to the ABR evoked with transient broadband clicks or tone bursts the ASSR is evoked using continuous tones modulated in amplitude, or amplitude and frequency [1, 7]. The use of continuous sinusoids allows for stimuli with narrower spectra than tone bursts resulting in more frequency specific threshold determination with the ASSR [15]. Furthermore, the ASSR technique allows for presentation of up to four different stimuli to both ears simultaneous with objective response determination by reliable statistical techniques [4, 9]. The ABR, however, assess a single frequency per ear and requires interpretation by experienced clinicians to determine the presence of responses except in the case of a screening ABR where automated algorithms analyse the response.

In recent years numerous studies have explored the clinical usefulness of the ASSR technique for objective audiometry. Reports have demonstrated significant correlations between ASSR, behavioural and ABR thresholds across various age groups including adults and children [1, 3, 4, 9]. Despite good correlations there are significant differences between studies reporting ranges of ASSR and behavioural threshold difference from 4 to 34 dB [2, 6]. This variability can be explained to a large extent by the fact that ASSR thresholds are closer to behavioural thresholds in patients with a sensorineural hearing loss than for normal hearing subjects due physiological recruitment [7]. Therefore ASSR thresholds in normal hearing subjects may be elevated by up to 30 dB whilst for profound hearing losses the difference approaches zero [10, 14].

Studies have demonstrated the accuracy of ASSR thresholds for confidently estimating behavioural hearing in infants and adults with ASSR thresholds above 60 dB but not for differentiating clearly between those with slight, mild, and moderate hearing losses [8, 12]. A recent study confirmed that the large variability in estimated behavioural audiograms with an average of 40 dB or less (0.5 – 4 kHz), obtained from physiological ASSR thresholds above this intensity, deviate too much to accurately estimate real hearing thresholds for specific frequencies [11]. Caution has therefore been recommended when using ASSR thresholds to differentiate mild and tentatively also moderate hearing losses [8, 11, 12]. The current study therefore investigated the clinical usefulness of the ASSR in determining moderate hearing losses.

MATERIALS AND METHODS

The study was approved by the appropriate institutional ethics committee in agreement with the 1964 Declaration of Helsinki. Informed consent was required for every subject before they could participate. Since almost all subjects were younger than 18 years of age consent was obtained from the parents or caregivers before it was obtained from the adolescents themselves. A sample of 7 subjects (12 ears), 3 of them female, with confirmed moderate sensorineural hearing loss were enrolled. The sample of ears consisted of nine flat configuration losses, two with gradual high frequency sloping losses and one low frequency sloping loss. All subjects were between the age of 15 and 18 years, with a mean age of 16 years and 9 months.

An audiological evaluation confirmed normal middle-ear functioning and according to the pure tone average (PTA) across 0.5, 1, and 2 kHz, 8 ears were classified with moderate (41-55 dB) and 4 ears with moderate-severe hearing loss (PTA = 56-70 dB). Normal middle-ear compliance was a pre-requisite for including any subject. Behavioural pure tone thresholds were obtained at 0.5, 1, 2, and 4 kHz in a sound-proof chamber using a diagnostic audiometer in a 10 dB down and 5 dB up threshold-seeking procedure. 48 behavioural thresholds (23 moderate, 13 mod-severe and 12 mild thresholds across 0.5, 1, 2, and 4 kHz).

ASSRs were evoked in a sound-proof chamber with patients reclining on a bed using a dichotic multiple frequency technique stimulating both ears simultaneously with the same carrier frequencies modulated at different rates. Test stimuli were 0.5, 1, 2, and 4 kHz tones modulated in amplitude and frequency with a relative AM/FM phase difference of 90°. The tones were 20% frequency modulated and 100% amplitude modulated at 82, 84, 87, and 89 Hz respectively for the 0.5, 1, 2, and 4 kHz tones in the left ear and 91, 94, 96, and 99 Hz for the 0.5, 1, 2, and 4 kHz tones respectively in the right ear. These modulation rates were according to the default specifications of the MASTER system (version 1.8). Test stimuli were presented through EAR 3A insert earphones calibrated in hearing level. Electrode placement was at Cz (Active), midline posterior neck (Reference), and Fpz (Ground) with all electrode impedances kept below 5 kOhm with inter-electrode impedance values below 3 kOhm. A maximum of 32 sweeps containing 16 epochs each was recorded per trial whilst a minimum of 5 sweeps were required to accept thresholds at all frequencies. Each epoch was 1.024 s and a complete sweep lasted 16.384 s. The presence of a response was determined using a F-ratio comparing the Fast Fourier components at the stimulus modulation frequencies to the 120 adjacent frequencies (60 bins above and 60 bins below the frequency) to determine if the difference was significantly different ($p<0.05$) from the background noise. A 10 dB down and 5 dB up threshold-seeking procedure was used. The initial stimulation intensity was based on the behavioural thresholds obtained and usually commenced 20 dB above the behavioural threshold of the worst ear.

RESULTS

Table 1 summarises the average behavioural and ASSR thresholds obtained for the sample of 96 thresholds. The smallest difference and least variation between behavioural and ASSR thresholds was observed at 1 kHz with a mean difference of 2 dB ± a standard deviation of 7 dB. The largest difference and variation was recorded at 0.5 kHz (8 ± 10 dB). The mean difference between all thresholds (0.5 – 4 kHz) is 5 dB with a standard deviation of 8 dB (range 20 – 0 dB). Comparing the pure tone average across 0.5 – 4 kHz with the same ASSR average reveals a mean difference of 5 dB with a smaller standard deviation of 5 dB.

The distribution of the difference scores for the sample is illustrated in figure 1. The vast majority of ASSR thresholds (84%) were recorded within 10 dB of behavioural thresholds compared to only 16% of ASSR thresholds differing by 15 to 20 dB from behavioural thresholds. Comparing mild to moderate (35 – 55 dB) and moderate to severe (60 – 80 dB) behavioural thresholds reveal that 86% (12/14) of ASSR thresholds were within 5 dB for behavioural thresholds of 60 dB and above compared to only 29% (10/34) for behavioural thresholds of 55 dB and below.

Figure 2 illustrates the Pearson product moment correlation between behavioural and ASSR thresholds for 0.5 – 4 kHz. Significant correlation coefficients ($p<0.05$) demonstrating a high degree of correlation between ASSR and behavioural thresholds were found at 1, 2 and 4 kHz (0.74 - 0.88). The correlation at 500 Hz was significantly poorer however ($r=0.36$). The overall correlation coefficient across all frequencies was 0.73. Considering correlation coefficients determined for behavioural thresholds equal to or less than 55 dB (34/48 mild to moderate thresholds) reveals a poor correlation ($r=0.21$) compared to a good correlation ($r=0.78$) for behavioural thresholds of between 60 - 80 dB (14/48 moderately-severe thresholds).

DISCUSSION

The range of threshold differences between behavioural and ASSR techniques for the current study (2 – 8 dB) fall well within the range of reported values for cases with hearing loss [6]. Reports do however indicate a degree of variability between threshold differences in patients with hearing loss ranging from 3 to 14 dB with standard deviations of 6 to 13 dB [6]. This variability is even more pronounced in normal hearing patients and can be attributed to several factors of which the most important include the frequency of the stimulus and the degree of hearing loss [7].

In the current study a higher difference and increased variability was noted between ASSR and behavioural thresholds for 0.5 kHz compared to higher frequencies (1 – 4 kHz). This is in agreement with previous reports that have indicated higher amplitude ASSRs for higher frequencies compared to 0.5 kHz [4, 6, 7, 8]. This leads to elevated ASSR thresholds for 0.5 kHz with a higher degree of variability. This was confirmed by the correlation coefficients indicating significantly poorer correlation between behavioural and ASSR thresholds at 0.5 kHz (r=0.31) compared to a high degree of correlation for 1 – 4 kHz regions (0.74 – 0.88). Although the correlations for the higher frequencies are in close agreement with previously published reports the poor correlation for the 0.5 kHz thresholds are lower than those reported previously [1, 4, 5, 9). This difference may be accounted for to a large extent by the fact that the current sample was confined to moderate hearing losses containing a number of thresholds in the mild hearing loss region for which the ASSR has demonstrated poorer accuracy [8, 11, 12]. The reduced accuracy of the 0.5 kHz ASSR thresholds was therefore exacerbated by the less severe degrees of hearing loss in the sample [7].

ASSR thresholds were within 10 dB of behavioral thresholds in 84% of cases (40/48). A small number (16%) of ASSR thresholds differed by more than 15 dB with a maximum difference of 20 dB. The maximum difference of 20 dB was observed in only 3 cases (6%) and in all these cases the thresholds were for 0.5 kHz as would be expected from previous findings [7, 9, 13].

The effect of degree of hearing loss can clearly be seen when considering that in the current study 86% of moderate to severe behavioural thresholds corresponded within 5 dB of ASSR thresholds compared to only 29% in the case of mild to moderate behavioural thresholds. According to correlation coefficients ASSR and behavioural thresholds were highly correlated (r=0.78) for those thresholds 60 dB and higher compared to poor correlation (r=0.21) for those thresholds less than 60 dB. This dramatic effect of hearing loss severity on ASSR accuracy has consistently been demonstrated by reports and is attributed to increased physiological recruitment in patients with increasingly severe degrees of sensorineural hearing loss [1, 7, 13]. Therefore for less severe the degrees of hearing loss more recording time is necessary to measure the small amplitude responses compared to less time required to obtain sufficient signal-to-noise ratios for more severe degrees of hearing loss.

Assessing mild to moderate hearing losses with current clinical ASSR protocols provides behavioural estimations that are highly variable especially at 0.5 kHz. For cases of mild and moderate hearing loss an average ASSR threshold value (0.5, 1, 2, and 4 kHz) may be more reliably compared to the pure tone average than estimations for individual frequencies [11]. The current study indicates a mean difference between these averages of 5 ± 5 dB for moderate hearing losses which is less variable than differences between individual frequencies. Scherf et al. [11] recommended a similar approach comparing ASSR and click evoked ABR thresholds.

In conclusion, the current study demonstrated that the ASSR reliably estimated behavioural thresholds of 60 dB and higher, but caution is recommended when estimating behavioural thresholds of less than 60 dB especially at 0.5 kHz. In such cases it may be more appropriate to consider the ASSR average threshold (0.5 – 4 kHz) to estimate the pure tone average behavioural threshold for patients.

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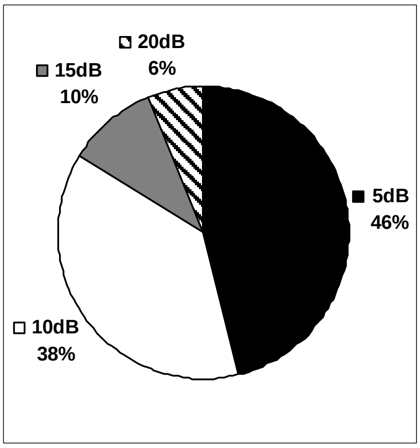

Fig. 1 ASSR and behavioural threshold differences for 48 threshold comparisons

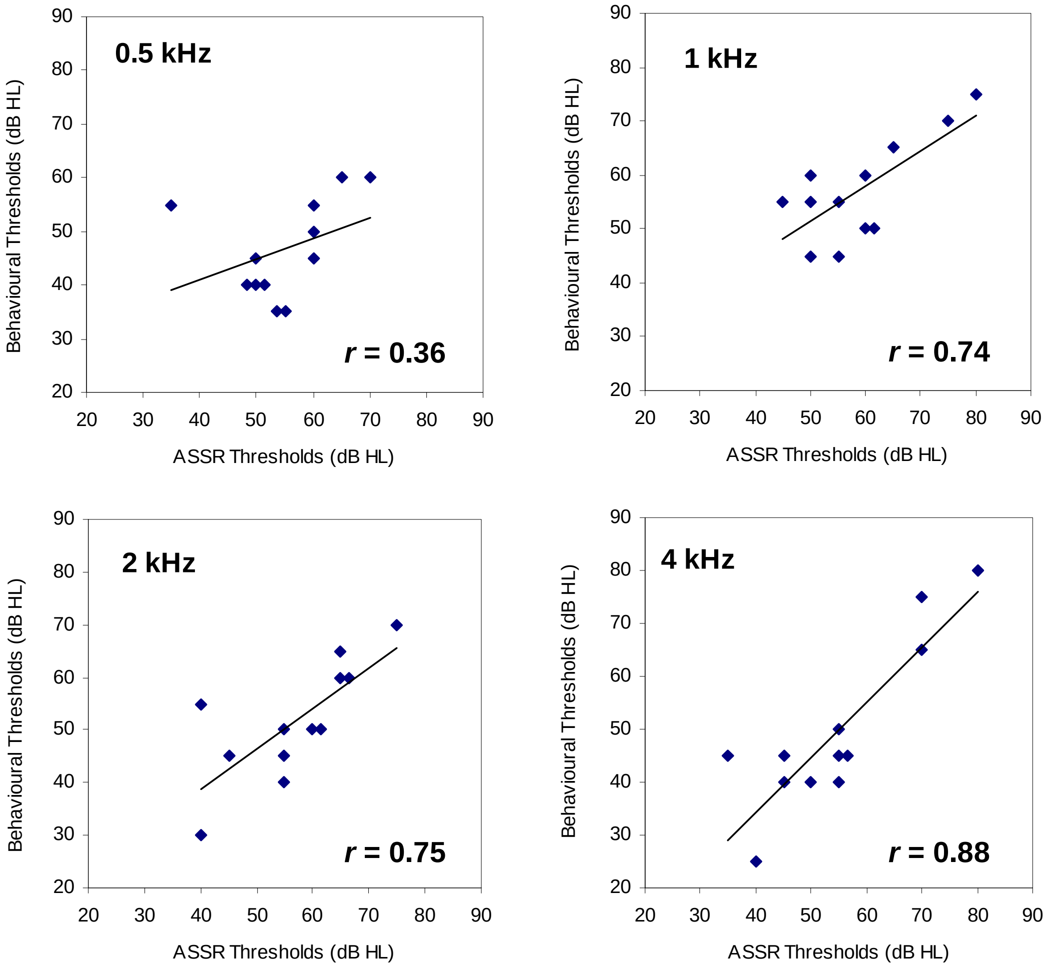

Fig. 2 Correlations between ASSR and behavioural thresholds at 0.5, 1, 2, and 4 kHz

Table 1. Mean behavioural and ASSR thresholds and the mean difference

SD – standard deviation, n – number of thresholds; Diff - difference

THRESHOLDS	0.5 kHz		1 kHz		2 kHz		4 kHz	
	Mean ± SD	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD	n
Behavioral	47±9	12	57±9	12	52±11	12	50±16	12
ASSR	55±9	12	59±11	12	57±11	12	55±13	12
Diff. Score	8±10	12	2±7	12	5±8	12	5±8	12