Research Article

Exploring the Effects of Alternate Auditory Attention Tasks on Electromotility of Cochlear Outer Hair Cells in Healthy Normal Hearing Adults

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Highlights

- Rostral efferent auditory pathway activity on OHCs is less understood than caudal
- Auditory attention may alter cochlear outer hair cell micromechanics
- Alternate auditory attention tasks may serve as effective contralateral suppressors

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ABSTRACT

Background and Aim: There is limited study on the role of rostral efferent auditory pathway on Outer Hair Cell (OHC) activity. We investigated the effect of integrating alternate auditory attention (ALAUDIN©) tasks with White Noise (WN) and its reliability using contralateral suppression of Transient Evoked Otoacoustic Emission (TEOAE).

Methods: This study was conducted at the Audiology Clinic, Universiti Kebangsaan Malaysia, with fifty normal-hearing adults. All subjects underwent standard audiological testing to ensure normal hearing, middle ear, and cochlear function. Contralateral suppressors with and without attention tasks were delivered randomly to the non-test ear while simultaneously measuring TEOAE amplitude in the test ear to investigate the effect of auditory attention on OHC electromotility. Suppressors with and without attention refer to the combination of a 1000 Hz tone and speech stimulus embedded in WN and WN alone, respectively. Subsequently, the difference in TEOAE amplitude during the presence and absence of suppressors was calculated, and thus suppression magnitude was determined.

Results: Intraclass correlation revealed that 4 suppressors produced high reliability. In paired sample t-tests, the tasks significantly reduced the amplitude of the TEOAE in the right ear compared to the left ear ($p<0.05$). However, the suppression magnitude did not differ significantly between ears ($p>0.05$). Descriptively, females showed greater TEOAE suppression.

Conclusion: This study demonstrated that directing ALAUDIN© tasks to one ear can affect OHC electromotility, as evidenced by TEOAE amplitude changes, but it did not impact the overall suppression magnitude. Additionally, it hinted at potential gender differences in TEOAE suppression, warranting further investigation.

Keywords: Suppression; otoacoustic emissions; efferent pathway; auditory attention

Introduction

The TEOAE test is a quick, non-invasive, and objective assessment used to examine the micromechanics of the Outer Hair Cells (OHC) in the cochlea [1]. It is recorded from healthy cochlear OHC with a hearing level no higher than 30 decibels (dB HL). These emissions result from the backward transmission of low acoustic energy from the OHC in response to the clicks. By positioning a miniature microphone in the tested ear canal, the low sound pressure level is measured as TEOAE amplitude.

One of the exciting investigations in TEOAE is the slight depression of OHC in the tested ear when the opposite (non-tested) ear is simultaneously presented with WN [2]. This is known as Contralateral Suppression of Otoacoustic Emissions (CSOAE). Indirectly, the CSOAE can possibly measure intactness of auditory efferent pathways [3]. CSOAE, defined as a positive difference in TEOAE amplitude when measured in quiet and with contralateral noise has been demonstrated to alter the micromechanics of the OHC of the cochlea [4, 5]. Previous studies indicate that CSOAE normally range between 1.0 and 3.0 dB [6].The presence of CSOAE is made possible due to the complex anatomical structure of crossed and uncrossed efferent medial olivocochlear bundle, also known as caudal efferent pathway, that originates from superior olivary complex in the brainstem. The medial olivocochlear bundle predominantly presents the crossed fibres to eventually innervates the OHC of the opposite cochlea. Hence, by delivering WN to the non-tested ear, the medial olivocochlear fibres decreases the electromotility of the opposite OHC and eventually reduces its amplitude. Hence, this makes WN a successful contralateral suppressor and eventually led previous research to focus on the caudal section of the brainstem. Nevertheless, this contributes to the lack of understanding and studies of another component of the efferent pathway, i.e. the rostral section. As such, it is important to further explore the efferent pathway's rostral section to better understand its role in the system.

In contrast to the caudal section, the rostral section is less understood because of its complex anatomical structure and neuronal network. A rostral efferent section involves the primary and secondary auditory cortex. It may also be influenced by activities in other related brain regions, such as the prefrontal cortex. Researchers believe that electrical activity in brain regions, at least in the auditory cortex, descends toward the nucleus bodies through the thalamus and brainstem. Their activity is coordinated with that of the caudal efferent section and ultimately terminates at the base of the OHC. Based on anatomical and neurological evidence, it appears that the electromotility of the OHC may also be influenced by the physiological activities of the auditory cortex. This is supported by findings that electrical stimulation of the auditory cortex leads to a decrease in OHC amplitude [7, 8]. Similarly, a study by Abdul Wahab suggest schizophrenia patients have stiffer cochlea and basilar membranes due to reduced OHC electromotility [9]. The hyperactivity of the efferent pathways during auditory hallucinations can be attributed to this. In spite of the limited studies and findings, very limited research has been conducted to investigate the role of the rostral efferent pathway in influencing the micromechanics of OHC. Further, the auditory cortex's connectivity to the frontal lobe could also affect its activity. Since the frontal lobe is responsible for attention tasks, changes in attention tasks may alter physiological activity in the auditory cortex. Notably, in the context of attention, it's worth mentioning that studies involving children with Attention-Deficit/Hyperactivity Disorder (ADHD) have not shown differences in otoacoustic emissions suppression [10] despite exhibiting attentional deficits associated with abnormal brain activation patterns [11]. This adds an intriguing dimension to current understanding of the intricacies of auditory processing and attentional mechanisms in the brain and raises questions about whether the rostral section have a significant role in regulating OHC micromechanics.

The rationale for the present study was to investigate the effects of ALAUDIN© tasks on OHC electromotility among normal-hearing healthy adults by using the CSOAE technique. We consider ALAUDIN© tasks as an innovative procedure because the tasks were embedded in the WN. These tasks were then delivered to the non-tested ear as suppressors. The amplitude of TEOAE and its suppression were then measured. The results of this study will be used to provide evidence of the effects of ALAUDIN© tasks on OHC electromotility. This may impact the current understanding of auditory attention effects on normal hearing-healthy adults.

Methods

This is a cross-sectional study which used random sampling method to investigate the effects of ALAUDIN© tasks on the micromechanics of OHC cochlea in healthy normal hearing adults by using CSOAE technique. This study was conducted at the Audiology Clinic, Universiti Kebangsaan Malaysia.

The recruitment of the participant has followed the Helsinki Declaration. A total of fifty consented subjects (Women: 25, Men: 25) aged between 19 and 30 years with mean and standard deviation of age 25.7±6.52 had participated in this study. All subjects had passed a-20 dB HL cut-off point pure-tone hearing screening at octave frequencies from 250 to 8000 hertz (Hz) normal otoscopic findings, normal tympanometry, normal ipsilateral acoustic stapedial reflex thresholds and normal speech perception in noise. Subjects with tinnitus, history of central auditory processing disorder or any complaint in difficulty to hear in noise were excluded.

The calibration of suppressors

In order to generate all contralateral suppressors, we used the Audacity software version 3.2.1 which is available for free download on the Internet. The intensity level of suppressors was measured with a sound level meter using an A-filter and a slow time weighting.

Contralateral suppressor 1: A WN set at 0.8 amplitude for a duration of one minute. It was calibrated at a sound pressure level of 75 decibel sound pressure level (dB SPL).

Contralateral suppressor 2: 19 trials of calibrated 1 kHz tone measured at 74 dB SPL (–1 signal-to-noise ratio, auditory attention task 1). 5.4 seconds (secs) and 0.9 secs are the longest and shortest intervals between tones, respectively. Later, the task was merged with the calibrated WN of 75 dB SPL.

Contralateral suppressor 3: 11 two-syllable Malay words, which include six animals and five transportation words (auditory attention task 2), calibrated to an average of 74 dB SPL. The interval between words was fixed at 5.4 secs. Later, the task was combined with the calibrated WN of 75 dB SPL.

Contralateral suppressor 4: 4 times 1 kHz tone with duration 0.1 secs followed by 7 two-syllable Malay words randomly arranged, which contain four alphabets and three numbers. We calibrated the tones and words to an average of 74 dB SPL (auditory attention task 3). A time interval of 5.4 secs was fixed between the signals. Later, the task was merged with a calibrated WN of 75 dB SPL.

Test-retest reliability of contralateral suppressors

In this phase, six Contralateral Suppressors (CS) consisted of WN alone and five ALAUDIN© tasks embedded in WN were delivered to ten normal hearing ears. These numbers were not included in actual data collection which involved fifty normal hearing subjects. The contralateral suppressor with WN alone was considered as without attention task. The ALAUDIN© tasks included WN+1 kHz tone, WN+Animals+Transport, WN+Alphabets+Numbers, WN+1 kHz tone+Animals+Transport and WN+1 kHz+Alphabets+Numbers. Based on the Intraclass Correlation (ICC) values, four suppressors had been chosen due to their moderate and high reliability values. The suppressors are named as CS1, CS2, CS3 and CS4 for WN, WN+1 kHz tone, WN+Animals+Transport and WN+1 kHz tone+Alphabets+Numbers, respectively. These suppressors underwent calibration and later installed in an MPEG-1 Audio Layer 3 player to be applied on all the fifty normal hearing subjects for actual study.

Standard audiological testing

The subjects underwent and passed standard audiological testing procedures conducted in a soundproof room with an ambient noise level of 30 dBA. Following are the procedures that were followed. In order to ensure that the ear canal and the tympanic membrane are intact, an otoscopic examination was performed. Using the Titan Suite immittance instrument (Interacoustics, United States of America), immittance testing was conducted, consisting of tympanometry and acoustic stapedial reflex. Each subject with a Type A tympanogram and the presence of reflexes across all frequencies tested is indicative of normal middle ear function. Hearing screening with a cutoff point of 20 dB HL at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz was conducted using a dual-channel audiometer (AC40, 400 Interacoustics, Denmark) with TDH-39 headphones. A Malay version of hearing in noise test was conducted to verify that all subjects are capable of hearing noise. The TEOAE procedure was conducted in both ears using a conventional test protocol by using Echoport I, Otodynamics, United Kingdom, to ensure healthy OHC functions. 80 milliseconds non-linear click stimuli at 80 dB peak SPL were presented to the subjects. A normal TEOAE is defined as a reproducibility value of 70%, stability of 80%, transient evoked of –10 dB, and transient evoked to noise floor of 3 signal-to-noise ratio. Afterwards, all fifty consented subjects underwent the actual data collection procedure for CSOAE.

Procedure

All subjects were asked to sit comfortably in a chair and were instructed to minimize body movement during recording. TEOAE suppression testing was conducted using the 1-channel TEOAE instrument (Echoport I, Otodynamics, United Kingdom). For each subject, both ears underwent the CSOAE procedure. Firstly, a 60 dB peak SPL click TEOAE stimuli, without a contralateral suppressor (in quiet), was delivered to the tested ear and the amplitude of TEAOE in the ear was measured. Secondly, the TEOAE amplitude was remeasured in the same ear. However, this time by simultaneously presenting a 75 dB SPL suppressor, via an MPEG-1 Audio Layer 3 player, to the contralateral ear. As mentioned earlier, based on ICC values, four contralateral suppressors consisting of CS1, CS2, CS3 and CS4 were selected for actual CSOAE data collection. These suppressors were randomly presented to each ear. We provided each ear with a 1-minute rest period between suppressors. This was done to ensure that the auditory system had time to recover before being subjected to another sound suppressor. This rest period helps to minimize any potential fatigue to the ear caused by prolonged exposure to the suppressors. Additionally, this precaution minimizes the subject from becoming fatigued during the test, which might lead to a loss of attention. The ALAUDIN© tasks required each subject to count the tones, categorize the words, and a combination of both. The TEOAE amplitude for each suppressor was measured in decibel. The magnitude of suppression for each suppressor was calculated by the difference in the TEOAE amplitude obtained with and without suppressors. Data were analyzed to investigate the effect of ears and genders. The measurements of TEOAE amplitude and suppression magnitude for all suppressors are listed below:

i) TEOAE amplitude for CS1
ii) TEOAE amplitude for CS2
iii) TEOAE amplitude for CS3
iv) TEOAE amplitude for CS4
v) Suppression magnitude 1 (dB)=TEOAE amplitude in quiet–TEOAE amplitude with CS1
vi) Suppression magnitude 2 (dB)=TEOAE amplitude in quiet–TEOAE amplitude with CS2
vii) Suppression magnitude 3 (dB)=TEOAE amplitude in quiet–TEOAE amplitude with CS3
viii) Suppression magnitude 4 (dB)=TEOAE amplitude in quiet–TEOAE amplitude with CS4.

Data analysis

All the data was compiled in Microsoft Excel and analyzed using the statistical software Jamovi 2.3.21. Kolmogorov Smirnov was applied to check for data normality. ICC was used to calculate ALAUDIN© tasks' test-retest reliability. Paired sample t-test was used in analyzing the differences in the amplitude of TEOAE between ears and the magnitude of TEOAE suppression between ears and genders, with and without the presence of attention tasks.

Results

Test-retest reliability of alternate auditory attention tasks

A moderate to high level of test-reliability was observed in four contralateral suppressors, namely WN, WN+1 kHz tone, WN+Animals+Transportations, and WN+1 kHz tone+Alphabets+Number (Table 1). They were referred to as CS1, CS2, CS3 and CS4, respectively, and were applied to actual CSOAE data collection in normal subjects.

Transient evoked otoacoustic emissions amplitude between ears

There was no significant difference in the mean TEOAE amplitude between ears ($p>0.05$) for the

Table 1. The test-retest reliability of contralateral suppressors analyzed in each ear

Stimulus	Ear	ICC Value	p	95% CI	
				Lower	Upper
WN	Right	0.750	0.045	–0.262	0.972
	Left	0.525	0.172	–1.401	0.947
WN+1 kHz	Right	0.909	0.002	0.539	0.990
	Left	0.912	0.002	0.556	0.990
WN+Anim+Tran	Right	0.790	0.029	–0.062	0.977
	Left	0.813	0.021	0.055	0.979
WN+Alph+Numb	Right	0.962	0.000	0.807	0.996
	Left	–1.339	0.785	–10.820	0.739
WN+1 kHz+Anim+Tran	Right	0.884	0.005	0.416	0.987
	Left	–0.188	0.536	–5.002	0.868
WN+1 kHz+Alph+Numb	Right	0.788	0.030	–0.073	0.976
	Left	0.594	0.129	–1.052	0.955

CI; confidence interval, ICC; intraclass correlation, WN; white noise, Anim; animals, Tran; transportations, Alph; alphabets, Numb; numbers

contralateral suppressor without auditory attention tasks (CS1) in all subjects. However, the mean TEOAE amplitude in all ALAUDIN tasks (CS2, CS3, and CS4) was significantly lower in the right ear ($p<0.05$) than in the left (Figure 1).

Magnitude of transient evoked otoacoustic emissions suppression between ears

Figure 2 presents that ear did not demonstrate any effect towards the magnitude of TEOAE suppression, in the absence and presence of auditory attention tasks. No significant changes in mean magnitude of TEOAE suppression between right and left ear, ($p>0.05$). Descriptively, CS3 gave larger suppression relative to other contralateral suppressors.

Magnitude of transient evoked otoacoustic emissions suppression between genders

Descriptively, for all contralateral suppressors, the study revealed larger magnitude of TEOAE suppression in female than male (Figure 3) when CS3 was used as suppressor. However, no statistically significant difference between genders was noted ($p>0.05$).

Discussion

This study revealed that three out of five ALAUDIN© tasks had produced higher test-retest reliability, which are WN+1 kHz tone, WN+Animals+Transportations and WN+1 kHz tone+Alphabets+Numbers. Based on this study, it is evident that three out of five ALAUDIN tasks display greater test-retest reliability. These tasks are specifically WN+1 kHz tone, WN+Animals+Transportation, and WN+1 kHz tone+Alphabets+Numbers. This suggests that these tasks are more consistent in their results. In other words, these tasks are more reliable when tested several times than the other two tasks. This means that the results obtained from these tasks are more likely to be accurate and reliable.

It is well known that MOC efferent influences the micromechanics of cochlear outer hair cells in the presence of contralateral sound stimuli. Changes in the micromechanics of outer hair cells in response to contralateral sound stimulation alter the level of OAE

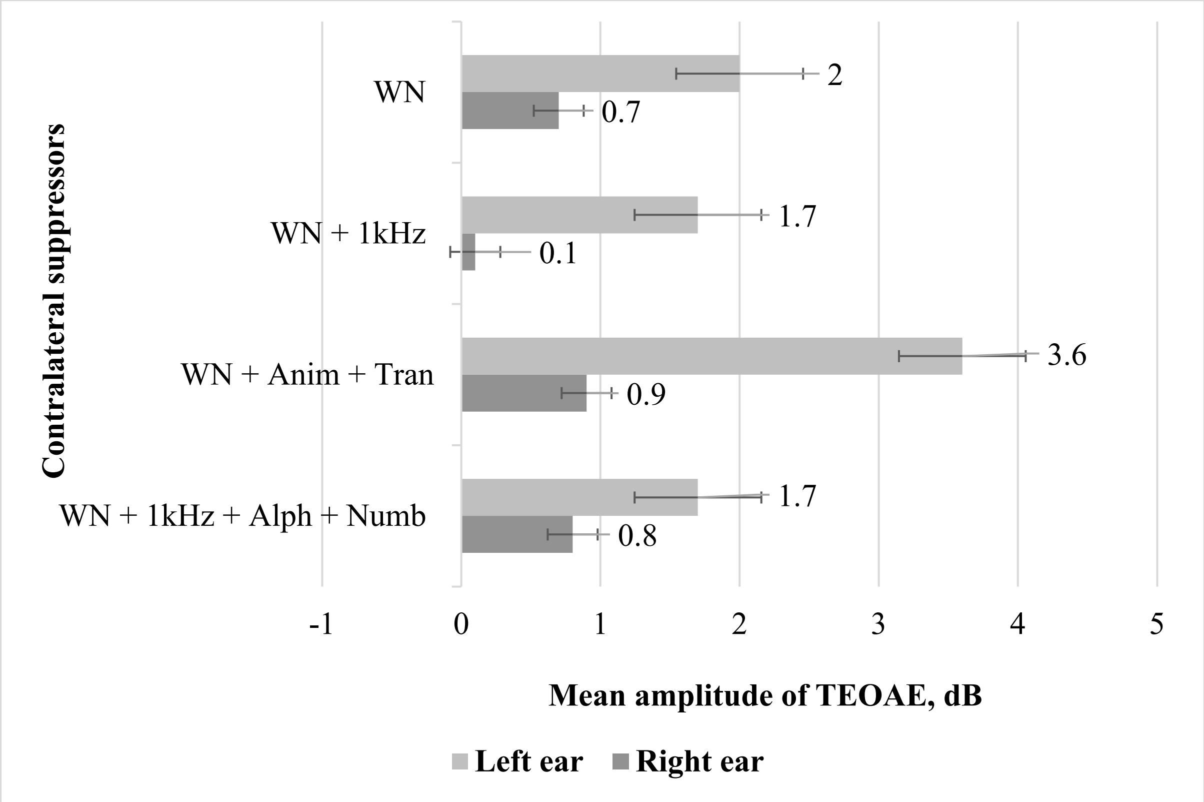

Figure 1. Histogram of mean transient evoked otoacoustic emissions amplitude between ears measured with each contralateral suppressor. WN; white noise, Anim; animals, Tran; transportations, Alph; alphabets, Numb; numbers, TEOAE; transient evoked otoacoustic emissions,

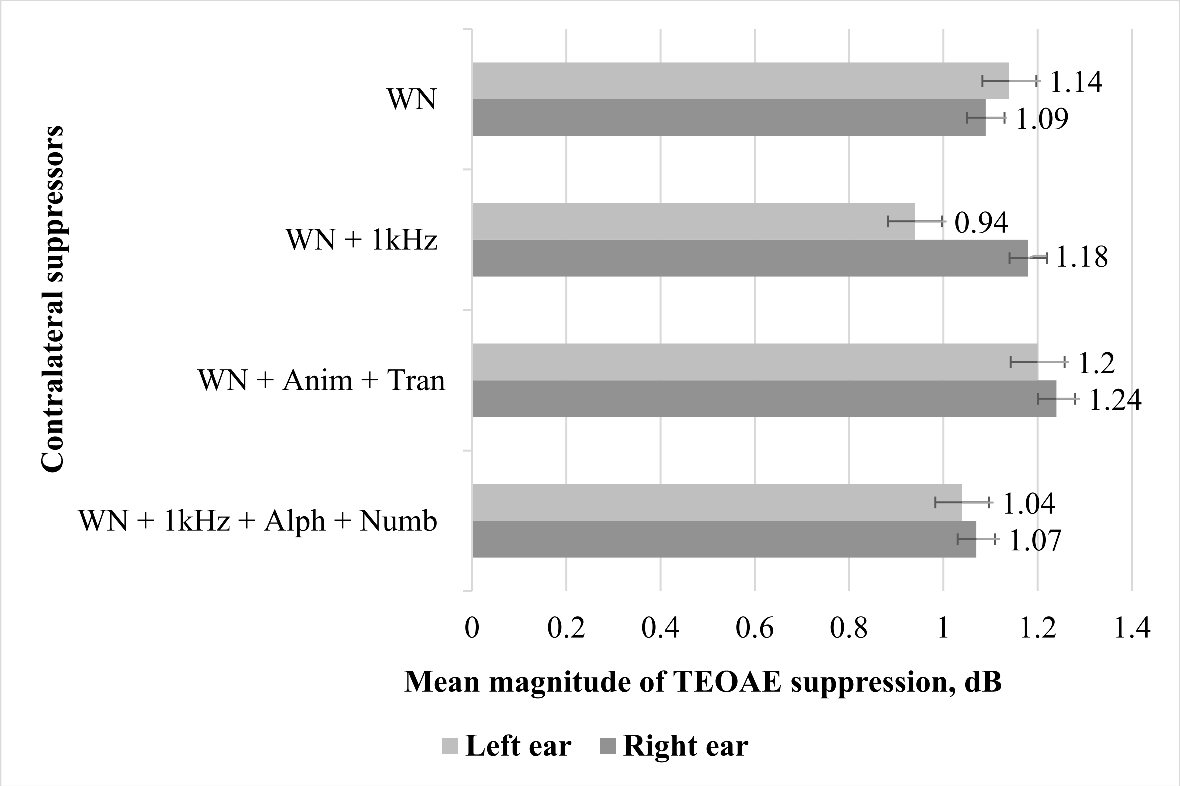

Figure 2. Histogram of mean suppression magnitude between ears measured for each contralateral suppressor. WN; white noise, Anim; animals, Tran; transportations, Alph; alphabets, Numb; numbers, TEOAE; transient evoked otoacoustic emissions,

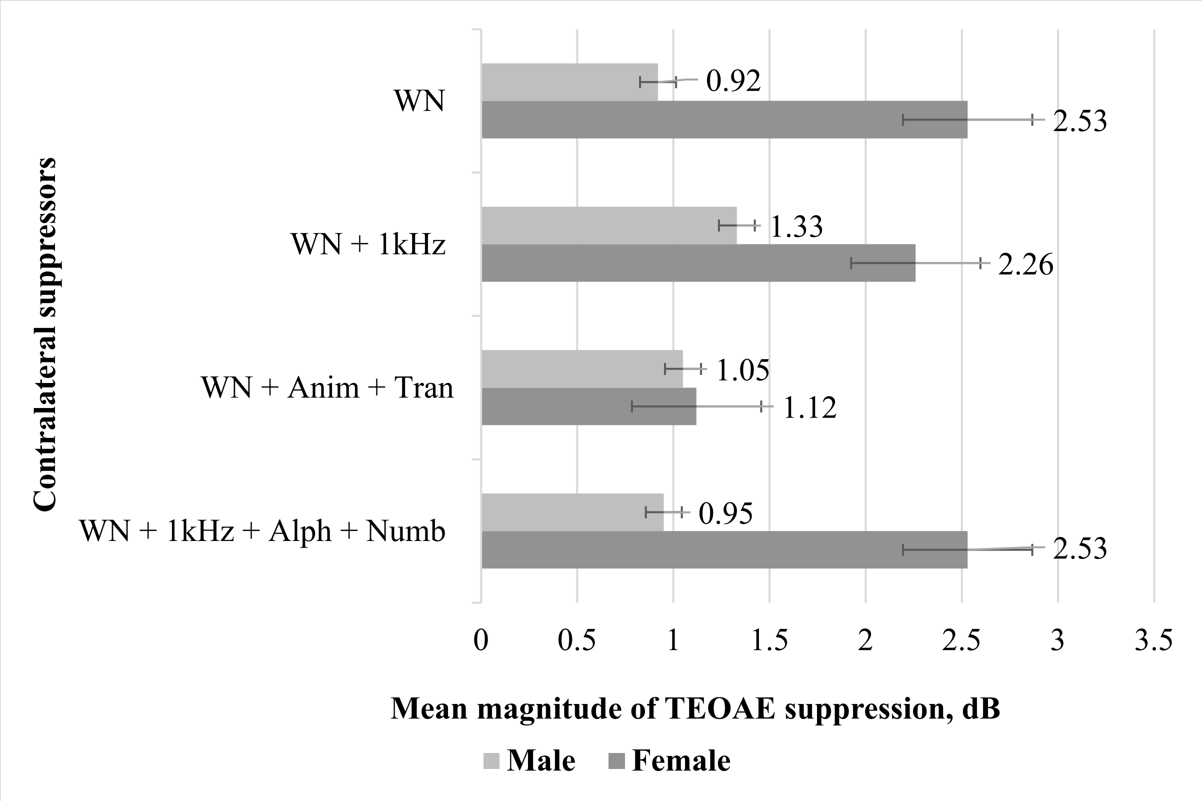

Figure 3. Histogram of mean suppression magnitude between genders measured for each contralateral suppressor. WN; white noise, Anim; animals, Tran; transportations, Alph; alphabets, Numb; numbers, TEOAE; transient evoked otoacoustic emissions

measurements in the external ear canal. This includes both the level of noise and the amplitude of the OAE. There have been previous studies studying the effect of auditory attention or behavioural tasks on OAE measurement results [12, 13]. According to these studies, the efferent MOC did not play a crucial role in changing the micromechanics of outer hair cells in response to auditory attention or behavioural tasks. The conclusion is based on the finding that there are no significant changes in the level of noise in the external ear canal, the magnitude of OAE, and the strength of the MOC reflex when normal subjects are given a multi-modality attention task and a range of auditory focus difficulties. Although the difficulty of the task was proven by the measurement of evoked response potential, namely the amplitude of P3, the contralateral attention task did not show a significant change in the OAE measurement which suggested the auditory cortex compensated for the MOC efferent. Our study differed from previous studies in that subjects in those studies were required to detect changes in noise levels in the contralateral stimulus sounds. Our study used 1000 Hz tones as well as several categories of words consisting of alphabets, letters, vehicles and animals combined with broadband noise. As a result of the use of these different stimuli, the OAE measurements may differ from those obtained in previous studies. Specifically, words or speech can stimulate brain regions associated with the processing of auditory, speech, and language information. We speculate that this will effectively stimulate the rostral efferent pathway in a more effective manner than tone detection or level detection.

This study found that there were significant differences ($p<0.05$) in the mean amplitude of TEOAE between the ears. Specifically, the mean amplitude of TEOAE was significantly lower in the right ear when auditory attention tasks were performed. These findings align with previous studies that investigated the left hemisphere's specialization in speech and language [14, 15]. This is because, in this current study, alternate auditory attention tasks consisting of speech stimuli were presented to the subjects. This resulted in the activation of circuitry in the left hemisphere involving the Broca and Wernicke areas, regardless of hand dominance. Also, this could be due to the right ear advantage phenomenon.

Due to the fact that this study embedded speech signals into the noise as a suppressor, the OHC amplitude needs to be reduced in order to protect the right ear cochlear and facilitate speech noise processing in the left auditory cortex [16].

In general, the presence of attention may also have an effect on TEOAE suppression. Previous studies have found that when auditory attention tasks are directed at listeners resulting in a significant reduction in OAE suppression, as opposed to non-auditory attention tasks [8]. This finding has been supported in a study which had found that active listening situations in comparison to passive listening situations, as this technique could reduce the variability seen in MOC function. Therefore, the author had proposed this technique as a useful tool in distinguishing children with and without auditory processing disorder for future studies [2, 6]. Also, changes in MOC reflex strength had been observed between the presentation of an easy auditory task and the presentation of a hard auditory task, which was found slightly higher for the harder task [17]. This is a clear indication that the information processing had been altered in the brain as the subjects were attending the presentation of the auditory task [9].

In contrast to previous studies [16, 18] this study showed insignificant differences in the mean magnitude of TEOAE suppression between ears. Our results showed that the magnitude of TEOAE suppression did not show any effect in the absence and presence of alternate auditory attention tasks which is consistent with the paper published by Jedrzejczak et al. [17]. We assumed that ALAUDIN© tasks are harder (from CS2 to CS4) as more complicated tasks were embedded in the WN. We speculate that this could be due to this study was carried out among people with normal hearing and intact caudal and rostral efferent auditory system. Therefore, no dysconnectivity issues were observed in healthy normal-hearing adults. In addition, this could agree with the idea that mutual compensation exists between periphery and auditory cortex [17]. In populations with attention deficits, a larger magnitude of TEOAE suppression can be observed. For instance, schizophrenia patients showed a larger suppression based on previous studies [9]. This is because the auto-activation of the auditory cortex itself without external triggers altered the OHC electromotility. Thus, hyperactivity had been observed along the efferent pathway which resulted in a larger magnitude of TEOAE suppression among schizophrenia patients. Also, similar findings (larger magnitude of TEOAE suppression) were found in children with ADHD, which could be due to reduced abnormal activation in prefrontal cortices (including inferior and dorsolateral regions and cingulate gyrus) and striatum, including caudate and ventral striatum. This factor could contribute to executive function deficits and inattention in ADHD children [19].

Greater TEOAE suppression had been observed on females [20]. This has been supported in a study in which contralateral suppression of TEOAE has been shown to be greater in women than in men, especially among the infants. However, despite there was a descriptive difference between genders, the current study revealed no significant difference in suppression between genders. Nevertheless, we supported that larger magnitude of TEOAE suppression had been observed in female than male subjects. As reported in previous studies, in which the differences in cochlea length between gender could contribute to the changes of electromotility of the OHC. Females had reported to have shorter cochlea length than males, which has been suggested as a contributor to their ability to respond sensitively to TEOAE than males, particularly in infants [18, 21]. Also, by having better motor organization and patterning of speech functioning associated with the frontal lobes had been suggested to be the contributor to females in having higher attention and speech articulation than males [22].

Research limitation

Subjectively, high-level tasks were more complex and required more attention from all subjects. Several tasks given in this study had assessed the subject by counting the tones and categorizing the speech stimulus. Therefore, this complex method requires simultaneous detection and identification processes in each subject.

Future recommendation

Future studies should also include large age groups, including the elderly, to examine cochlear maturation and its effect on TEOAE suppression in the absence and presence of auditory attention. In addition, future studies may want to investigate objectively the difficulty and attention levels of ALAUDIN© tasks and examine how these correlates with the suppression of TEOAE amplitude and magnitude. The ALAUDIN© tasks on distortion product OAE may also be investigated in future research studies.

Conclusion

The findings of this study suggest that ALAUDIN© tasks are reliable suppressors of contralateral suppression of otoacoustic emissions. In particular, the tasks significantly affected the mean amplitude of Transient Evoked Otoacoustic Emission (TEOAE) in the right ear. This can be explained by the left hemisphere function and the right ear advantage phenomenon. Nevertheless, there is no significant difference observed in the magnitude of suppression of TEOAE between ears. A lack of dysconnectivity issues among healthy normal-hearing adults may explain this result. Despite the possibility that gender may impact ALAUDIN© tasks, further research is required since no statistically significant effects were observed.

Ethical Considerations

Compliance with ethical guidelines

The authors would like to thank the UKM ethics committee for approving this research study (JEP-2022-068) and the Centre for Innovation & Technology Transfer (INOVASI@UKM) for copyright approval to ALAUDIN© tasks (UKM.IKB.800-4/1/4034).

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Authors' contributions

SAMT: Data acquisition, drafting the manuscript, statistical analysis, and critical revision of the manuscript; CMACA: Data acquisition, statistical analysis, and interpretation of the results; NAAW: Study design and supervision, drafting the manuscript, statistical analysis, interpretation of the results, and critical revision of the manuscript; MNZ: Co-supervision, statistical analysis, and interpretation of the results; SW: Co-supervision, and drafting the manuscript; NHAW: Co-supervision, and drafting the manuscript; NM: Co-supervision, drafting the manuscript, and critical revision of the manuscript.

Conflict of interest

We declared that there is no conflict of interest in this study.

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