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REVIEW ARTICLE Open Access

The effects of changes in stimulus properties on acoustic stapedius reflex response: a systematic review

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Abstract

Background: The acoustic stapedius reflex is formed by the contraction of the stapedius muscle in the middle ear cavity when a loud sound is given to both ears. Changes in properties such as the intensity, frequency, duration, and speed of stimulus affect reflex responses.

Methods: As a result of the literature review conducted between 2005 and 2020, 2846 articles were reviewed and 30 articles evaluating the effects of stimulus changes on acoustic reflex responses were included in the study.

Main text: In the studies reviewed, it was observed that lower threshold values were obtained by using noise as a stimulus instead of pure sound. Different results were found regarding the duration and frequency of the stimulus. It has been reported that stimulus frequency does not have a significant effect on acoustic reflex delays and the acoustic stapedius reflex threshold increases in the presence of opposite side noise.

Conclusion: As a result of the studies reviewed, it was seen that the changes in many properties of the stimulus that activate the middle ear muscles affected the reflex response.

Keywords: Acoustic stapedius reflex, Acoustic reflex measurement, Stimulus duration, Wideband, Stimulus frequency

Background

The acoustic reflex or stapedius reflex is caused by contraction of the stapedius muscle in the middle ear cavity when a sufficiently loud sound is presented to both ears [1]. The bilateral pathway of the acoustic stapedius reflex causes both right and left sided muscles contraction when only one ear is stimulated. Facial nerve motor neurons transmit action potentials to terminals that form cholinergic neuromuscular synapses with the stapedius muscles, thus completing the stapedius reflex arc [2]. The acoustic reflex arc, first described by Borg [1], has two pathways: afferent and efferent. These pathways cross at the level of the superior olivary complex [3]. The afferent pathway consists of the auditory nerve [8th nerve] and the central auditory pathways [up to the auditory cortex]. The efferent part is formed by the n. facialis and connections between the auditory cortex and the facial nerve nucleus [4].

The acoustic reflex has an important place in terms of protecting the inner ear from high-level sounds and providing an advantage for understanding speech in noise [4]. On the other hand, the acoustic stapedial reflex (ASR) test is an important measure of auditory function and allows comparison of the findings of different audiological tests in children [5]. Contraction of the stapedius muscle causes an increase in the impedance of the middle ear system, which can be measured non-invasively with an electro-acoustic impedance/admittance or immitance measurement system [2]. Measurement can be made ipsilaterally and contralaterally. Ipsilateral acoustic reflex means that stimulus presentation and reflex measurement are made in the same ear. On the other hand,

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contralateral acoustic reflex means that the stimulus is given from one ear and the measurement is made from the opposite ear [6]. Acoustic reflex testing is usually performed at 70–115 dB SPL with a stimulus at frequencies of 500, 1000, 2000, and 4000 Hz [3]. One-second tones are presented with rest periods of 3 to 5 s. The highest changes in acoustic admittance equivalent to at least 0.02 mmho indicate a possible acoustic reflex. However, this should be confirmed by repetition of the response at the same loudness level or if possible, by increasing 5 dB again with a growth of at least 0.02 mmho [7].

The 226 Hz probe tone is ideal for routine tympanometry and acoustic reflex measurements for adults [8]. In infants younger than 6 months of age, a higher frequency probe tone such as 1000 Hz is recommended due to the middle ear system dominated by stiffness [9]. In some studies, broadband noise (BBN) was used instead of pure tone for acoustic reflex test, and the thresholds were lower with BBN [10]. The time between the onset of a high-intensity auditory stimulus and the contraction of the stapedius muscle is defined as the acoustic reflex latency [11], and this interval varies between 68 and 200 ms in individuals with normal hearing [12].

The aim of this review is to examine in the light of the literature, what kind of differences in the acoustic reflex response of the changes made in some properties such as frequency, duration, bandwidth, and intensity.

Main text

Stimulus type

ANSI (2012) accepts an acoustic stimulus of sufficient intensity that produces the acoustic stapedius reflex as a "stimulus" [4]. However, since "stimulus" is a general term [probe is also a stimulus], this section will discuss the changes in the properties of the activator and its results.

In conventional clinical measurements, the acoustic reflex is measured at tympanometric peak pressure (TPP) and the reflex activator stimulus is pure tone (500, 1000, 2000, or 4000 Hz) or broadband noise [4]. A 226 Hz probe tone is typically used for ASRT measurements in older children and adults. ASRT varies with probe frequency, and higher probe tone frequencies (660, 800, and 1000 Hz) are used to improve perception of ASRT in infants due to developmental differences. However, normative data are limited for high frequency probe tone, the option is not available on all equipment, and it takes extra time to obtain ASRT measurements with multiple probe tone frequencies when the option is available [13].

Immittance measurements obtained with a broadband probe tone, such as a click or chirp, are called wideband acoustic immittance (WAI). Measuring the acoustic reflex with a broadband probe instead of a single probe frequency allows simultaneous detection in several octaves, thus providing a suitable reflex test for adults and infants, whereby changes in acoustic immitance can be observed regardless of age and developmental changes [13].

Feeney et al. [14] and Mepani et al. [15] in their studies presented a click probe stimulus and a BBN activator selected from the white noise signal. Mean broadband acoustic stapedius reflex thresholds (ASRT) were found to be lower than click ASRT by a statistically significant difference [14, 15]. In a different study, ASR was evaluated with pure tone and BBN activator in children exposed to lead, and lower acoustic reflex thresholds were obtained with BBN activator compared to pure tone. In addition, amplitude amplification was highest at 0.5 kHz and the ASR amplitude growth function was lower for BBN than for the tonal activator [2]. Mazlan et al. [16] compared BBN and 2 kHz pure tone stimulus in newborns and found higher mean ASRT values for pure tone. Similarly, in other studies reviewed, in infants and the pediatric population, ARTs were found to be lower at all frequencies when using BBN activator compared to pure tone and were more successful in eliciting the acoustic reflex in children [8, 17–21]. On the other hand, Hunter et al. [22] reported that ASRT for BBN had a more significant increase with age compared to pure tone, and they also found that broadband ASRT increased in newborns with sensorineural hearing loss who failed screening tests compared to those with normal hearing.

In studies using click stimulus as activator, it was found that the thresholds obtained by simultaneously presenting reflex activating clicks to one ear and the probe tone to the other ear were lower than the thresholds obtained by alternately presenting [23] and the reflex thresholds that increase non-monotonically with frequency have been found to be lower than clinical tympanometry [24].

Using a basilar membrane tone complex (BMTC) that has essentially the same phase characteristics as the original chirps but allows an easier analysis of the residual signal for reflex detection than the original chirps and compensates for basilar membrane distribution as a different type of stimulus and random-phase tone complexes (rTC) as a reference, Müller-Wehlau et al. [25] aimed to make a comparison between individuals with normal hearing and hearing loss. Thresholds obtained with rTC are lower than BMTC in those with normal hearing; the opposite results were obtained in individuals with hearing loss [25]. In another study, a complex activating stimulus called the Schroeder phase with monotonically increasing or decreasing frequencies was used as a stimulus. As a result of the study, it has been reported that individuals with hearing loss have a greater reflex growth function than those with normal hearing, since these waveforms generate a greater cochlear stimulation [26].

Acoustic reflex evaluation performed in the geriatric group, high-frequency band (HP), and low-frequency (LP) band noise were used as well as wideband (WB) stimulus. It has been observed that acoustic reflex thresholds, which cannot be obtained with pure sound at some frequencies, can be obtained when a noise stimulus is used [27]. In the same year, Prabhu et al. [28] found that there was a decrease in acoustic reflex amplitude at high intensities when BBN, HBN, and 2 kHz pure tones were used. The articles reviewed in this study on stimulus type are summarized in Table 1.

Duration and rate

Temporal summation can be observed with acoustic reflex thresholds by increasing the activator duration or rate. Acoustic reflex thresholds decrease by increasing the stimulus duration or by increasing the rate. The recovery in acoustic reflex thresholds due to increased stimulus duration and rate was documented in a study with groups of younger and older participants. According to Rawool, there is recovery in thresholds up to 150/s in each group. While reflex thresholds from 200/s to 300/s improve further in the younger group, a slower recovery is observed in the elderly group at this rate [29].

It is known in the literature that stimulus duration affects both hearing thresholds and acoustic reflex thresholds. When the stimulus duration is reduced from 500 to 10 ms, the hearing thresholds increase by approximately 12–13 dB. Studies have shown that acoustic reflex thresholds increase as the stimulus duration decreases. It has reported that acoustic reflex threshold difference of up to 35 dB when comparing short and long duration tones. Emmer et al. [30] evaluated the effects of changes in activator duration (12, 25, 50, 100, 200, 300, 500, 1000 ms) on the acoustic reflex in the older and younger adult group. They observed that the BBN acoustic reflex threshold decreased as the duration increased but there was no significant interaction between activator duration and age [30].

The effect of inter-stimulus interval (ISI) was investigated as a reason why acoustic reflexes could not be obtained at 4 kHz, even in those with normal hearing by Guest et al. [31]. Results reported that extending this time from 2.5 to 8.5 s did not appreciably reduce ARTs or increase the level of safety [31]. The articles reviewed in this study on duration and rate are summarized in Table 2.

Frequency

Acoustic reflex test is usually performed at 70–115 dB SPL with a stimulus at frequencies of 500, 1000, 2000, and 4000 Hz [3]. When we look at the effects of frequency changes, Ferekidou et al. [32] obtained the lowest reflex threshold at 1 kHz stimulus frequency on adults. In a study conducted with newborns, reflex thresholds were higher than 2 kHz at 0.5 kHz and higher than 4 kHz at 2 kHz [18]. According to You et al. [33], 4 kHz is the frequency with the highest acoustic reflex threshold. Therefore, studies have not found a significant effect of frequency on acoustic reflex latencies [34–36].

In a study conducted in 2005, acoustic reflex thresholds in infants were determined by calculating the cross-correlation between the reflex shift and the response from the highest activator level. The test was performed using band-pass noise between 2500 and 11,000 Hz and the best cross-correlation was shown to be between 1000 and 8000 Hz. Similar results were obtained with adults using a tonal activator [37].

In addition, studies showed that higher acoustic reflex thresholds were obtained in the presence of contralateral noise stimuli [38–40], and when reflex latencies were examined, it was observed that the latencies for on-time reflexes were lengthened while those for off-time reflexes were shortened [41]. The articles reviewed in this study on frequency are summarized in Table 3.

Methodology

In this study, a literature search was conducted between 2005 and 2020 using PubMed, Google Scholar, ScienceDirect, and EBSCO databases. The terms "acoustic reflex," "acoustic stapedius reflex," and "acoustic reflex measurement" were used for the search. In the next stage, we searched by combining the keywords "stimulus duration," "stimulation intensity," "stimulation frequency," "stimulation time," and "wideband". Following this search strategy, articles were reviewed by reading titles and abstracts. Eligible articles have been thoroughly read and references screened as well.

Inclusion and exclusion criteria

Clinical studies and controlled trials with all age groups were reviewed and all individuals with normal hearing and no disease were included. Animal experiments, books, thesis, systematic reviews, reviews, and meta-analyses were excluded. In addition, stapedial reflexes that occur with non-acoustic stimulation were not included in the study.

In the light of all these criteria, 1220 articles were found, and titles of these articles were reviewed. Nine hundred eighty-eight articles were not relevant, 9 articles were animal studies, 24 of the results were book chapters, and 25 studies used electrical stimulation. For these reasons, a total of 1046 articles were not included in the study. Abstracts of the remaining 174 articles were

Table 1 Summaries of reviewed articles on stimulus type

Authors	Year	Participants	Methodology	Results
Feeney et al. [14]	2017	13 males and 20 females (mean age; 25) who have normal audiometry and clinical immittance	Wideband and clinical ASRTs were compared	The wideband ipsilateral ASRT test for a BBN activator provided a 12 dB lower ASRT than a clinical test with a 226-Hz probe tone
Mepani et al. [15]	2019	165 normal-hearing healthy subjects, between the ages of 18 and 63	226 Hz probe tone ASRT and wideband ASRT measured	Mean broadband acoustic stapedius reflex thresholds (ASRT) were found to be lower than click ASRT by a statistically significant difference
Counter et al. [2]	2011	2–18 aged 60 males and 57 females children with chronic lead (Pb) exposure	Pure tone and BBN ASR Test evaluated	Lower acoustic reflex thresholds were obtained with BBN activator compared to pure tone. In addition, amplitude amplification was highest at 0.5 kHz and the ASR amplitude growth function was lower for BBN than for the tonal activator
Mazlan et al. [16]	2009	70 6-week-old infants who passed a transient evoked otoacoustic emission test and an automated auditory brainstem response screening test	Ipsilateral acoustic reflex thresholds for a 2 kHz pure tone and broadband noise were recorded with a probe tone of 1000 Hz	The mean AR thresholds obtained were 67.3- and 80.9-dB HL for the broadband noise and 2 kHz tone, respectively
Hunter et al. [22]	2006	748 infants, grouped according to their newborn hearing screening outcomes	Effects of hearing- screening outcomes on ASRT measurements and normative threshold ranges over the first year after birth were evaluated using wideband and pure tone ASRT	ASRT for BBN had a more significant increase with age compared to pure tone and broadband ASRT increased in newborns with sensorineural hearing loss who failed screening tests compared to those with normal hearing
Rawool and Parrill [23]	2018	30 men and 30 women within the age-range of 19–29 years, with normal auditory sensitivity	Left and right contralateral ARTs were obtained in two conditions. In the alternated condition, the probe tone presentation was alternated with the presentation of the reflex activating clicks. In the simultaneous condition, the probe tone and the clicks were presented simultaneously	The ARTs were significantly lower/better in the simultaneous condition compared to the alternated condition
Boothalingam and Goodman [24]	2020	Twenty young, clinically normal hearing volunteers (mean age: 22 ± 2.7 years; 2 males)	Measured ASRT using a series of clicks presented at six levels (65 to 95 dB peak-to-peak SPL in 6 dB steps)	ASRTs estimated using this method were lower than that obtained from a clinical tympanometer in ~ 94% of the participants
Müller et al. [25]	2005	Eight normal-hearing and six hearing-impaired subjects	ASRT were measured with three types of tone complexes with different phase characteristics: A stimulus that compensates for basilar-membrane dispersion, thus causing a large overall neural synchrony (basilar-membrane tone complex—BMTC), the temporally inversed stimulus (iBMTC), and random-phase tone complexes (rTC)	Thresholds obtained with rTC are lower than BMTC in those with normal hearing; the opposite results were obtained in individuals with hearing loss
Kubli et al. [26]	2005	Nine normal-hearing (aged 31–55 years) and nine hearing-impaired subjects (aged 31–79 years)	Harmonic complexes with fundamental frequencies of 50, 100, and 200 Hz were constructed with positive and negative-Schroeder phases	Individuals with hearing loss have a greater reflex growth function than those with normal hearing, since these waveforms generate a greater cochlear stimulation

Table 1 (continued)

Authors	Year	Participants	Methodology	Results
Unsal et al.[27]	2016	25 elders between ages 65 and 84 years and 25 individuals between ages 18 and 45 years	Ipsilateral acoustic reflex thresholds were obtained with high-frequency band, low-frequency band, and wide band noise, and the results were compared with ipsilateral acoustic reflexes at 500, 1000, 2000, and 4000 Hz	Acoustic reflex with high-frequency band noise was observed in five of nine elders whose acoustic reflexes were not obtained in 2000 and 4000 Hz, whereas acoustic reflex with low-frequency band noise was observed in one of six elders who did not show reflexes at 500 and 1000 Hz
Prashanth et al. [28]	2016	30 normal hearing subjects between age group of 17 and 30 years	A comparison between baseline acoustic reflex threshold and amplitude (at 10 dB SL) with the presence and absence of 40 dB SL white noise in the contralateral ear was recorded	There was suppression of acoustic reflex threshold and reflex amplitude for 500 Hz, 1000 Hz, and 2000 Hz, low band noise, high band noise, broad band noise and clicks

Table 2 Summaries of reviewed articles on duration and rate

Authors	Year	Participants	Methology	Results
Rawool [32]	2017	20–74 aged five different groups (15 ears each); younger with normal hearing, older with normal hearing, older with mild high-frequency loss, older with moderate high-frequency loss, older with low- and high-frequency loss	Ipsilateral acoustic reflex thresholds were obtained from the left and/or right ear/s by presenting clicks at the repetition rates of 50, 100, 150, 200 and 300 clicks/s	The click-RIF is significantly reduced in older individuals compared to younger adults. There is improvement in thresholds up to 150/s in each group. While reflex thresholds from 200/s to 300/s improve further in the younger group, a slower recovery is observed in the elderly group at this rate
Emmer et al. [33]	2006	20 young adults (ten males and ten females, ages 18–29 years) and 20 older adults (ten males and ten females, ages 59–75 years)	The effect of age on temporal integration of the ART was investigated for a broad-band noise (BBN) activator. Activating stimulus durations were 12, 25, 50, 100, 200, 300, 500, and 1000 ms	As the duration increased, the acoustic reflex threshold for BBN decreased
Guest et al. [34]	2019	Two participant groups; 20 females and 4 males (mean age of 22.8 years) and 24 females and 12 males (mean age of 23.3 years) who have normal immitancemetry and audiogram	Effects of ISI on ARTs in normally hearing young humans, measured at 1 and 4 kHz. For the short ISI, a duration of 2.5 s was selected and for the long ISI, a duration of 8.5 s was selected	Increasing ISIs from 2.5 to 8.5 s did not reduce ART level, nor raise ART reliability

Table 3 Summaries of reviewed articles on frequency

Authors	Year	Participants	Methodology	Results
Ferekidou et al. [35]	2008	20–29, 30–39, 40–49, 50–59, and 60–69 years old 100 healthy adults	Acoustic reflex threshold was determined at 226-, 678- and 1000- Hz probe tones, using 500-, 1000-, 2000- and 4000-Hz stimuli	The lowest threshold level was recorded at 226 Hz using stimulus 1000 Hz
Kei [24]	2012	68 neonates (29 males and 39 females) who passed the automated auditory brainstem response, transient evoked otoacoustic emission, and HFT tests, completed at least one ASR test	ASR thresholds were elicited by presenting pure tones of 0.5, 2, and 4 kHz and broadband noise (BBN)	Reflex thresholds were higher at 0.5 kHz than 2 kHz and higher at 2 kHz than 4 kHz
You et al. [36]	2019	104 young listeners with normal hearing (53 female and 51 male) participated	ART measurement was performed in twelve conditions consisted of 3 probe tones (e.g., 226, 678, 1000 Hz) and 4 stimulus frequencies (e.g., 500, 1000, 2000, 4000 Hz)	All probe tones had the highest ART at 4000 Hz
Feeney and Sanford [40]	2005	Eight six-week-old infants and three adult subjects	Acoustic reflex thresholds were determined by calculating the cross-correlation between the reflex shift and the response from the highest activator level. The test was performed using band-pass noise between 2500 and 11,000 Hz	The best cross-correlation was shown to be between 1000 and 8000 Hz. Similar results were obtained with adults using a tonal activator

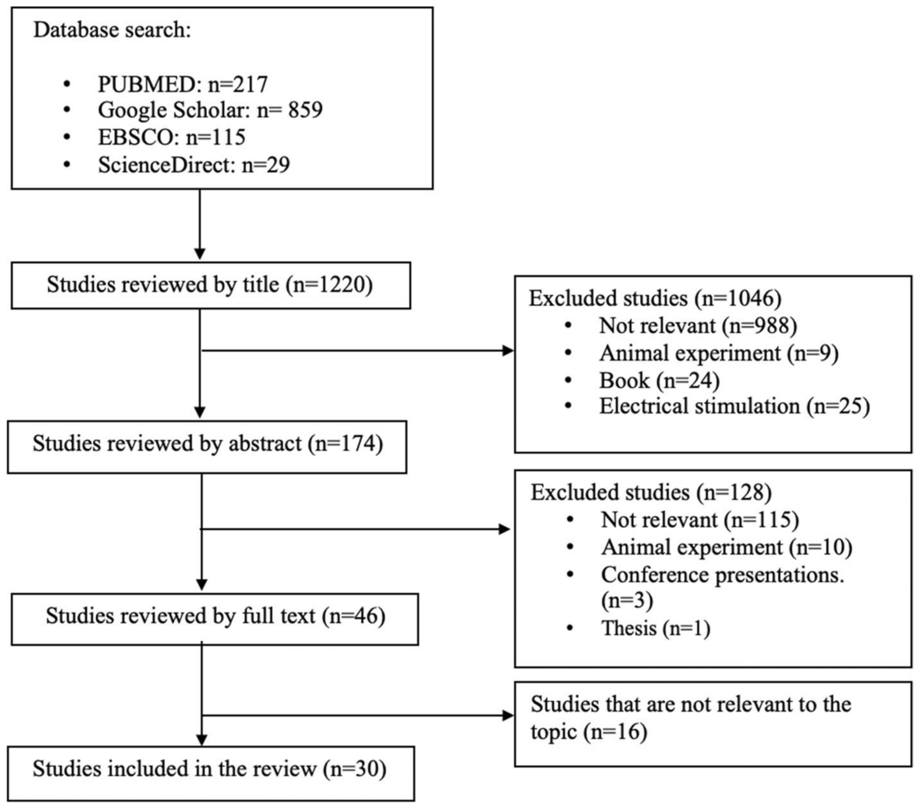

Fig. 1 Flowchart of articles through screening and selection process

reviewed. Since 115 articles were not suitable (5 studies on acoustic startle reflex, 10 studies on acoustic trauma, 84 studies using standard acoustic reflex procedure, 8 studies on vestibular evoked myogenic potentials, 8 studies evaluated otoacoustic emission-reflex results not evaluated) for the subject, 10 articles were animal experiments and 3 studies were excluded because they were conference presentations. All the remaining 46 studies were read. Sixteen articles not relevant (in 2 studies the correlation between acoustic reflex and speech test was evaluated, in 1 study test–retest evaluation of acoustic reflex test was performed, in 12 studies standard acoustic reflex test was used, and in 1 study the tuning curve effect of contralateral acoustic reflex was evaluated) to the subject were not included. After all this study was carried out with a total of 30 references (Fig. 1).

Discussion

If the acoustic reflex measurement tone is constant (220 or 226 Hz), the characteristic of the evoked reflex depends on the external conditions (intensity, frequency, duration, and stimulus type) affecting the acoustic stimulus [42]. In studies examining the effect of stimulus differences on acoustic reflex responses, it was observed that acoustic reflex thresholds were obtained lower with noise stimulus when noise stimulus and pure tone stimulus were compared [2, 8, 14–21].

In studies using click stimulus as activator, the stimulus was presented bilaterally, and middle ear muscle reflexes were examined [23, 24]. Compared to clinical acoustic reflex testing, its use is not common in routine evaluation, but this method also suggests that it may be a good tool to evaluate the level of superior olivary complex (SOC) involved in the acoustic reflex arc.

According to Peyvandı and Mahdavi [36], acoustic reflex latency depends on stimulus parameters such as frequency and intensity and is more stable at low frequencies. In another study conducted in 2019, the mean ARL was found to be shorter at 0.5 kHz than at 4 kHz, but it was not statistically significant [34]. In contrast in a different study, they found that the ARL of the elderly group at 2 kHz was significantly prolonged compared to the young and middle-aged groups [35]. These studies have shown that the latency-frequency relationship may reveal different findings.

While reflexes elicited by 0.5 kHz and 1 kHz pure tones in stimulus presentation in the presence of contralateral noise had acceptable reliability, they were not found reliable at 2 kHz [39]. On the other hand, Pichelli et al. [38] evaluated chirp stimulus at 2 kHz and showed that muscle response tended to increase when efferent suppression was activated compared with the test condition with contralateral noise. The results of these two studies agree with each other and show that low frequencies are more reliable.

Conclusion

As a result of the studies reviewed, it was seen that the changes in many properties of the stimulus that activate the middle ear muscles affected the reflex response. However, evaluation on a small number of subjects in studies leads to the inability to obtain meaningful data that can be used in the clinic. Despite this, the difference in reflex responses caused by the contralateral noise effect in individuals with tinnitus is less, the acoustic reflex can be obtained at low sound intensity levels in newborns with BBN, and the method using click stimulus, which allows us to detect the presence of binaural summation, is important for clinical evaluation.

Abbreviations

ASR: Acoustic stapedius reflex; ASRT: Acoustic stapedius reflex threshold; SOC: Superior olivary complex; BBN: Broadband noise; HBN: High band noise; LBN: Low band noise; WBN: Wideband noise; BMTC: Basilar membrane tone complex; rTC: Random-phase tone complex; ISI: Interstimulus interval.

Supplementary Information

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Additional file 1.

Additional file 2.

Additional file 3.

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Authors' contributions

All authors read and approved the final manuscript. MB: data collection, article writing, EO; data collection, article writing, EK: data collection, article writing, NB: data collection, ÖG: data collection.

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Declarations

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Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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