Comparing tone Audiometry and ASSR on adults.

Michael Tappis

SAERA. School of Advanced Education Research and Accreditation

ABSTRACT

ASSR is an objective electrophysiological method for determining hearing loss thresholds in specific frequencies. Exploring the reliability of this method through comparison with the tonal audiometry has often been the subject of articles in audiology.

A methodical review of published articles in English of the last fifteen years have been processed and after the systematic study and correlation, eight articles were included. In all articles, adult participants were examined with a tonal audiometry and then with ASSR and an attempt was made to compare the thresholds obtained from the two examinations with statistical methods. Results were expressed in terms of the correlation of the thresholds resulting from the two methods in relation to the examined frequency and also in groups of patients with different degrees of hearing loss.

Regarding the degree of hearing loss, most authors converge that the correlation of the two types of tests is higher in people with moderate sensorineural hearing loss and the lowest in subjects with normal hearing. Two of the eight authors reported that no statistically significant difference was found in the accuracy of ASSR thresholds depending on the degree of hearing loss. In terms of frequency, the correlation between the thresholds of the tonal audiometry and the ASSR was high for all frequencies. Three researchers found larger deviations of the thresholds at the frequency of 500 Hz. The other authors did not report statistically significant differences between different frequencies.

ASSRs are a reliable tool in assessing hearing loss. Disadvantages such as the difference of the ASSR thresholds from those of the tonal audiometry in people with normal hearing found in several studies and also larger deviations in some frequencies compared to others need further improvement.

Keywords: *Audiology, ASSR, tonal audiometry*

INTRODUCTION

The measurement of acoustic acuity is usually based on behavioural methods in which the patient is actively involved in the process. Tonal audiometry is the main method for measuring acoustic acuity (gold standard). However, there are categories of patients such as infants, newborns, young children and adults with mental retardation or in a coma who in fact cannot cooperate to assess their hearing with the traditional tonal audiometry. The development of Electric Response Audiometry (ERA) responded to the need to create reliable objective methods for measuring acoustic acuity that do not require the active participation of the patient. This category of tests uses electrophysiological methods to determine acoustic acuity by recording electrical activity along the auditory nerve pathway. In this category of electrophysiological methods belong the Auditory brainstem response (ABR), Auditory steady state responses (ASSR) but also others such as Cortical electric response audiometry (CERA). ASSR is a newer method than ABRs and offer advantages over the latter in terms of test objectivity and threshold determination at various frequencies (Rosser, 2011). It is obvious that ASSR is a very useful test and that is why in recent years an increasing number of studies investigate the effectiveness and reliability of the ASSR method in diagnostic audiology. There are many factors that can affect the accuracy of ASSRs in achieving thresholds close to those of the tonal audiometry. Such is the frequency examined each time (carrier frequency), the degree of hearing loss but also others such as the modulation frequency (MF), the patient's age, the patient's state during the examination (awake or sleeping), the duration of the examination and in particular the time given to each stimulus presented to receive a response, the stimulus presentation technique that are either presented as one frequency at a time (single frequency stimulation) or as 4 frequencies simultaneously (multifrequency stimulation), the examination of one ear each time or both at the same time and the type of equipment used and some other factors. All these factors have been examined from time to time and now every equipment has built-in protocols with appropriate settings per case. There are many publications that have contributed to the optimal configuration of the examination and in this study these results are analysed.

What is ASSR

ASSR is an electrophysiological response to a continuous stimulus that remains constant over time and can be presented as single or multiple (Picton, 2003). Specifically, it is an auditory stimulus that occurs in the ear with headphones and is induced in the brain as a nerve impulse. The stimuli in ASSR are frequency specific which means they are sounds that stimulate specific areas of the cochlear that correspond to specific frequencies (carrier frequencies). These stimuli are either pure tones, tone bursts, filtered clicks, or chirps (Douglas, 2007). Each stimulus in ASSRs is modulated before it occurs. 4 types of modulation are used: Amplitude modulated (AM), frequency modulated (FM), mixed modulation (MM), and finally repeating sequence gated (RSG). Each type of configuration has advantages and disadvantages. AM tones are the most frequency-specific stimuli while MM tones are the least frequency-specific but also produce wide range and distinct responses (John, 2003). In summary, the carrier frequency is the one at which the stimulus is presented in the test, while the modulation frequency (MF) refers to how often per second the stimulus is repeated or changes in amplitude or frequency depending on the type of configuration.

Single and multiple ASSR

There are 2 techniques for presenting stimuli in ASSRs. In the first technique, a single stimulus is presented that corresponds to a single carrier frequency at a time. In the second, many carrier frequencies are examined simultaneously in both ears. Each of these carrier frequencies have their own unique modulation frequency so that it is distinct from the others. This technique has the advantage that it significantly reduces the examination time without affecting the quality of the result. (Herdman, 2001, 2003) The technique of presenting the stimuli as single or multiple has been the subject of research as to which one brings the best results and is an element that is always mentioned when processing the results. The term MASTER refers to an ASSR type that uses the technique of multiple frequencies in 2 ears simultaneously while the AUDERA system uses the technique of single frequency.

Modulation frequency

When the first measurements of acoustic acuity were made using ASSRs, a frequency of 40 Hz was used to modulate the carrier signal. However, the results were reliable only in adults who were awake (Jerrger et al., 1987; Linden et al., 1985). This restriction created the need to define new parameters that would allow a reliable examination of infants and young children in a state of sleep. Later it has been proven that ASSRs can be recorded reliably at higher modulation frequencies >70 Hz (Cohen et al., 1991). Subsequent studies have found that the 80 Hz ASSR is more suitable for examination in infants and children as at this modulation frequency the response amplitude is greater than at the 40 Hz modulation frequency (Tomlin et al., 2006). There is a disagreement in the literature as to the most appropriate modulation frequency for the adult examination.

Anatomical elements of the nervous system and ASSR

When recording a response from the auditory nervous system and making a diagnosis based on that response it is useful to know where this response comes from and how it arises. ASSRs are produced by stimulating the cochlear hair cells. The neurons of the peripheral auditory pathway respond synchronously with the rate of stimulus presentation, while as we move more centrally towards the auditory cortex the neurons respond simply by increasing their rate of depolarization (Picton et al., 2003). The more centrally we move along the auditory nerve pathway, the smaller the range of stimulus presentation rate to which neurons can respond synchronously. Cortical neurons have been found to be able to depolarize at a maximum rate of 50-100 Hz while brainstem neurons are able at frequencies up to over 1000Hz. After years of research in humans and experimental animals, it is considered that depending on the modulation frequency (40 or 80 Hz) ASSRs are produced at a different point. The 80 Hz ASSR is produced closer to the brain stem while the 40 Hz ASSR is produced more centrally in the cortex (Picton et al., 2007; Swanepoel et al., 2007; Herdman et al., 2002).

Signal to noise ratio (SNR)

The response we get with the ASSR test is a record of the electrophysiological activity produced by the stimulation of the auditory nerve pathway and must be distinguished through the electrophysiological "noise" of the electroencephalogram. To do this, techniques are used that suppress the noise and amplify the signal (John et al., 2002; Picton et al., 2003). Noise levels have been found to decrease with increasing test time as well as with increasing modulation frequency (John et al., 2002). Various studies have been carried out to find the most appropriate carrier signal modulation frequency that ensures the best SNR in children. At 40 Hz MF the noise is high so the 80 Hz MF is more optimal for the pediatric population (Picciotti et al., 2012).

Objectives

The purpose of this study is to review the available literature in order to answer the following questions:

• What is the correlation between the thresholds resulting from the tonal audiogram and the thresholds resulting from the ASSR depending on the degree of hearing loss in adults.

• What is the correlation between the thresholds resulting from the tonal audiogram and the thresholds resulting from the ASSR depending on the frequency in adults.

• Are ASSRs a reliable method to determine hearing loss?

• What is the position of ASSRs as a diagnostic tool in audiology today.

Methods

A review of the international literature on the subject was carried out. The bibliography was searched on online platforms like PubMed, Cochrane Library and Google Scholar. The search was done in the fields: title, topic, summary and keywords. It was done using the following keywords: ASSR, pure tone audiogram, hearing threshold, pure tone audiometry, comparison, hearing loss, normal hearing and their combination. The combination of words that had the most relevant results on the subject were: ‘’ASSR and pure tone audiometry ‘’and ‘’ASSR vs pure tone audiometry’’. With this search there was a total of 31 articles and some of them excluded and the number reduced to 21. The reason for the exclusion was no English text or no summary. The ones with duplicate references and no direct correlation with the research field excluded and finally 8 articles included in the review.

Results

Results from articles on the correlation of the TA and the ASSR according to the frequency and degree of hearing loss

Picton et al., (2005), investigated the correlation between tonal thresholds and ASSRs in 30 patients. They used a MASTER device and examined the patients at the 4 basic frequencies (CF) that were modified in amplitude and frequency with the frequencies of 78-110Hz (MF). Regarding MF the results showed that with MF ~ 78-95 dB the largest deviations of the thresholds were found at the frequency of 500Hz and increased as the test duration decreased for all groups of subjects.

Specifically, the average difference of the thresholds for the 4 frequencies and for the 3 groups of participants were: For the first group 21.3, 6.8, 9.5 and 13 respectively, for the second group it was 21.3, 7.3, 11.3, 11.5 respectively, for the last group it was 10.8, -4, 2.5, 5.3 respectively. Regarding the degree of hearing loss, the authors found that the ASSR thresholds showed the smallest deviations from those of the tonal audiometry in patients with sensorineural hearing loss and the largest in those with normal hearing. Specifically, the mean deviation for the 3 groups of patients was: For Normal hearing group 12.6 ± 8.7 dB, for the elderly with normal hearing or mild hearing loss 12.4 ± 11.9 dB and for the sensorineural hearing loss group 3.6±13.5 dB. These differences were attributed to the phenomenon called "physiological recruitment".

Canale et al., (2006), attempted to compare the thresholds resulting from ASSRs with those of the tonal audiogram in order to determine their correlation according to the degree of hearing loss. Eleven subjects, 13 ears with normal hearing and 9 with hearing loss (8 sensorineural and 1 mixed type) were examined, of which 3 had severe hearing loss, the 3 moderate degree and the 3 mild degree. A MASTER device was used and the MF was 77-105Hz. The subjects were all adults at rest but not asleep. The average test duration was 45 minutes. Response to the ASSR test gave 19 ears. In the 3 ears with thresholds in the tonal audiogram >70 dB it was not possible to receive a response in the ASSR. In 2 ears with normal hearing, it was not possible to achieve a threshold between TA and ASSR thresholds for all ears was 28 dB. Ahn et al., (2007), compared the thresholds of tonal audiogram and ASSR at different degrees of hearing loss and by frequency. 18 ears were excluded with profound hearing loss not measurable on the tonal audiogram nor in the ASSR and those who had no threshold at least one of the 4 main frequencies in any of the 2 methods. MASTER device was used to record the ASSRs and the MF was 82-99 Hz for TA thresholds 90 dB HL. Regarding the frequency, it was found that the TA and ASSR show a high correlation. The correlation coefficients for all the subjects were found as follows: At 500Hz the coefficient was 0.94, at 1000Hz it was 0.95, at 2000Hz it was 0.94 and at 4000Hz it was 0.92. Regarding the degree of hearing loss, the subjects were divided into 3 groups: normal hearing, mild to moderate hearing loss and severe hearing loss. This study found a very strong correlation of thresholds for patients with mild to severe hearing loss and a weak correlation for those with normal hearing.

Ozdek et al., (2010), compared the thresholds of TA and ASSR in patients with normal hearing and in patients with sensorineural hearing loss as well as the correlation of the thresholds by frequency. The patients were divided into 2 groups and only 1 ear was examined in each person: 1st group with normal hearing, 2nd group with sensorineural hearing loss. ASSRs were recorded with the AUDERA system, the MF was 46 Hz and the patients were awake but relaxed. From the above results a strong correlation of the TA and ASSR thresholds for the group with sensorineural hearing loss and a weaker one for the group with normal hearing. In both groups the average difference of the thresholds did not exceed 15 dB. In terms of frequency, this study concluded that in both groups there is a stronger correlation of TA and ASSR thresholds at frequencies 500, 1000 and 2000

Hz and weak at 4000Hz frequency. Beck et al., (2014), studied the correlation of TA and ASSR in people with normal hearing. They included 26 adults. All participants underwent tonal audiogram and showed thresholds less than or equal to 25dB HL. The ASSR measurement was done with a device MASTER and MF 82-99 Hz. The authors note that the ASSR test was performed on all participants under excellent conditions. The results showed a high correlation coefficient of the thresholds for the two methods. Specifically, the average differences of the thresholds in dB per frequency were: At 500Hz 7.12dB, at 1000Hz 7.6dB, at 2000Hz 8.27dB and at 4000Hz 9.71dB. The average difference between the thresholds for all frequencies is a total of 8.175dB and no statistically significant difference was found between the frequencies.

Hosseinabadi et al., (2015), compared the thresholds of tonal audiogram with those of ASSR depending on the degree and the type of hearing loss. Regarding the type of hearing loss, no differences were found in the correlation with the TA thresholds between the 2 groups. The mean difference of the ASSR and TA thresholds for the 2 hearing groups was similar in all 4 frequencies and no statistically significant difference was found between them. In terms of frequency, it was observed that the differences between the TA and ASSR thresholds decreased as the frequency increased for the 2 groups of hearing loss while this was not observed in the group with normal hearing. Regarding the degree of hearing loss, the differences between the groups were statistically significant with the exception of the frequency of 500 Hz. As a result, ASSRs have the ability to distinguish between different degrees of hearing loss, which is very important in detecting even small threshold drops in children that must be treated immediately so that there are no consequences in their learning and development. Another important point that emerged was that the differences between the TA thresholds and those of the ASSRs became smaller as the degree of hearing increased.

Wadhera et al., (2017), examined the correlation of TA and ASSRs according to frequency and degree of hearing loss. This is the study with a larger number of patients, 120 people, all adults divided into 3 groups depending on the degree of hearing loss: 1st group: normal hearing, 2nd group: sensorineural hearing loss. This group was divided into 2 subgroups. One included patients with a TA threshold of 26-55 dB and the other included patients with a TA threshold > 55 dB. 3rd group: Conductive hearing loss. The ASSR test was performed with a MASTER device and MF 77-93 Hz. Regarding the degree of hearing loss, the ASSR and TA thresholds showed a high correlation in all frequencies for the groups of sensorineural and conductive hearing loss, while the correlation was found to be weaker for the group of normal hearing. In terms of frequency, the highest correlation for both groups of hearing loss occurred at 1000 Hz. Strong correlation of the thresholds was shown in the group of sensorineural hearing loss. No threshold difference greater than 15dB was found in all groups and at any frequency.

Himanshu et al., (2019), compared the thresholds of the TA with those of the ASSR in 70 patients with normal hearing and in patients with hearing loss. The patients were divided into 3 groups as follows: 1st group: normal hearing, 2nd group: 25 people with sensorineural hearing loss. 3rd group: conductive hearing loss.

The MF was 80Hz and 100 Hz. In terms of frequency, a strong correlation was found between TA and ASSR at all frequencies at the 3 groups. Regarding the degree of hearing loss in all 3 groups and in the 4 frequencies the ASSRs showed thresholds 10dB above the thresholds of the TA.

The following table summarizes the results extracted by the above studies. Table 2 shows if the correlation between the tonal audiometry and ASSR's is high, mid or low for the different types of hearing loss in each frequency.

Table2. *Comparison results of tonal audiogram thresholds and ASSRs*

	500hz	1Khz	2Khz	4Khz
NORMAL	low	low	low	Low
MILD	mid	mid	mid	mid
MODERATE	high	highest	high	high
DEEP	n/a	n/a	n/a	n/a
CONDUCTIVE	mid	mid	mid	mid

According to the above, the correlation is higher the greater is the degree of hearing loss but at severe hearing loss no ASSR's can be detected. Also, the correlation is higher at the frequency of 1khz. For conductive hearing loss the result is that the correlation is not that high as sensorineural hearing loss but it is much higher than normal hearing. Finally, ASSR's have the ability to distinguish between different degrees of hearing loss and this is very important for determining hearing loss in children.

Discussion

One of the main goals of ASSR is to achieve results that are as close as possible to TA. Whether this goal is achieved in different groups of patients with different degrees of hearing loss but also in terms of accurate determination of thresholds at each frequency has been the subject of research. The comparison between thresholds derived from TA and those of ASSR were made by calculating the mean difference of values with their standard deviation or the correlation coefficient. This depends on how the results were presented in each study.

Comparison of TA and ASSR according to the degree of hearing loss

Picton et al., (2005), examined 30 patients divided into 3 groups with different TA thresholds. For all groups the same MF was used, MF = 78-95. For the 1st group the mean difference of the TA and ASSR thresholds with the SD for the frequencies of 500, 1000, 2000, 4000 Hz was 21.3 ± 8.3 dB, 6.8 ± 7.8 dB, 9.5 ± 5.8 dB and 13 ± 6.8 dB. For the 2nd group the mean difference of the thresholds with the standard deviation was 21.3 ± 14 dB, 7.3 ± 10.2 dB, 11.3. 7 dB and 11.5. 9.6 dB for the frequencies 500, 1000, 2000, 4000 Hz respectively. For the 3rd hearing group the mean difference of the thresholds with the standard deviation for the above frequencies was 10.8 ± 18.4 dB, -4 ± 9 dB, 2.5 ± 11.3 dB and 5.3. 12.3 dB. In total for all 4 frequencies and after recording 9.8 minutes for each stimulus, the mean difference of the TA and ASSR thresholds was for the 1st group 12.6 dB with a minimum value of 3.9 dB and a maximum of 21.3 dB. For the 2nd group the corresponding mean difference was 12.4 dB with a minimum value of 0.5 dB and a maximum value of 24.3 dB, and for the 3rd group the mean difference was 3.6 dB with a minimum and maximum value of -9.9 and 17.1 dB respectively. It is obvious that the mean deviation of the TA and ASSR thresholds was significantly higher in people with normal hearing or mild hearing loss (1st and 2nd group) than in those with sensorineural hearing loss (3rd group). For all 3 groups the MF, the examination conditions and the recording time for each stimulus were common. In fact, the recording time was found to play a very important role in the reliability of the response. Picton et al., (2005) found that as the number of sweeps increased, the thresholds recorded in the ASSRs decreased and converged with the behavioral ones in all groups. The fact that the TA and ASSR thresholds for patients with sensorineural hearing loss are more correlated than those of normal hearing thresholds has been found in previous studies and attributed to the phenomenon of "physiological recruitment". As a result, the range of ASSR responses are greater for near threshold intensities in hearing-impaired patients than in normal-hearing individuals, and a sharp increase in the perception of stimulus intensity near the threshold is recommended.

Canale et al., (2006), examined 17 ears in 4 groups: 1st group normal hearing with threshold, 2nd group mild sensorineural hearing loss with threshold, 3rd group moderate sensorineural hearing loss and group 4 severe sensorineural hearing loss. The mean difference of the TA and ASSR thresholds for the for the first group was 32 dB (SD = 13.8), for the group with mild hearing loss 30 dB (SD = 12.5) and for the third group 11.7 dB (SD = 2.9). These differences indicate that the greatest deviation of the thresholds for the two examinations was observed in the group of normal hearing and mild hearing loss, while the greatest convergence was observed in the group of moderate hearing loss. It should be noted that ASSR thresholds were not detected in patients with TA threshold > 70 dB. The correlation of the thresholds of the two tests was significant, with r = 0.71, and the difference between their thresholds is, in the case of people with normal hearing, about 35 dB, and is reduced in patients with hearing loss. The test was performed with MF = 77-105 Hz and MASTER technique. Regarding the relationship between the degree of hearing loss and the difference between the thresholds of the two tests, Canale et al., (2006) agree with Picton et al., (2005) that the accuracy in determining the ASSR threshold is greater in the presence of hearing loss. The authors, in this case too, attribute this fact to the phenomenon of "physiological recruitment". However, the mean threshold difference for all groups, as determined by Canale et al., (2006), is higher than that of Picton et al., (2005).

Ozdek et al., (2010), used the technique of single ASSR (AUDERA) and MF = 46 Hz. Participants divided into 2 groups as follows: 1st group, normal hearing, 2nd group, moderate sensorineural hearing loss. The correlation coefficient of the thresholds TA and ASSR was: 1st group. At 500 Hz 0.165, at 1000Hz 0.352, at 2000Hz 0.146, at 4000Hz 0.472. 2nd group. At 500 Hz 0.92, at 1000 Hz 0.931, at 2000 Hz 0.953, at 4000 Hz 0.774. From the above results a strong correlation of the TA and ASSR thresholds for the group of sensorineural hearing loss and a weaker one for the group of normal hearing. Nevertheless, the mean difference between the TA and ASSR thresholds was Komazec et al., (2010), used a large sample of patients, who were examined by

MASTER technique and MF = 40 Hz. This frequency was chosen, according to the authors, because in the literature it showed that it has better results in awake adults (Cone-Wesson et al., (2002); Yeung et al., (2007). Specifically, the 92 ears were divided into 6 groups: 1st group, normal hearing, 2nd group, very mild hearing loss, 3rd group, mild hearing loss, 4th group, moderate hearing loss, 5th group, severe hearing loss, 6th group, profound hearing loss. For profound hearing loss group, no ASSR threshold could be identified. For each group the correlation coefficients r between TA and ASSR thresholds were: 0.64, 0.63, 0.79, 0.93, 0.67 for the first 5 groups in order from 1st to 5th. The lowest correlation coefficients were found in individuals with normal hearing (0.64) and very mild hearing loss (0.63), while the highest in individuals with moderate sensorineural hearing loss (0.93). In 85% of the ears, the mean difference between the TA and ASSR thresholds was <10 dB. Individually, the difference ranged between 0 and 45 dB. The biggest difference was found in an ear with normal hearing. These findings confirm the findings of previous researchers regarding the correlation of TA and ASSR thresholds according to the degree of hearing loss.

Beck et al., (2014), studied the association of TA and ASSR thresholds only in individuals with normal hearing. The study included a sample of 52 ears, one of the largest in the literature. The test was performed with MASTER technique and MF 82-98 Hz. The average differences of the thresholds in dB per frequency were as follows: At 500 Hz 7.12 dB, at 1000 Hz 7.6 dB, at 2000 Hz 8.27 dB and at 4000 Hz 9.71 dB, while the average difference between of the thresholds for all frequencies was 8.175 dB. These average differences are among the smallest in the literature for people with normal hearing. This is probably due to the large sample size, the ideal test conditions, the sufficient test time and the small "step" (5 dB) of reducing the stimulus intensity when finding the threshold. It is important to note that such conditions are very difficult to achieve in day-to-day clinical practice.

Hosseinabadi et al., (2015), examined 54 patients who were divided into three groups. 1st group, with normal hearing. 2nd group, sensorineural hearing loss, divided into two subgroups according to the threshold (1st subgroup: moderate HL, 2nd subgroup: moderate HL). 3rd group, conductive hearing loss. Regarding the type of hearing loss, no correlation was found between TA and ASSR which means that the type of hearing loss has no significant effect on the ASSR thresholds. Regarding the degree of hearing loss, the average difference of the TA and ASSR thresholds for the frequencies 500, 1000, 2000, 4000 Hz respectively were: 1st group 17.6 ± 7.5 dB, 18.7 ± 7.3 dB, 15.4 ± 7.2 dB, 14.7 ± 8.3 dB, 2nd group: 1st subgroup 17.8 ± 9.4 dB, 11.8 ± 7.5, 10.0 ± 7.7, 7.0 ± 8.1, 2nd subgroup 13.3 ± 10.6 dB, 8.6 ± 7.8 dB, 10.4 ± 9.6 dB, 6.0 ± 8.0 dB. From the above it can be seen that the average difference between TA and ASSR thresholds decreases as the frequency and degree of hearing increase, a finding that is consistent with the results of the previous studies. Regarding the degree of hearing loss, the differences between the groups of normal hearing, mild hearing loss and moderate hearing loss were statistically significant with the exception of the frequency of 500 Hz. As a result, ASSRs have the ability to distinguish between different degrees of hearing loss, which is very important in detecting even small threshold drops in children that must be treated immediately so that there are no consequences in their learning and development. Another important point that emerged was that the differences between the TA thresholds and those of the ASSRs became smaller as the degree of hearing increased.

Wadhera et al., (2017), divided the participants into 3 groups: 1st group: normal hearing. 2nd group, sensorineural hearing loss. This group was divided into 2 subgroups. One included patients with a TA threshold of 26-55 and the other included patients with a TA threshold> 55 dB. 3rd group: conductive hearing loss. The test was performed with MASTER technique and MF 77 - 101 Hz. The average difference of the TA and ASSR thresholds in each group for the frequencies 500 - 4000 Hz was as follows: 1) Normal hearing group: 9 ± 7 dB at 500 Hz, 8 ± 7 dB at 1000 Hz, 9 ± 6 dB at 2000 Hz and 10 ± 8 dB at 4000 Hz. 2) sensorineural hearing group: 11 ± 9 dB at 500 Hz, 12 ± 8 dB at 1000 Hz, 13 ± 10 dB at 2000 Hz and 13 ± 11 dB at 4000 Hz. 3) Conductive hearing loss group: 15 ± 12 dB at 500 Hz, 14 ± 11 dB at 1000 Hz, 13 ± 10 dB at 2000 Hz and 12 ± 10 dB at 4000 Hz. Although the smallest mean difference of TA and ASSR thresholds was found in the normal hearing group at 1000 Hz, the ASSR and TA thresholds showed higher correlations across the frequencies for the sensorineural and conductive hearing loss groups, while lower correlation was found for the normal hearing group. Specifically, the correlation coefficients r for the three groups at the frequencies 500, 1000, 2000, 4000 Hz were as follows: 1st group -0.176, 0.014, -0.03, -0.322, 2nd group 0.766, 0.827, 0.796, 0.680, 3rd group 0.640, 0.664, 0.624, 0.655. These findings are consistent with the studies mentioned before as they attribute this fact to the phenomenon of "physiological recruitment".

Himanshu et al., (2019), divided the participants into 3 groups as follows: 1st group, normal hearing, 2nd group: sensorineural hearing loss. 3rd group: conductive hearing loss. The test technique was MASTER and MF 80-100 Hz. For the 1st group, the mean TA thresholds achieved at the frequencies 500 - 4000 Hz were: 4.6, 5.2, 6.04 and 5.3 dB for the right ear, and 5.7, 5, 5.9 and 6.4 dB for the left ear respectively. The mean ASSR thresholds for the same frequencies were: 14.4, 15.2, 16.04, 15.3 dB for the right ear, and 15.7, 15, 15.9 and 16.4 dB for the left ear, respectively. In the normal hearing group, the mean ASSR thresholds were approximately 10 dB higher than the TA thresholds. In the 2nd group of sensorineural hearing loss, the mean thresholds of TA for the frequencies 500 - 4000 Hz were: 38.9, 38.7, 42.9 and 41.2 dB for the right ear, and 41.5, 42.9, 43.7 and 46.1 dB for the left ear respectively. The mean ASSR thresholds for the same frequencies were: 48.6, 48.7, 52.5 and 51.4 dB for the right ear, and 51.7, 52.6, 53.7 and 56.1 dB for the left ear, respectively. In this case the average ASSR thresholds were about 10 dB higher than the TA thresholds. Finally, in the 3rd group of conductive hearing loss, the mean TA thresholds for the frequencies 500 - 4000 Hz were: 19.7, 20.5, 19.8 and 20.3 dB for the right ear, and 21.3, 20, 21.9 and 19.1 for the left ear respectively. The mean ASSR thresholds for the same frequencies were: 29.1, 30.5, 29.8 and 30.3 dB for the right ear, and 31.4, 30.3, 31.5 and 29.1 dB for the left ear respectively. And in this group, the findings agree with the previous ones that the average ASSR thresholds were about 10 dB higher than the TA thresholds. The correlation of TA and ASSR in all groups was very strong, with P = 0.0005. Overall, for all groups and all frequencies, the mean difference between the TA and ASSR thresholds was 9.92 dB in the right ear and 10 dB in the left ear. The correlation between the two tests was statistically significant, with P = 0.0005. In the literature, the mean differences of the TA and ASSR thresholds found are between 4 and 34 dB HL. In this study, the mean threshold difference was approximately 10 dB for both ears at all frequencies and hearing groups, and no threshold deviation or convergence was found depending on the degree of hearing as in some of the other studies.

One of the factors that is considered to affect the correlation of the TA and ASSR thresholds is the degree of hearing loss as reflected in TA. There are many studies that suggest that the correlation of the thresholds of the two tests is better in sensorineural hearing loss compared to normal hearing Lins et al., (1996); Valdes et al., (1997). This finding is supported by Picton et al., (2005); Ozdek et al., (2010); Komazec et al., (2010); Canale et al., (2006); Wadhera et al., (2017). This phenomenon is probably due to "physiological recruitment" as described in Picton et al., (2005). However, Beck et al., (2014) and Himanshu et al., (2019) support that no difference is found for the thresholds between people with normal hearing and those with sensorineural hearing loss.

Factors that need further investigation into their influence are MF modulation frequency, recording technique, recording time, and test conditions. In the case of Beck et al., (2014), the high correlation of the TA and ASSR thresholds for the normal hearing group could be attributed to some of these factors such as ideal test conditions, sufficient test time and small "step" reducing the intensity of the stimulus when finding the threshold. Modulation frequency cannot be isolated as a factor that may affect hearing-impairment outcomes, as the authors came to common conclusions using both the 40 and 80 Hz ASSR. The same goes for the recording technique since all but one of the authors used multiple ASSR technique.

Conductive hearing loss was examined in 3 studies (Himanshu, Wadhera et al., (2017); Hosseinabadi et al., (2015)) In all cases it is a matter of recording and comparing thresholds of air and not bone treatment. In the first 2 the correlation of the thresholds was found to be quite strong, less strong than that of sensorineural hearing loss but stronger than that of normal hearing. Himanshu et al., (2019) found mean threshold differences of small and no significant deviations for conductive hearing loss, sensorineural hearing loss but also for normal hearing.

Comparison of TA and ASSR by frequency:

Picton et al., (2005) found that the largest threshold deviations were found at 500 Hz and increased as the test duration decreased for all groups of subjects. Specifically, 30 patients were examined who were divided into 3 groups. In all groups the largest mean difference was found in the frequency of 500 Hz compared to the rest frequencies. This fact was attributed to the fact that with MF 78-95 Hz at 500 Hz CF the SNR ratio is very high and the response is difficult to be detected.

Hosseinabadi et al., (2015) although compared the TA and ASSR thresholds in terms of type and degree of hearing loss found that the differences between the TA and ASSR thresholds decreased as the frequency increased for the 2 hearing loss groups while this was not observed in the normal hearing group.

Ozdek et al., (2010) found a strong correlation between the TA and ASSR thresholds at 500, 1000 and 2000 Hz and a weak correlation at 4000Hz. It should be noted that this study was performed with the technique of single ASSR and with MF = 46 Hz.

Komazec et al., (2010) divided the participants into 6 groups according to the degree of hearing loss. A high correlation coefficient was found between the ASSR and TA thresholds at all frequencies. As in other studies, the strongest correlation was found at 1 kHz.

Beck et al., (2014), studied the correlation of TA and ASSR thresholds with MASTER and MF 82 98 Hz technique only in people with normal hearing in a sample of 52 ears, one of the largest in the literature. They conclude that there are no significant deviations in the mean threshold differences per frequency. This is in contrast to the other studies, which find large threshold differences between 500 and 1000 Hz but in this study no significant threshold difference was found in any of the four frequencies. This is probably due to the large sample size, the ideal test conditions, the sufficient test time and the small "step" of reducing the stimulus intensity when finding the threshold. Though, such conditions are very difficult to achieve in day-to day clinical practice.

Himanshu et al., (2019) examined 70 patients divided into 3 groups as follows: 1st group with normal hearing, 2nd group with sensorineural hearing loss, 3rd group, with conductive hearing loss. The test technique was MASTER and MF 80-100 Hz. The mean TA and ASSR thresholds for all three groups in total on each frequency were: 1) At 500 Hz, the mean TA threshold was 21.3 dB for the right ear and 23.1 dB for the left ear. The corresponding ASSR mean thresholds were 31.1 dB for the right ear and 33.2 dB for the left ear. 2) At 1000 Hz, the average TA threshold was 21.7 dB for the right ear and 23 dB for the left ear. The mean thresholds of the ASSR were 31.7 and 33 dB respectively. 3) At 2000 Hz, the average TA threshold was 23.3 dB for the right ear and 24.2 dB for the left ear. The mean ASSR thresholds were 33.2 and 33.4 dB respectively.

4) At 4000 Hz, the average TA threshold was 22.6 dB for the right ear and 24.4 dB for the left ear. The mean ASSR thresholds were 32.7 and 34.4 dB respectively. The correlation of the mean thresholds at 500 Hz for both ears is large, with P = 0.0005. The same was found for the other four frequencies. No statistically significant difference in mean thresholds was observed between frequencies.

Wadhera et al., (2017) examined 120 people with MASTER technique and at MF 77 -101 Hz, divided the patients into 3 groups. The other studies found a small correlation coefficient between the TA and ASSR thresholds at 500 Hz compared to the other frequencies, but this study at 500 Hz found a poor correlation in the normal hearing group but strong correlation for the groups of sensorineural hearing loss and conductive hearing loss. For all frequencies and all groups of patients, the mean difference was not greater than 15 dB. High threshold correlation was shown in the sensorineural hearing group. No threshold difference greater than 15dB was found in all groups and at any frequency.

Some studies suggest that there is a higher difference in the TA and ASSR thresholds at 500 Hz than the other frequencies. Lins et al., (1996) hypothesized that this was due to the fact that in ASSRs, low-frequency thresholds are more difficult to detect due to the "nerve asynchrony" that can be observed at this frequency relative to the higher ones. This finding is supported by Picton et al., (2005); Hosseinabadi et al., (2015); Wadhera et al., (2017) but only for people with normal hearing. The others do not report statistically significant differences in the ability of ASSRs to detect hearing thresholds between different frequencies.

CONCLUSION

The processing of the results revealed deviation between the studies in terms of design, the examination technique, the examination parameters used by each author (MF, duration, step used to determine the threshold, environment) but also in the analysis of the results. The general conclusion regarding the degree of hearing loss is that a direct comparison between the studies was not possible because the categorization of patients into groups according to the degree of hearing loss, as found in the TA, was performed differently in each study. The majority of the studies conclude that the correlation between tonal thresholds and ASSRs is better in sensorineural hearing loss compared to normal hearing (Picton et al., (2005); Ozdek et al., (2010); Komazec et al., (2010); Canale et al., (2006); Wadhera al. (2017)). In studies in which patients with sensorineural hearing loss were further categorized according to the degree, the highest correlation was found in the group of patients with moderate hearing loss. This fact is attributed by all authors to the phenomenon of "physiological recruitment". Also, there were 2 studies in the present review that found no difference in thresholds between people with normal hearing and those with sensorineural hearing loss and the correlation of thresholds did not differ statistically significantly between people with varying degrees of hearing loss (Beck et al., (2014); Himanshu et al., (2019). In this case the role of the parameters "test conditions", "duration of recording of each stimulus", "step of changing the intensity of the stimulus in the threshold detection technique" should be investigated, the regulation of which seems to be able to optimize the test results.

Regarding the modulation frequency, it cannot be considered as a factor that influences the deviation of the results in terms of the degree of hearing loss, as the different authors who come to common conclusions used different modulation frequencies (40 Hz and 80 Hz). Regarding the frequency, the correlation of tonal audiometry thresholds and ASSRs was high for all frequencies. Three researchers (Picton et al., (2005); Hosseimabadi et al., (2014); Wadhera et al., (2017)) found larger deviations of the TA and ASSR thresholds for the 500 Hz frequency. The other authors do not report statistically significant differences in the ability of ASSRs to detect hearing thresholds between different frequencies. An important conclusion is that in all studies reviewed the smallest difference between the thresholds of the TA and the ASSR found was 2db and the largest 45db HL. Finally, it is necessary to prepare new studies which can be homogeneous in terms of design and technical parameters in order for the results to be comparable. The parameters of modulation frequency and examination technique need further research in order to be automated in such a way that the examination has the best results in the categories of patients who show the greatest deviations.

REFERENCES

Ahn, J. H., Lee, H. S., Kim, Y. J., Yoon, T. H., & Chung, J. W. (2007). Comparing pure-tone audiometry and auditory steady state response for the measurement of hearing loss. Otolaryngology--head and neck surgery: official journal of American Academy of Otolaryngology-Head and Neck Surgery, 136(6), 966–971. https://doi.org/10.1016/j.otohns.200 6. 12.008

Beck, R. M., Ramos, B. F., Grasel, S. S., Ramos, H. F., Moraes, M. F., Almeida, E. R., & Bento, R. F. (2014). Comparative study between pure tone audiometry and auditory steady-state responses in normal hearing subjects. Brazilian journal of otorhinolaryngology, 80(1), 35–40. https://doi.org/10.5935/1808 8694.20140009.

Beck DL, Speidel DP, Petrak M. Auditory steady-state response: A beginner's guide. Hearing Review. 2007;14(12) [Nov]:34-37.

Canale, A., Lacilla, M., Cavalot, A. L., & Albera, R. (2006). Auditory steady-state responses and clinical applications. European archives of oto rhino-laryngology: official journal of the European Federation of Oto-Rhino Laryngological Societies (EUFOS): affiliated with the German Society for Oto-Rhino-Laryngology - Head and Neck Surgery, 263(6), 499–503. https://doi.org/10.1007/s00405-006 0017-y

Cohen, L. T., Rickards, F. W., & Clark, G. M. (1991). A comparison of steady-state evoked potentials to modulated tones in awake and sleeping humans. The Journal of the Acoustical Society of America, 90(5), 2467–2479. https://doi.org/10.1121/1.402050.

Cone-Wesson, B., Dowell, R. C., Tomlin, D., Rance, G., & Ming, W. J. (2002). The auditory steady-state comparisons with the response: auditory brainstem response. Journal of the American Academy of Audiology, 13(4), 173–226.

Herdman, A. T., & Stapells, D. R. (2001). Thresholds determined using the monotic and dichotic multiple auditory steady-state response technique in normal-hearing subjects. Scandinavian audiology, 30(1), 41–49. https://doi.org/10.1080/0105039017 5 0069563.

Herdman, A. T., Lins, O., Van Roon, P., Stapells, D. R., Scherg, M., & Picton, T. W. (2002). Intracerebral sources of human auditory steady-state responses. Brain topography, 15(2), 69 86. https://doi.org/10.1023/a:102147082 2 922.

Herdman, A. T., & Stapells, D. K. (2003). Auditory steady-state response thresholds of adults with sensorineural hearing impairments. International journal of audiology, 42(5), 237–248. https://doi.org/10.3109/1499202030 9 078343

Himanshu Swami, Santosh Kumar, (2019). Comparison of frequency Specific hearing thresholds between pure-tone audiometry and auditory steady-state response., Indian journal of otology 25(2) 59-65

Hosseinabadi, R., & Jafarzadeh, S. (2014). Auditory steady-state response thresholds in adults with conductive and mild to moderate sensorineural hearing loss. Iranian Red Crescent medical journal, 17(1), e18029. https://doi.org/10.5812/ircmj.18029. D.,

Jerger, J., Chmiel, R., Glaze, D., & Frost, J. Jr (1987). Rate and filter dependence of the middle-latency response in infants. Audiology: official organ of the International Society of Audiology, 26(5), 269–283. https://doi.org/10.3109/0020609870 9 081555

John, M. S., Dimitrijevic, A., & Picton, T. W. (2001). Weighted averaging of steady-state responses. Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology, 112(3), 555–562. https://doi.org/10.1016/s1388 2457(01)00456-4.

John, M. S., Dimitrijevic, A., & Picton, T. W. (2002). Auditory steady-state responses to exponential modulation envelopes. Ear and hearing, 23(2), 106 117. https://doi.org/10.1097/00003446 200204000-00004.

John, M. S., Dimitrijevic, A., & Picton, T. W. (2003). Efficient stimuli for evoking auditory steady-state responses. Ear and hearing, 24(5), 406–423. https://doi.org/10.1097/01.AUD.000 00 90442.37624.BE

Linden, R. D., Campbell, K. B., Hamel, G., & Picton, T. W. (1985). Human auditory steady state evoked potentials during sleep. Ear and hearing, 6(3), 167–174. https://doi.org/10.1097/00003446 198505000-00008.

Lins, O. G., Picton, T. W., Boucher, B. L., Durieux-Smith, A., Champagne, S. C., Moran, L. M., Perez-Abalo, M. C., Martin, V., & Savio, G. (1996). Frequency-specific audiometry using steady-state responses. Ear hearing, 17(2), and 81–96. https://doi.org/10.1097/00003446 199604000-00001.

Ozdek, A., Karacay, M., Saylam, G., Tatar, E., Aygener, N., & Korkmaz, M. H. (2010). Comparison of pure tone audiometry and auditory steady-state responses in subjects with normal hearing and hearing loss. European archives of official journal oto-rhino-laryngology: of the European Federation of Oto-Rhino-Laryngological Societies (EUFOS): affiliated with the German Society for Oto-Rhino Laryngology - Surgery, 267(1), Head and Neck 43–49. https://doi.org/10.1007/s00405-009 1014-8.

Picciotti, P. M., Giannantonio, S., Paludetti, G., & Conti, G. (2012). Steady state auditory evoked potentials in normal hearing subjects: evaluation of threshold and testing time. ORL; journal for oto-rhino-laryngology and its related specialties, 74(6), 310–314. https://doi.org/10.1159/000345497.

Picton, T. W., John, M. S., Dimitrijevic, A., & Purcell, D. (2003). Human auditory steady-state responses. International journal of audiology, 42(4), 177–219. https://doi.org/10.3109/1499202030 9 101316.

Picton, T. W., Dimitrijevic, A., Perez Abalo, M. C., & Van Roon, P. (2005). Estimating audiometric thresholds using auditory steady-state responses. Journal of the American Academy of Audiology, 16(3), 140–156. https://doi.org/10.3766/jaaa.16.3.3

Picton, T. W., van Roon, P., & John, M. S. (2007). Human auditory steady-state responses during sweeps of intensity. Ear and hearing, 28(4), 542 557. https://doi.org/10.1097/AUD.0b013e 3 1806dc2a7.

Roeser, R. J., Valente, M., & Hosford Dunn, H. (2011). AUDIOLOGY Diagnosis (2nd ed.). Thieme.

Swanepoel, D., & Erasmus, H. (2007). Auditory steady-state responses for estimating moderate hearing loss. European archives of oto-rhino laryngology: official journal of the European Federation of Oto-Rhino Laryngological Societies (EUFOS): affiliated with the German Society for Oto-Rhino-Laryngology - Head and Neck Surgery, 264(7), 755–759. https://doi.org/10.1007/s00405-007 0327-8.

Tomlin, D., Rance, G., Graydon, K., & Tsialios, I. (2006). A comparison of 40 Hz auditory steady-state response (ASSR) and cortical auditory evoked potential (CAEP) thresholds in awake adult subjects. International journal audiology, 45(10), of 580–588. https://doi.org/10.1080/1499202060 0 895170.

Valdes, J. L., Perez-Abalo, M. C., Martin, V., Savio, G., Sierra, C., Rodriguez, E., & Lins, O. (1997). Comparison of statistical indicators for the automatic detection of 80 Hz auditory steady state responses. Ear and hearing, 18(5), 420 429. https://doi.org/10.1097/00003446 199710000-00007

Wadhera, R., Hernot, S., Gulati, S. P., & Kalra, V. (2017). A controlled comparison of auditory steady-state responses and pure-tone audiometry in patients with hearing loss. Ear, nose, & throat journal, 96(10-11), E47–E52. https://doi.org/10.1177/0145561317 0 96010-1109

28. Yeung, K. N., & Wong, L. L. (2007). Prediction of hearing thresholds: comparison of cortical evoked response audiometry and auditory steady state response audiometry techniques. International journal of audiology, 46(1), 17–25. https://doi.org/10.1080/1499202060 1 102238.

APPENDIX

Table1. *Studies reviewed, their objective and their results.*

Author	Title	Objective	Results
Picton et al., (2005)	Estimating audiometric thresholds using auditory steady-state responses.	Correlation of PTA and ASSR thresholds depending on the frequency, degree of hearing loss, age and duration of recording.	Frequency: largest deviations at 500Hz. Degree of hearing loss: larger deviations in normal hearing, smaller in sensorineural hearing loss.
Canale et al., (2006)	Auditory steady-state responses and clinical applications.	Correlation of tonal audiometry thresholds with ASSR thresholds depending on the degree of hearing loss.	Greater correlation of thresholds in patients with moderate HL. In those with normal hearing or mild hearing loss was significantly lower. In very severe hearing loss no ASSR thresholds detected.
Ozdek et al., (2010)	Comparison of pure tone audiometry and auditory steady-state responses in subjects with normal hearing and hearing loss.	Correlation of tonal audiogram thresholds and ASSR in individuals with normal hearing and in people with sensorineural hearing loss and correlation of thresholds by frequency.	Strong correlation of TA and ASSR thresholds for the sensorineural hearing group and weaker for the normal hearing group. Strong correlation of TA and ASSR thresholds at 500, 1000 and 2000 frequencies, weak at 4000Hz.
Komazec et al., (2010)	Comparison between auditory steady-state responses and pure-tone audiometry.	Assessment of the reliability of ASSRs in finding thresholds by frequency and depending on the degree of hearing loss compared to the tonal audiogram.	High correlation coefficient for all 4 frequencies > 0.9, with a higher frequency at 1000Hz and in each case a threshold difference <10db. High correlation rate for moderate hearing loss and lower in people with normal hearing.
Beck et al., (2014)	Comparative study between pure tone audiometry and auditory steady-state responses in normal hearing subjects.	Correlation of tonal audiogram thresholds and ASSR in people with normal hearing.	The mean difference between the thresholds for all frequencies was a total of 8,175 dB and no statistically significant difference was found between the frequencies.
Hosseinabadi et al., (2015)	Auditory steady-state response thresholds in adults with conductive and mild to moderate sensorineural hearing loss.	Comparison of the thresholds of the tonal audiogram with those of the ASSR depending on the degree and the type of hearing loss.	ASSRs have the ability to distinguish between different degrees of hearing loss, which is very important in detecting even small threshold drops in children. The differences between the TA thresholds and those of the ASSRs became smaller as the degree of hearing increased.
Wadhera et al., (2017)	A controlled comparison of auditory steady-state responses and pure-tone audiometry in patients with hearing loss.	Correlation of tonal audiogram thresholds and ASSRs according to frequency and degree of hearing loss in people with normal hearing, in people with conductive hearing loss and in people with sensorineural hearing loss	Regarding the degree of hearing loss, high correlation of the thresholds in the total frequencies for the group of sensorineural hearing loss, lower for the conductive hearing loss, while the correlation is weaker in the group of normal hearing. In terms of frequency the highest correlation for both groups of hearing loss occurred at 1000 Hz
Himanshu et al., (2019)	Comparison of frequency specific hearing thresholds between pure tone audiometry and auditory steady state responses	Comparison of tonal audiogram thresholds and ASSR in 3 groups of patients 1st group normal hearing. 2nd group sensorineural hearing loss. 3rd group conductive hearing loss	Frequency: Strong correlation between the 2 tests at all frequencies with no differences per frequency. Degree and type of hearing loss: ASSR thresholds 10 dB above the threshold of tone audiometry in all patient groups