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Auditory Steady-State Responses in Children and Adults with Normal Hearing, and Sensorineural Hearing Loss

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Auditory Steady-State Responses in Children and Adults with Normal Hearing, and Sensorineural Hearing Loss

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Abstract

Objectives: This study was conducted at Amman University to test the clinical effectiveness of auditory steady-state response (ASSR) for estimation hearing threshold in patients with normal hearing and sensorineural hearing loss

Method: The study was carried out on 25 normally hearing students at Amman University and 35 patients who had sensorineural hearing loss (SNHL). The subjects underwent behavioral audiometric evaluation, impedance testing, distortion product otoacoustic emissions, and steady-state response testing. A t test was performed to compare the means of ASSR predicted behavioral thresholds and behavioral responses. Pearson correlation coefficients were calculated at each tested frequency, 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz, using the same data. Special care was taken to minimize possible aliasing and high-intensity multiple stimulation effects. Differences and correlations between the ASSR and pure tone audiogram were determined.

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Results: In normally hearing subjects, the ASSR thresholds are significantly higher than the behavioral pure tone thresholds specially at low frequency. In patients with sensorineural hearing loss, the ASSR thresholds are approximately similar to the behavioural pure tone hearing thresholds. The correlations between the two measures ranges from 0.84 at 0.5 kHz carrier frequency to 0.96 at 2 kHz. The correlation between ASSR and pure tone hearing thresholds increases with increasing hearing loss

Conclusions: ASSR seems to be a reliable tool for prediction of the behavioral pure tone hearing threshold in patients with SNHL. It over-predicts the severity of the loss by 15 to 20 dB above 500 Hz at each test frequency (1,000, 2,000, and 4,000 Hz). Correlation coefficients display a strong correlation at 500 Hz, 1,000 Hz, and 2,000 Hz. The reliability of ASSR in estimation hearing threshold increases with increasing hearing thresholds

فحص السمع الدماغي للنغمة الثابتة في قياس مستوى السمع للأطفال والكبار الطبيعيين والمصابين بضعف سمع حسي عصبي

ملخص

أجريت هذه الدراسة في عيادات السمع – جامعة عمان الأهلية باستعمال فحص السمع الدماغي للنغمة الثابتة وفحوصات السمع التقليدية الأخرى. اشتملت هذه الدراسة على مجموعتين, المجموعة الأولى والمكونة من 25 طالب طبيعيي السمع والمجموعة الثانية والمكونة من 35 مريض مصاب بضعف سمع حسي عصبي بمستويات مختلفة. وقد بينت الدراسة إن مستوى السمع للنغمة الثابتة للأشخاص الطبيعيين أعلى منه بقليل لمستوى السمع المقاس باستعمال الفحوصات السمعية التقليدية الأخرى, كما وبينت الدراسة إن مستوى السمع الدماغي للنغمة الثابتة للأشخاص المصابين بضعف سمع حسي عصبي مساوية لمستوى السمع المقاس باستعمال الفحوصات السمعية التقليدية الأخرى. خلصت الدراسة إلى أن فحص السمع الدماغي للنغمة الثابتة فعال ويعطي نتائج دقيقة وبمعدل 10-20 ديسبل فوق مستوى السمع للفحوصات الأخرى التقليدية على الذبذبات 1000-4000 هيرتز.

Introduction

The importance of early identification of hearing loss and its management in infants and children has led to the need for an objective neural tool to efficiently predict the audiograms over the entire auditory pathway, from the periphery to the central locations. An objective tool is necessary for this group because behavioral audiometry is difficult and in some cases impossible to conduct reliably. At present, cochlear and auditory brainstem system functions are assessed by measuring otoacoustic emissions (OAEs), Electrocochleography, auditory brainstem response (ABR) in response to clicks or tone burst. However, all of these methods have limitations.

The presence of OAEs in response to clicks indicates normal functioning of the outer hair cells only, and accordingly, auditory hearing threshold is less than 30 dB HL.[1]. The absence of OAEs may not have any clinical relevance for the prediction of hearing loss. By contrast, the ABR response to clicks is considered a cochlear-neural tool, but it lacks specificity for frequency, providing information primarily in the narrow range of 2-4 kHz. The use of tone burst increases the predictive value of the test, but it also prolongs the test duration and is associated with a restriction at the transducer output, The absence of ABR indicates the hearing threshold is more than 85 dB HL.[2] Some studies also questioned the frequency-specificity and reliability of threshold estimation in the low-frequency tone burst range.[3,4]

The auditory steady-state response (ASSR) may serve as an alternative objective tool, combining frequency-specificity and a high level of stimulation. ASSRs are elicited by continuous tones modulated in amplitude and/or frequency rather than by transient stimuli, as in ABRs.[5,6] The response is a complex periodic wave and is phase-locked to the modulation envelope of the stimulus. Low modulating rates reflect cortical activation, and high modulating rates

(more than 70 Hz) reflect subcortical activation, including the auditory brain-stem pathways, and can be recorded in sleeping infants. The potential evoked using a modulation rate of around 70-80 Hz has an equivalent latency of approximately 10 msec, supporting late brain-stem generators.[7-11]

Recent clinical studies have reported a close correlation between behavioral auditory responses and ASSR thresholds in infants, children, [12-14] and adults.[7,15] ASSRs could be reliably recorded even in cases of severe SNHL, when ABRs to clicks could not be obtained. By using different carriers and modulation rates through air or bone conduction, it was possible to identify objective thresholds close to the behavioral responses. [15] Moreover, the application of multiple modulating tones presented simultaneously to both ears significantly reduced the test duration without affecting its predictive efficacy, further supporting the use of this tool in infants and children in whom behavioral responses are limited. [16,17] Only one study to date has reported the application of ASSR in children with auditory neuropathy. [18]

It is important to note that when the ASSR is used to predict hearing thresholds in patients with severe to profound hearing loss, and when multiple auditory stimuli are presented simultaneously, two factors need to be considered: the aliasing effect and the interaction among the auditory stimuli.

During testing, there is an overlap in time between the response and the stimulus, especially for high stimulus levels with relatively high side-band energy. Thus, the stimulus energy can be aliased back to exactly the same frequency as the ASSR modulation rate and be incorrectly interpreted as a biological response. This will occur for any frequency above the request frequency (half-rate of the sampling rate). For example, at a 1 kHz sampling rate with an 80 Hz modulation rate, the 920 Hz side-band energy of the 1 kHz carrier frequency produces a spurious signal at 80 Hz (1000 Hz-920 Hz= 80

Hz), which is exactly the same frequency as the modulation rate of 1 kHz. Several techniques have been proposed to overcome or minimize the likelihood of aliasing, including the use of a sampling rate for which the carrier frequencies are not integer multiples, filtering out the EEG for all sampling rates, adding steep anti-aliasing filters, and using stimuli with frequency spectra that do not alias back to the response frequencies.[19-22] Alternating the polarity of the carrier frequency at every cycle of the modulation rate, or alternating the polarity of the auditory stimuli, may also diminish the artifacts.[19,20]
The second factor that may produce a spurious ASSR result is the interaction among the simultaneous auditory stimuli. It has been shown that if the carrier frequencies are separated by less than half an octave, especially when presented at high intensities, the responses to the low-frequency carriers are attenuated in the presence of stimuli of higher frequency, and the responses to the high frequencies are enhanced in the presence of low-frequency stimuli.[16,23] In a recent study in patients with severe to profound hearing loss, ASSRs were recorded to high-intensity auditory stimuli although no behavioral responses were obtained. This finding was attributed to possible aliasing or interactions of the auditory stimuli.[19,24]
The aim of the present study was to test the audiological clinical relevance of the ASSR technique to evaluate hearing thresholds in adults with normal hearing and SNHL average range 25-115 dB HL

Methodology

Subjects

The study was conducted on 25 normally hearing thresholds students at Amman University and 48 hearing impaired adults mean age of 43 years (range 20-68 years). All subjects had normal external ear and middle ear functions as approved by pneumatic otoscopic examination and tympanometry (multifrequency probe-tones of 226 Hz and 1000 Hz). The hearing impaired subjects were divided, according their

average hearing thresholds at 250-4000 HZ, into moderate, severe, and profound hearing loss.

The normal hearing group comprised of 11 males and 14 females volunteer students. Their average age was 19 years (range 17-23) with hearing thresholds less than 20 dB HL across frequencies of 0.25-8 kHz (total 50 ears)

The group with moderate hearing loss comprised of 11 males and 9 female. All were tested bilaterally (total 40 ears). The average aged was 47 years (range 25-56). The average pure tone hearing thresholds at 500 Hz was 47.7 (SD=8) dB HL, at 1000 Hz was 51 (SD=7) dB HL, at 2000 Hz was 47 (SD= 5) dB HL, and at 4000 Hz was 52 (SD= 6) dB HL

The group with severe hearing loss was comprised 0f 8 males and 7 female (total 30 ears)..The average pure tone hearing thresholds at 500 Hz was 77 (SD=9) dB HL, at 1000 Hz was 81 (SD=6) dB HL, at 2000 Hz was 76 (SD= 9) dB HL, and at 4000 Hz was 83 (SD= 8) dB HL.

The group with profound hearing loss was comprised 0f 8 males and 10 female (total 36 ears). The average pure tone hearing thresholds at 500 Hz was 99 (SD=5) dB HL, at 1000 Hz was 101 (SD=6) dB HL, at 2000 Hz was 114 (SD= 4) dB HL, and at 4000 Hz was 113 (SD= 3) dB HL.

Equipment

Pure tone audiometry and tympanometry measurements

All audiological tests were carried out at the Audiology department at Amman University in audiometry booths using calibrated interacoustic AC 30 audiometer and GSI (Grason Stadler) middle ear analyzer.

ASSR Recordings

ASSRs were assessed in a sound-attenuated room using the Bio-logic MASTER version 2.02 (Bio-logic System Corp). In this version, the

sampling rate A/D can be increased to 1200 Hz, and auditory stimuli above 80 dB HL are presented in a single-carrier frequency per ear. This prevents auditory stimulus artifacts from interfering with the auditory modulation frequencies, thereby rectifying the aliasing effect. The potentials were collected from a scalp electrode located at Cz and referenced to the mid-line posterior neck. Ground electrodes were attached to the right mastoid. Electrode impedance was kept below 5 kOhm at 20 Hz. Participants in the normal-hearing and SNHL groups conducted the test in the supine position; they were asked to relax, and most of them slept through the test.

Responses were collected at a sampling rate of 1200 Hz at 12-bit resolution. The electroencephalography (EEG) responses were amplified at a filter band-pass of 3-300 Hz. Consecutive data epochs of 1024 seconds were linked together to form sweeps of 16.384 seconds, which were then averaged and analyzed by a fast Fourier transform (FFT) to yield an amplitude spectrum with a resolution of 0.061 Hz. Epochs containing electrophysiologic activity exceeding 90 nV were rejected, and the next acceptable epoch was used to build the sweep.

To determine if the FFT components and the stimulus modulation frequencies were different from the background EEG activity, the values at each of these frequencies were compared by F ratio to the 120 adjacent frequencies (60 bins above and 60 below the stimulus frequency or 3.7 Hz). Frequencies at which other stimuli were modulated were excluded. This ratio was calculated against the critical values for F at 2 and 240 degrees of freedom to obtain the probability of the response being within the distribution of the background noise.[27,28] The statistical significance of the difference between the response and the background noise was set at $p < 0.05$.

To determine the ASSR threshold, stimuli were presented at 20 dB above the behavioral pure tone audiogram or the estimated behavioral free-field response. If the initial stimulus level failed to elicit a

significant response, the intensity was increased by 20 dB until the response reached significance. Inversely, if clear responses were recorded, the stimulus level was reduced in 10 dB increments until no responses were observed. In cases in which no responses could be detected in the multiple auditory stimulation test up to a level of 80 dBHL, a single, specific pure tone of up to 132 dB SPL was presented. This was done to minimize the possibility of multiple interactions among auditory stimuli presented simultaneously at stimulus levels above 80 dB HL. If the stimulation caused discomfort to the subject, the recording was stopped immediately. If the mean noise level exceeded 20 nV or the recording did not reach significant levels after 17 minutes, the test was stopped.

ASSR thresholds were primarily defined as the lowest level at which there was a significant response. The absence of a response to any of the frequencies tested using the highest stimulus level was categorized as "no response".

Auditory Stimuli for ASSRs.

Each auditory stimulus consisted of a sinusoidal tone with a carrier frequency modulated in both frequency (FM) (25%) and amplitude (AM) (100%). FM and AM modulation was conducted at the same rate. The relative phases between the AM and FM components were chosen so as to elicit the largest combined response.[29] The carrier frequencies were adjusted for maximum energy of the spectra at 500, 1000, 2000 and 4000 Hz for the left ear; the same carrier frequencies were then used for the right ear. For each carrier, the modulation frequency was unique for each ear. Stimuli were calibrated at hearing level in the MASTER setup using the reference values of Wilber and colleagues.[30] The ASSR stimuli were presented to the ears by insert phones sealed in the external ear canal, which permitted delivery of stimuli up to 132 dBSPL for single-frequency stimulation.

Statistical Analysis

Each group was analyzed separately to determine the differences between the behavioral and the ASSR threshold, and the groups were combined to correlate the behavioral and objective thresholds. Changes were evaluated using a two-way group X carrier frequency analysis of variance (ANOVA) with repeated measures across carrier frequencies. Relationships between variables were evaluated by linear regression, and the significance of these relationships was assessed by Pearson product-moment correlation coefficients. Significance was set at $p < 0.05$. A separate analysis was conducted for cases of no behavioral and/or objective responses.

Results

Figure 1 shows the mean behavioral and ASSR thresholds for each subject group. In general, ASSR threshold curves averaged across subjects corresponded well with behavioral audiometric contour averaged across subjects in all groups. The mean differences between pure tone thresholds and ASSR for each group, as illustrated in this figure, was greatest for subjects in the normal hearing group, particularly at 500 Hz. The ASSR thresholds were significantly higher ($p < 0.001$). than the pure-tone hearing thresholds at all frequencies and especially at the low-frequency range . The average behavioral threshold at 500-4000 Hz was 4 dB compared to 17 dB for the ASSR. The ASSR thresholds in the SNHL groups were similar to the pure tone hearing thresholds, and there was no statistically significant difference between them

The mean behavioral pure tone threshold – ASSR difference varied significantly between subject groups ($p < 0.001$) and by test frequency ($p < 0.001$), but there was no significant interaction between these factors ($p = 0.578$). The mean threshold difference for the normal hearing group was significantly larger than the hearing impaired groups ($p < 0.001$).A larger behavioral -to- ASSR threshold difference

was found at 500 Hz than for all other frequencies ($p < 0.001$). Table 1 details the differences between the behavioral and ASSR thresholds in the 4 groups. In the normal hearing group, the mean ASSR thresholds were higher than the average behavioral thresholds by 19 dB at 500 Hz and about 14 dB in the high frequencies . In the SNHL groups, the mean difference at all frequency does not exceed 5 dB.

Figure 2 presents the linear regression lines for the correlations between the ASSR and the pure-tone thresholds for each carrier frequency, as well as overall. The data show a strong correlation between the two thresholds, with a correlation coefficient of 0.92 for 0.5 kHz, up to 0.98 for 4 kHz; the ASSR threshold correlated with the behavioral hearing threshold by a coefficient of 0.93, regardless of carrier frequency.

Figure 2_details the linear regression formula of the ASSR and behavioral hearing thresholds for all ears and for each frequency carrier as well as for all carriers combined.

DISCUSSION

Reliable behavioral response to auditory stimulation is regularly difficult to be established in infants and young children. It is more difficult in children with intellectual challenging or multi-handicap. It may be difficult to obtain a clear for a reliable audiogram. Furthermore, the use of sound field audiometry in infants is limited by the stimulation level of the loudspeakers, which ranges between 80 and 90 dB HL across frequencies. Sound field stimulation is also not useful for detecting unilateral losses. The reliability of infant pure tone audiometry is questionable when the infants have middle ear effusion or Eustachian tube dysfunction [36]. This study was directed to assess the predictive value of ASSRs in clinical audiology as an objective, frequency-specific audiometric tool in normal hearing and three groups of adults with various degrees of hearing loss

The results of this study for normal-hearing group which illustrates the ASSR is significantly higher ($p<0.05$) than the behavioral pure tone hearing threshold mainly at the low-frequency range. The mean differences were similar to those reported in other studies.[15,27,31,37] The poorer estimation of behavioral thresholds with the ASSR in this group may have been related to the method of response detection, changes in the ASSR amplitude, and the level of noise and artifacts during the ASSR test. Furthermore, the ASSR amplitude decreased as the stimulus level was attenuated, reaching about 20 nV 5-10 dB HL, which is very close to the EEG noise level. Thus, the detection of small ASSR signals around the hearing thresholds in normal-hearing subjects is difficult, particularly when the subjects are awake and producing muscle and environmental noise, as some were in our study. This explanation is supported by the finding that within a single stimulation-intensity level, the ASSR amplitude was higher in the high frequencies (2-4 kHz) than in the low frequencies (0.5-1 kHz).[15, 21] Consequently, in our study, the mean difference between the ASSR and behavioral thresholds decreased to 13 dB HL at the high-frequency range compared to 19 dB HL at the low-frequency range.

Differences in hearing thresholds between pure-tone audiograms and the ASSR may also be related to differences in the threshold determination technique. In the present study, the physiologic thresholds were recorded using a bracketing technique. Initially a stimulus was presented at sufficient intensity level to record the ASSR. The stimulus was then reduced in 10-dB HL increments until no response was obtained. The ASSR threshold was defined as the lowest stimulus intensity at which a significant response could be distinguished from background noise. By contrast, in the pure-tone audiogram test, we used a 10 dB-down, 5 dB-up threshold as recommended by the British Society of Audiology method A [40], which yielded more accurate hearing thresholds. Applying the latter

technique to the ASSR would significantly increase testing time while not necessarily increasing accuracy, considering the low ASSR amplitudes around thresholds, especially with multiple auditory stimulations. Thus, the ASSR does not seem to be the optimal audiometric tool for objectively determining hearing thresholds in normal-hearing subjects

The ASSRs predicted the behavioral thresholds with more accuracy in the groups with hearing loss than in the group with normal hearing. The differences in the prediction value of the ASSR between the normal-hearing subjects and the patients with SNHL may be explained by the finding that the amplitude of the ASSR is higher in subjects with SNHL than in normal-hearing subjects[15,21,31] resulting in a better ASSR signal-to-noise ratio and, consequently, a more easily detected threshold level. The high ASSR amplitude in the SNHL group is caused by the presence of loudness recruitment.[31] Thus, in this group, the ASSR can accurately predict the behavioral thresholds across frequencies, making it a suitable tool not only for assessing the degree of the hearing loss but also for objectively predicting the configuration of the audiogram.[28,32] This is very important in cases of hearing loss in a restricted frequency range, such as noise-induced hearing loss.[33, 39]

Correlation and regression analysis of the ASSR findings with the behavioral pure-tone audiograms within each frequency yielded coefficients for 0.92 at 500 Hz to 0.98 at 4000 Hz. Across all carriers, the coefficients is 0.93,. The mean physiological ASSR threshold were greater than the behavioral thresholds by 7 dB HL (range 0 – 40 dB). The wider scattered results is clearly noticed for normal hearing groups. These results are incoherence with previous studies [15,37,39]._which reported similar correlations between ASSR and pure-tone audiograms. Together, these studies emphasize the clinical value of ASSRs as an objective audiometry tool for predicting the behavioral audiogram across different frequencies.

The most efficient audiometric tool in terms of duration and accuracy is the pure-tone audiogram. However, in cases Pseudohypacusis, the ASSR test is preferred. Testing two ears with 8 frequencies takes 25 to 40 minutes. Sound field audiometry tests for 4 frequencies take 20 minutes, but they cannot detect unilateral thresholds. One the other hand, infants pure tone audiometry which allows testing unilateral behavioral pure tone thresholds at for 5 frequencies may take 20-30 minutes and required an skillful in pediatric audiology [38]. Thus, the information yielded by the ASSR is more accurate, although in some young children, and also the new technology of ASSRs [41] which does not require sedation is an additional advantage.

Conclusions

It can be concluded from this study that the ability of ASSR to detect thresholds in the 0.5-4 kHz range is close to that of pure-tone or conditioning tests. The ASSR identifies not only the degree of hearing loss but also its configuration. In normal-hearing subjects, the large differences between the behavioral pure-tone audiogram and the ASSR suggest that the ASSR is not the optimal audiometric tool in this group. However, in contrast to the SNHL groups where the ASSR thresholds was almost equal (within 10 dB) to the behavioral thresholds and probably owing to the better detection accuracy of the MASTER technique and its higher stimulus level as compared to behavioral techniques for specially needed patients. Therefore, this measure may serve as a valuable clinical tool in assessing the hearing thresholds for infants, young children and especially needed patients. It also probably, facilitates the efficacy of early intervention either by conventional or cochlear implantation.

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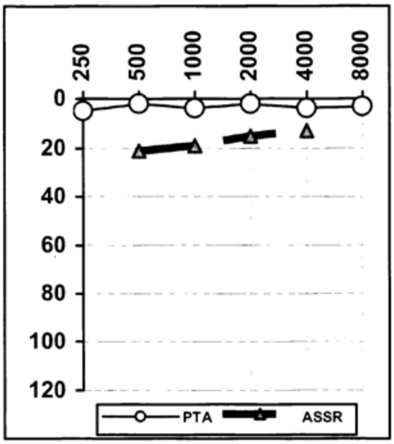
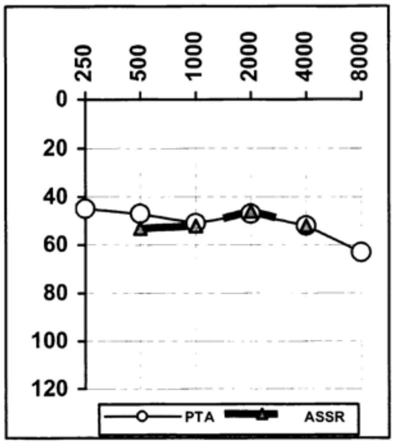
Table 1: Differences between pure tone hearing thresholds and ASSR thresholds (dBHL) by carrier frequency

		Threshold difference			
		(ASSR-pure tone dB)			
Group	Statistics	500	1000	2000	4000
	Mean dB	19	15	13	14
Normal	SD	9	9	8	8
	Max	35	30	25	30
	Min	5	0	0	0
Moderate	Mean dB	5	2	2	2
SNHL	SD	3.7	3	3	4
	Max	10	10	10	10
	Min	0	0	0	-10
Severe	Mean dB	2	2	1	1
SNHL	SD	4	4	5	2
	Max	10	10	10	10
	Min	0	-5	-10	0
profound	Mean dB	2	1	1	0
SNHL	SD	5	3	4	2
	Max	10	5	5	10
	Min	0	-5	-5	0

Figure 1 ASSR and behavioral thresholds for each group in frequencies of 500, 1000, 2000, and 4000 Hz.



Normal Hearing group



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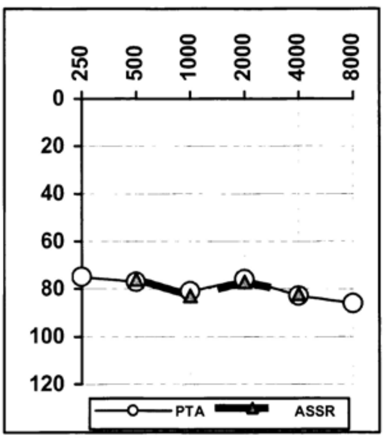
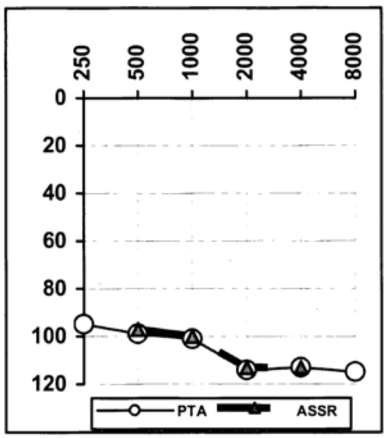


Severe SNHL



Profound SNHL

Figure 2 Correlations between <u>ASSR</u> and pure-tone thresholds