Objective assessment of noise-induced hearing loss:

a comparison of methods

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Abstract

Objective measures may be required to estimate hearing thresholds in individuals who feign hearing loss. This study compared two auditory evoked potential techniques, slow cortical auditory evoked potential (SCAEP) and auditory steady-state response (ASSR) for estimating behavioural hearing thresholds in adults exposed to occupational noise. Participants had either normal hearing (n=15), or a hearing loss with a history of occupational noise exposure (n=16). Mean differences between SCAEP and behavioural thresholds for both participant groups varied between 0 to 6 dB across 0.5, 1, 2, and 4 kHz with standard deviations of ±10 dB. The mean difference between ASSR and behavioural thresholds was larger varying between 22 to 32 dB with standard deviations of ±13 to 14 dB. Overall SCAEP correlation with behavioural thresholds was 0.85 compared to 0.75 for ASSR. Findings suggest SCAEP may be the objective measure of choice for this population but, unlike the ASSR, require interpretation of responses by experienced clinicians.

Key words: occupational noise-induced hearing loss, nonorganic hearing loss, auditory steady state responses (ASSR), slow cortical auditory evoked responses (SCAEP), auditory evoked responses, clinical effectiveness, stimulus and recording parameters

Introduction

The considerable financial gain resulting from exaggeration of behavioural pure tone thresholds since implementation of laws regarding hearing safety in the workplace, may account for the high incidence of nonorganic hearing loss (malingering) in this population.[1-2] Objective measures may be required to estimate hearing thresholds in individuals who feign hearing loss when behavioural audiograms continue to demonstrate inconsistencies in thresholds. Frequency specific estimations of behavioural thresholds are required for the calculation of the percentage loss of hearing.[3] Recent studies have compared the accuracy of behavioural threshold estimation using two objective auditory evoked potential measures, namely the slow cortical auditory evoked potential (SCAEP) and the auditory steady-state response (ASSR).[4-7] Auditory evoked potentials are the synchronous neural activity recorded from scalp electrodes in response to auditory stimulation.[8] By reducing the intensity of the stimuli, an electrophysiological threshold of auditory activation in the nervous system can be determined. This electrophysiological threshold is closely correlated with the behavioural pure tone audiometric threshold when frequency-specific stimuli are used.[9] Electrophysiological thresholds demonstrate greater variability when compared to the gold standard of behavioural pure tone audiometry and are typically elevated when compared to behavioural thresholds because the potential is masked by background intra-subject electroencephalic activity close to threshold.

Both the SCAEP and ASSR are non-invasive procedures capable of providing frequency-specific estimates of behavioural hearing thresholds without requiring co-operation or a specific response from the individual. The SCAEP makes use of a frequency specific transient stimulus (called a tone burst) while the ASSR uses a continuous modulated stimulus. The advantages of the SCAEP are that it is unlikely to be affected by neurologic disorders, is representative of the complete auditory system, and is more resilient to electrophysiologic noise arising from small movements than are the earlier evoked potentials.[1,10] The individual is, however, required to be alert throughout the test as drowsiness or sleep results in elevated thresholds.[11] Another disadvantage of the SCAEP is that waveforms need to be interpreted and responses identified by an experienced clinician. The ASSR offers independence of patient attention or state of arousal, although it is easily influenced by any myogenic noise related to muscle movement in the head and neck area.[12,13] In addition, ASSR software makes use of objective response detection algorithms making subjective interpretation of the waveforms unnecessary and the type of stimuli used allow for assessment at higher output levels.[14]

Although not widely used in South Africa, the SCAEP was, in the past, considered the auditory evoked potential of choice for the purpose of estimating behavioural hearing thresholds.[11,15-17] A few more recent studies have indicated that the ASSR, as the more recent technique, is capable of providing accurate estimations of hearing thresholds.[6,17-19] There is, however, disagreement regarding the choice of methods for objective behavioural threshold estimation in adults, with two of the recent comparative studies suggesting the SCAEP is more accurate whilst two others advocate the ASSR.[4-7] Only a single study has compared SCAEP and ASSR in adults claiming compensation for occupational hearing loss[6] and there are no comparative studies on the use of SCAEP and a single frequency ASSR technique for adults exposed to occupational noise. This research project therefore aimed to compare the clinical effectiveness of the SCAEP and single frequency ASSR for behavioural audiometric threshold estimation in adults exposed to occupational noise. For this purpose, clinical effectiveness was defined as the accuracy of electrophysiological thresholds in estimating behavioural audiometric thresholds.

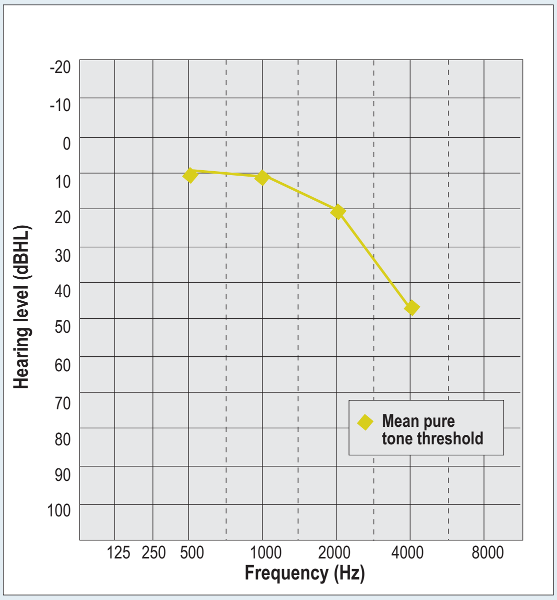


Figure 1. Mean audiogram for the hearing impaired participant group

> ***"...considerable financial gain resulting from exaggeration of behavioural pure tone thresholds...may account for the high incidence of nonorganic hearing loss..."***

Methodology

A comparative quasi-experimental research design[20] was selected in order to collect the quantitative data. The research proposal was approved by the Research Ethics Committee of the Faculty of Humanities of the University of Pretoria. Participants were divided into two groups based on audiogram and noise exposure. The group of participants with normal hearing (behavioural thresholds ≤20 dBHL) was composed of 15 adults recruited from colleagues and friends. The group of participants with hearing loss was composed of 16 adults with sensorineural hearing loss, recruited from individuals referred for audiometric screening, as part of hearing conservation programmes, and who were, therefore, exposed to occupational noise.

An experienced audiologist performed behavioural threshold testing (0.25 to 8 kHz), speech reception testing, otoscopy, tympanometry, SCAEP and ASSR testing on the same day for each participant. In order for an individual to be considered for participation in the study, behavioural thresholds had to be judged as consistent by the audiologist, and the pure tone threshold average had to fall within 7 dBHL of the speech reception threshold. Reliability of behavioural thresholds were paramount as this was the gold standard measurement of hearing sensitivity against which accuracy of behavioural threshold estimation by the SCAEP and ASSR techniques were judged.[2] As displayed in Figure 1 and Table 1, the group with hearing loss typically presented with a mild to moderately high frequency sloping hearing loss.

The GSI Audera electrophysiological system[21] was used for both SCAEP and ASSR threshold measurement. In addition to the practical advantage of the use of a single electrophysiological system and the elimination of extraneous variables that may potentially have contaminated the data had two separate systems been used, the GSI Audera was

Table 1. Mean behavioural thresholds for the group with hearing loss in dBHL (n = 30 ears)

	500 Hz	1000 Hz	2000 Hz	4000 Hz	Average of 0.5, 1, 2 and 4 kHz
Mean behavioural threshold	10.5	10.8	21.0	47.3	22.4
Standard deviation	9.7	10.3	16.1	16.2	20.1
Range	-5 to 35	-5 to 30	-10 to 50	15 to 85	-10 to 85

chosen as it makes use of a single frequency ASSR protocol. Calibration of the GSI TIP 50 insert HA-2 tubephones was completed in dBHL using a Larson Davis 824 type 1 sound level meter and a 711 coupler, in accordance with SANS 10154-1.[22] The same two-channel electrode montage was selected for both ASSR and SCAEP, namely Cz-Ai with the ground electrode midline on high forehead (Fz).

Four thresholds were measured in each ear at 0.5, 1, 2 and 4 kHz using the SCAEP and ASSR techniques. The SCAEP toneburst stimuli were 100 ms in duration with a 10 ms rise/fall time and an 80 ms plateau. Tone bursts were presented using an alternating polarity at a rate of 0.7/sec. Two to three replications of 20 sweeps were presented at each intensity, starting at 60 dBnHL, increasing the intensity by 10 dBnHL when no response could be identified, and decreasing the intensity by 20 dBnHL when a response was judged to be present. A SCAEP threshold response was defined as the lowest intensity that the P1-N1-P2 complex could be identified between 80 and 150 ms[23] by two independent clinicians.

Due to the importance of an awake and alert state of attention for SCAEP threshold determination, the ASSR threshold determination was completed after SCAEP threshold determination. The GSI Audera's recommended protocol for ASSR stimulus and acquisition parameters was used with 100% amplitude-modulation (AM) and 15% frequency-modulation (FM). A low, 46 Hz amplitude-modulation rate protocol was selected. Dobie and Wilson[24] reported that due to the decreased electroencephalic activity levels when participants are asleep, a 40 Hz amplitude-modulation protocol, despite producing smaller amplitude responses in sleeping patients, remains sufficiently robust to identify the neural response at a level close to behavioural hearing threshold. The same threshold-seeking procedure with 10 dB intensity increments and 20 dB decrements, as used for the SCAEP threshold determination was employed during ASSR testing. The GSI Audera ASSR makes use of objective response detection statistical analyses that use a phase coherence (PC^2) algorithm.[21] An ASSR threshold was defined as the lowest intensity at each frequency (single replication) where the statistical algorithm detected a response that was significantly larger than the background electroencephalic activity.

Results

The difference values between SCAEP or ASSR thresholds and behavioural thresholds were calculated by independently subtracting the thresholds obtained with the objective techniques from the behavioural thresholds (referred to as 'difference scores'). The difference scores, standard deviation and participant numbers are depicted in Figure 2.

The mean difference score for SCAEP for the combined participant groups is 2.2±10.2 dB across 0.5, 1, 2 and 4 kHz and ranged from 0 to 6 dB, in comparison to 26.6±13.1 dB for ASSR with a range of 22 to 32 dB. The largest difference scores were measured for 2 kHz for both SCAEP and ASSR.

Table 2. Pearson product correlation co-efficients for combined group of subjects with and without hearing loss

	SCAEP	ASSR
500 Hz	0.53	0.40
1000 Hz	0.48	0.49
2000 Hz	0.79	0.72
4000 Hz	0.92	0.85
All frequencies	**0.85**	**0.75**

Marginally better SCAEP difference scores were measured for the group with hearing loss (mean = 1.6 dB) compared to the group with normal hearing (mean = 3 dB).

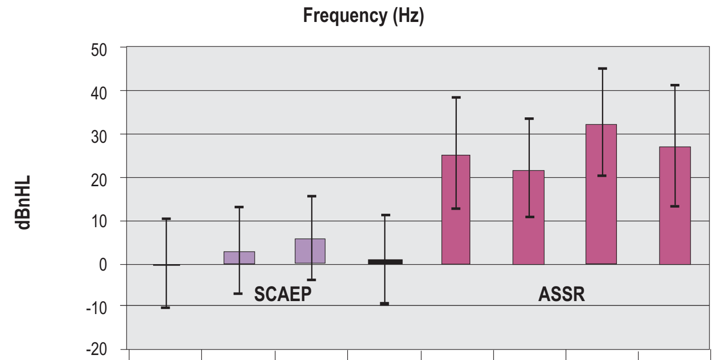
The comparative distribution of difference scores for both participant groups is illustrated in Figure 3. The majority of SCAEP thresholds (66.7%) fell within 10 dB of behavioural thresholds, with 100% of thresholds within 30 dB. In contrast, only half of the ASSR thresholds (viz. 50.2%) fell within 30 dB while 93% thresholds were identifiable within 50 dB of behavioural thresholds.

The Pearson correlation data for both participant groups are presented in Table 2. Strong mean Pearson product correlation co-efficients were measured between the SCAEP and ASSR thresholds, and behavioural thresholds. The SCAEP correlation across frequencies (r = 0.85) was stronger than ASSR correlations (r = 0.75). Both SCAEP and ASSR displayed stronger correlations at high frequencies (2 to 4 kHz; r = 0.72 to 0.92) than at mid and low frequencies (r = 0.4 to 0.53).

Discussion

In relation to the proximity of objective electrophysiological thresholds to behavioural thresholds, and consistency of this relationship, the SCAEP, rather than ASSR, is the technique of choice. The studies by Tomlin et al.[5] and Yeung and Wong[7] comparing SCAEP and ASSR threshold estimations reported similar conclusions. In contrast, the studies by Van Maanen and Stapells[6] and Kaf, Durrant et al.[4] advocated the use of ASSR as opposed to the SCAEP for behavioural threshold estimation.

Van Maanen and Stapells[6] reported a closer proximity of ASSR thresholds to behavioural thresholds for both the high and low modulation rate multiple ASSR techniques (thresholds obtained using the two rates were compared) than between SCAEP thresholds and behavioural thresholds. However, the mean SCAEP difference scores reported were 14 to 20 dB larger than the mean difference scores reported in the current study, and larger than has been reported elsewhere[1,4,5,15-17,25] which the authors attributed to the calibration method used. Van Maanen and Stapells[6] also measured ASSR thresholds which were on average 17 and 13 dB closer to behavioural thresholds across frequencies for the 40 and 80 Hz ASSR techniques respectively than was reported in the present study. This is likely to be due to the longer recording duration offered by the specific multiple frequency ASSR system used, the Biologic MASTER ASSR system[26] at threshold intensity levels (maximum of 8 min



	500	1000	2000	4000	500	1000	2000	4000
Mean diff	-0.2	2.8	5.8	0.5	25.3	21.7	32.3	27.1
Std deviation	10.2	10.1	9.7	10.4	12.8	11.3	12.2	13.8
Mean diff - std deviation	-10.4	-7.3	-3.9	-9.9	12.5	10.4	20.1	13.3
Mean diff + std deviation	10.0	12.9	15.5	10.9	38.1	33.0	44.5	40.9
n	49.0	52.0	53.0	53.0	57.0	56.0	56.0	56.0

Figure 2. Difference between SCAEP and behavioural thresholds compared to difference between ASSR and behavioural thresholds for the combined participant group

(diff = difference between SCAEP or ASSR and behavioural thresholds; std dev = standard deviation; n = number of ears)

"Auditory evoked potentials are the synchronous neural activity recorded from scalp electrodes in response to auditory stimulation.[8] "

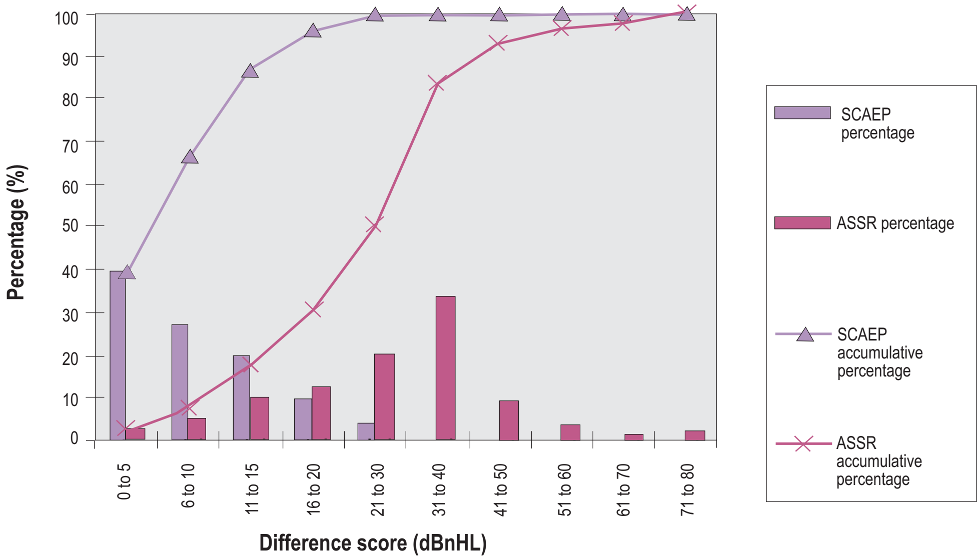


Figure 3. Distribution of difference scores between SCAEP and behavioural thresholds compared to the distribution of difference scores between ASSR and behavioural thresholds for the combined participant group

(difference score = difference between SCAEP or ASSR and behavioural thresholds)

recording duration utilized in the study by Van Maanen & Stapells[6]) as compared to the considerably shorter maximum 89 sec recording duration allowed by the GSI Audera ASSR system[21] used in the current study.

Kaf, Durrant et al.[4] compared multiple frequency ASSR thresholds obtained using a high modulation rate to SCAEP thresholds at 2 kHz only. The proximity of ASSR and SCAEP thresholds to behavioural thresholds was the same for participants with normal hearing, but ASSR thresholds were closer to behavioural thresholds than SCAEP thresholds in participants with a simulated sensorineural hearing loss. Again, it is postulated that the longer response recording time allowed by the Biologic MASTER ASSR system resulted in a reduction of noise levels and, consequently, in lower ASSR thresholds.

It is important to note that the conclusion regarding the closer estimation of behavioural thresholds with the SCAEP technique reached in the current study arose from comparisons between the SCAEP and a specific ASSR technique. A monotic, single frequency ASSR technique was used with a 40 Hz modulation rate to assess restful or sleeping adults that presented with normal hearing or with a hearing loss. The two defining factors that played a significant role in determining the ability of the ASSR technique to estimate behavioural thresholds were the response recording duration and the typical degree of hearing loss of the target population.

The short response recording duration offered by the GSI Audera ASSR system[21] (maximum of 89 sec) limits the potential accuracy of behavioural threshold estimation, and increases the amount of excessively noisy responses measured with a high modulation rate. When using the GSI Audera ASSR system, noise cannot be reduced by prolonged averaging over time. A single recording can only be repeated in the event of high noise levels. The GSI Audera makes use of the Rance et al.[27] regression formulae[21] to counteract the short recording duration and to improve accuracy of estimation of behavioural thresholds from ASSR thresholds. In contrast, the Biologic MASTER technique allows for continuation of response recording for up to 15 min or until a 10 nV noise level is reached,[26] which is considerably longer than is allowed by the GSI Audera ASSR system. Studies that utilized ASSR systems with longer recording durations, reported mean ASSR thresholds (across all frequencies) that were 7 to 26 dB smaller than in the current study.[4,6,19,28-37]

The manufacturer protocol of the GSI Audera ASSR system recommends making use of an 80 Hz ASSR protocol when testing sleeping adults.[21] However, this was found to be impractical during the pilot study as ASSR thresholds could not be obtained at 80 dB or less for the majority of the frequencies tested in two of the three participants with normal hearing when using a high modulation rate protocol due to the excessive noise levels measured. This was true

regardless of the fact that all participants slept peacefully and that the testing took place within a double walled soundproof booth. The observation of frequent high noise levels with use of the 80 Hz ASSR modulation rate parallels that of Luts and Wouters[32] (using the GSI Audera ASSR system) and Van Maanen and Stapells[6] (using the Biologic MASTER ASSR system). De Koker[18] even reported requiring the use of a sedative for sleeping adult participants in order to reduce noise levels when using the GSI Audera with a high modulation rate. This is not always a clinically feasible option. A longer recording duration facilitates the reduction of high noise levels associated with the 80 Hz ASSR. The current research found that the short recording duration allowed by the GSI Audera ASSR system did not permit a sufficient reduction in noise levels when using the 80Hz modulation rate in restful or sleeping adults.

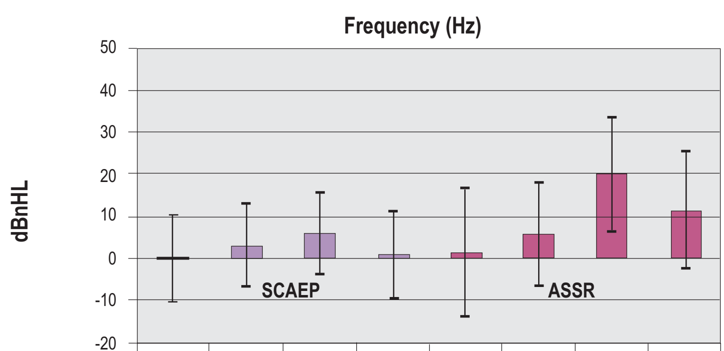
When applying the Rance et al.[27] regression formulae[21] to correct for the discrepancy between ASSR and behavioural thresholds, the corrected ASSR thresholds were still poorer than SCAEP estimations of behavioural thresholds (see Figure 4). The mean GSI Audera ASSR estimate of behavioural threshold at 2 kHz was 19.7 dB above the behavioural threshold. This elevated estimate of the behavioural threshold at 2 kHz may lead to overestimation of behavioural threshold and a greater percentage loss of hearing.[3] In addition, the standard deviation scores were slightly larger once the Rance et al.[27] regression formulae were applied (std dev scores ranged from 12.3 to 15.1 dB. The concern regarding possible overestimation of behavioural thresholds by the GSI Audera ASSR system, was affirmed by Ballay, Tonini, Waninger, Yoon and Manolidis[38] who examined the ability of the GSI Audera ASSR, using the Rance et al.[27] regression formulae, to estimate behavioural thresholds in a group of children with steeply sloping sensorineural hearing losses. The study concluded that the GSI Audera ASSR system may overestimate the degree of hearing loss above 0.5 kHz by 15 to 20 dB. In occupational noise-induced hearing loss, a 15 to 20 dB overestimation would result in inaccurate diagnosis of percentage loss of hearing[3] and excessive compensation. Therefore, despite the improved accuracy of the GSI Audera estimates of behavioural thresholds, SCAEP thresholds remained closer to the behavioural thresholds.

The second critical factor affecting accuracy of behavioural threshold estimation using the ASSR technique is degree of hearing loss. The typical adult population exposed to occupational noise will include both individuals with normal hearing and individuals with hearing loss, the latter of which will typically exhibit normal hearing at low frequencies, with a mild hearing loss at 2 kHz and a moderate hearing loss at 4 kHz. A recent study by Swanepoel and Erasmus[36] drew attention to the poor correlation between ASSR threshold and behavioural thresholds of less than 55 dB. Scherf et al.[39] confirmed these findings with considerable variation reported for estimations of behavioural thresholds when the average ASSR thresholds across 0.5, 1, 2 and 4 kHz was equal to or less than 40 dB. Therefore, because of the typical degree of hearing loss of individuals exposed to occupational noise, the ASSR may not be the best choice in objective assessment of hearing. In contrast, the SCAEP difference scores were not negatively affected by normal or mildly elevated behavioural thresholds.

Conclusion and recommendations

The SCAEP is clinically more effective (accurate) than the single stimulus 40 Hz ASSR technique to estimate behavioural audiometric thresholds in adults exposed to occupational noise. Accuracy of ASSR estimation of behavioural thresholds is however strongly influenced by stimulus, recording and participant variables and adaptations of these may result in improved estimations. The SCAEP technique, however, has been used for at least three decades and offers an accurate tool in estimation of hearing thresholds for adult populations in whom reliable behavioural testing may not be possible or may be questioned. Occupational health care practitioners should consider the SCAEP for objective estimation of behavioural audiometric thresholds but experienced clinicians who are able to record and interpret these, must however be available.

"Only a single study has compared SCAEP and ASSR in adults claiming compensation for occupational hearing loss[6]...."



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Mean diff	-0.2	2.8	5.8	0.5	1.2	5.6	19.7	11.3
Std deviation	10.2	10.1	9.7	10.4	15.1	12.3	13.6	14.0
Mean diff - std deviation	-10.4	-7.3	-3.9	-9.9	-13.9	-6.7	6.1	-2.7
Mean diff + std deviation	10.0	12.9	15.5	10.9	16.3	17.9	33.3	25.3
n	49.0	52.0	53.0	53.0	57.0	56.0	56.0	56.0

Figure 4. Difference between SCAEP and behavioural thresholds, compared to difference between GSI Audera ASSR estimates of behavioural thresholds and behavioural thresholds (combined participant group)

(diff = difference score between SCAEP or ASSR minus behavioural thresholds; std dev = standard deviation; n = number of ears)

Lessons learned

Objective measures may be required to estimate hearing thresholds in individuals who feign hearing loss when behavioural audiograms continue to demonstrate inconsistencies in thresholds.

Both the SCAEP and ASSR are non-invasive procedures capable of providing frequency-specific estimates of behavioural hearing thresholds without requiring co-operation or a specific response from the individual.

In relation to the proximity of objective electrophysiological thresholds to behavioural thresholds, and consistency of this relationship, the SCAEP, rather than ASSR, is the technique of choice in this clinical population.

The SCAEP technique offers an accurate tool in estimation of hearing thresholds for adult populations in whom reliable behavioural testing may not be possible or may be questioned.

Occupational health care practitioners should consider the SCAEP for objective estimation of behavioural audiometric thresholds but experienced clinicians who are able to record and interpret these, must however be available.

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