EFFECT OF AUDITORY SELECTIVE ATTENTION ON MEDIAL OLIVOCOCHLEAR REFLEX

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CERTIFICATE

This is to certify that this dissertation entitles "**Effect of auditory selective attention on medial olivocochlear reflex**" is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student with registration number: P01II21S0085. This has been carried out under the guidance of the faculty of this institute and has not submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
September, 2023

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CERTIFICATE

This is to verify that this dissertation entitled "**Effect of auditory selective attention on medial olivocochlear reflex**" has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Effect of auditory selective attention on medial olivocochlear reflex**" is the result of my own study under the guidance of Dr. Ajith Kumar U, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru and has not submitted earlier to any other University for the award of any other Diploma or Degree.

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September, 2023

DEDICATED TO MY FAMILY

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ABSTRACT

Aim:

To study the effect of auditory attention on the medial olivocochlear reflex (MOCR) strength.

Objectives:

1. To compare speech identification in noise scores and reaction time across different signal to noise ratio (SNRs) and speech stimuli (monosyllables and words)
2. To compare the MOCR strength (as measured by contralateral inhibition of transient evoked otoacoustic emissions) with the following types of contralateral acoustic stimulations (CAS)

    a. White noise alone
    b. Monosyllables embedded at +4 dB and 0 dB SNRs (active listening) in the white noise. Participants are required to identify the monosyllables in a closed set speech identification task.
    c. Words embedded at +4 dB and 0 dB SNRs (active listening) in the white noise. Participants are required to identify the words in a closed set speech identification task.
    d. Same as conditions b and c but contralateral acoustic stimulation is presented in time reversed fashion (passive attention).
3. To study the relationship between inhibition of TOAE and speech perception and noise (SPiN) scores in all the above conditions.

Method:

A total of 35 normal hearing participants between the age range of 18 to 30 years were included. TEOAEs were recorded at 65 dB SPL with and without CAS of 60 dB HL of white noise. Words and monosyllables were embedded in the white noise at +4 dB and 0 dB SNR for the active listening task, and participants were required to identify the stimuli in a closed-set identification task. In the passive listening task, the same stimuli were presented in a time-reversed manner. The inhibition magnitude was compared across different conditions.

Results:

The study showed no effect of attention on the magnitude of inhibition, but a significant interaction effect was seen between SNR, and attention. These effects showed that the magnitude of MOCR was modulated by attention and SNR. There was no correlation found between SPiN and inhibition of TOAE.

Conclusion:

The MOCR strength is modulated by a complex interaction between SNR and attention.

CHAPTER - I

Introduction

Speech perception in noise (SPiN) is a ubiquitous process. SPiN involves complex interactions between top-down and bottom-up auditory processing streams. In the auditory system top-down influences reach the peripheral organ, the cochlea, via the efferent auditory pathway. The peripheral auditory efferent pathway – the most studied among the auditory efferent system – originates from superior olivary complex (SOC) in the caudal brainstem (Rasmussen, 1946). This efferent system - known as olivocochlear bundle (OCB) – has two distinct projections: the medial olivocochlear bundle (MOCB) originating from medial SOC and the lateral olivocochlear bundle (LOCB) originating from lateral SOC. Majority of the research experiments were conducted on MOCB because of its anatomical and physiological accessibility (Charles Liberman, 1988; De Boer et al., 2012; Liberman, 1988; Mishra & Lutman, 2014; Warr & Guinan, 1979).

MOCB connects to the outer hair cells (OHCs) of ipsilateral and contralateral cochlea. The contralateral projections are denser than ipsilateral projections (Guinan & Gifford, 1988). One of the non-invasive procedures to assess MOCB is measuring otoacoustic emissions (OAE) in the presence and absence of contralateral acoustic stimulation. Studies have shown that acoustic stimulation of the contralateral ear activates the medial olivocochlear neurons, which in turn produces an inhibitory response (De Boer et al., 2012; Liberman, 1988; Maison & Liberman, 2000; Robertson, 1984). This is measured as reduction in the amplitude of OAEs measured in the other ear called contralateral inhibition of OAE (Berlin et al., 1993) or medial olivocochlear reflex (MOCR).

Earlier studies on animals have indicated that MOCR helps in detecting signals in the presence of noise (Ferry & Meddis, 2007; Geisler, 1974; May et al., 2004). Based on animal models, it was hypothesized that, in humans, the medial olivocochlear bundle aids in SPiN (Kalaiah et al., 2022; Mishra, 2010; Kumar & Vanaja, 2004; Smith et al., 2003; Narne & Kalaiah, 2018). Over the last three decades, several studies have assessed the role of the efferent auditory pathway, particularly the medial olivocochlear bundle, in SPiN in humans (Guinan, 2006). However, the results of these studies are controversial (Galhom et al., 2022; Yashaswini & Maruthy, 2019). One of the reasons for inconsistencies in the results could be because most of the studies evaluating the relationship between MOCR and SPiN have used correlational approaches. Meaning, MOCR – measured as contralateral inhibition of OAE – and SPiN – measured as percent correct scores or SNR-50 - are measured in separate instances and relationship between the two were assessed using correlation. Such an approach will not indicate the contribution of MOCR when listeners are performing SPiN task. Furthermore, attention also influences the MOCR strength (de Boer & Thornton, 2007; Garinis et al., 2011; Lukas, 1980; Michie et al., 1996; Walsh et al., 2015). Assessing the MOCR strength during SPiN task ensures that person is attending to the auditory stimuli. Therefore, in the current investigation we assessed the relationship between MOCR and SPiN scores while person is preforming the SPiN task. We varied the signal to noise ratio (SNR) and type of the stimuli (monosyllable and words) to modulate the difficulty level of SPiN. With this approach, if MOCR contributes to SPiN, we hope to see an effect of attention on MOCR and modulation of MOCR strength with task difficulty of SPiN. Furthermore, we also evaluated the relationship between SPiN scores and MOCR magnitude.

Aim of the study

To study the effect of auditory selective attention on the MOCR in young neurotypical and the relationship between MOCR strength and SPiN scores.

Objectives of the study

1) To compare speech identification in noise scores and reaction time across different SNRs (+4 dB SNR and 0 dB SNR) and speech stimuli (monosyllables and words)
2) To compare the MOCR strength (as measured by contralateral inhibition of TEOAEs) with following types of contralateral acoustic stimulations
    a. White noise alone
    b. Monosyllables embedded at +4 dB and 0 dB SNRs (active listening) in the white noise. Participants are required to identify the monosyllables in a closed set speech identification task.
    c. Words embedded at +4 dB and 0 dB SNRs (active listening) in the white noise. Participants are required to identify the words in a closed set speech identification task.
    d. Same as conditions b and c but contralateral acoustic stimulation is presented in time reversed fashion (passive attention).
3) To study the relationship between inhibition of OAE and SPiN scores in all the above conditions.

CHAPTER - II

Review of Literature

The auditory system of mammals contains descending projections that originate from the cortex and relays at various levels in the system before reaching organ of corti (Huffman & Henson, 1990). The efferent auditory system can be divided as rostral and caudal efferent systems (Maruthy et al., 2017).

The olivocochlear bundle (OCB), is one major component of caudal efferent pathway that arise from the cell bodies in the Superior Olivary Complex (SOC) at the level of brainstem (Michie et al., 1996). The olivocochlear system (caudal efferent), is formed by two groups of neurons: the medial olivocochlear (MOC) neurons and lateral olivocochlear (LOC) neurons (Warr & Guinan, 1979).

It is said that the caudal efferent auditory system can modulate the micromechanical properties of the cochlea, particularly in the outer hair cells (Siegel & Kim, 1982). Amongst the studies assessing the OCB, many studies focus on the medial olivocochlear bundle (MOCB) rather than the lateral olivocochlear bundle (LOCB) because it is accessible through non-invasive simple procedures.

Suppressive nature of OCB:

Earlier studies on animal efferent auditory system activation have found that there is a depression in the spontaneous firing of afferent auditory fibres when there is electrical stimulation to the efferent nerve fibres. An experiment was done by Guinan and Gifford (1988), where they examined the suppression of spontaneous activity of auditory nerve fibres in cats by efferent stimulation and they have considered a hypothesis, i.e., decreased endocochlear potential reduces the standing current that flows from the scala media through the inner hair cells (IHCs) which in turn hyperpolarizes the IHCs and this hyperpolarization reduces the spontaneous activity in the auditory – nerve fibres. Since stimulating midline – OCB produces a small decrease in the endocohlear potential this might reduce the spontaneous activity of auditory nerve fibres (Sewell, 1984). These authors have obtained tuning curves with and without efferent shocks for the auditory fibres which were categorized as low spontaneous fibres, medium spontaneous fibres and high spontaneous fibres and they concluded that an inhibitory response from the efferent fibres to the outer hair cell (OHC) reduces the spontaneous activity of the fibres and increases its threshold of stimulation (Guinan & Gifford, 1988).

The efferent neurons that originate in the brainstem has an innervation to the acoustic-lateralis organs and they release acetylcholine (ACh) when stimulated, that inhibits the hair cells. The Ach shunts and suppresses the outer hair cell's (OHC's) electromotility and that reduces the amplified basilar membrane motion. These inhibitory properties shows reduced frequency selectivity of the afferent neurons (Fuchs & Lauer, 2019)

Contralateral inhibition of OAEs

One of the most effective procedures in assessing the caudal efferent pathway includes, measuring otoacoustic emissions (OAE) in the presence and absence of contralateral stimulation. Studies have proved that stimulating the contralateral ear would activate the medial olivocochlear neurons, which in turn produces an inhibitory response (De Boer et al., 2012; Liberman, 1988; Maison & Liberman, 2000; Robertson, 1984)

A study done by Berlin et al. (1993), where contralateral suppression of OAEs were measured in eleven adults in the age range of 29 to 65 years with normal hearing sensitivity. Non-linear clicks were given to the right ear as a stimulus for eliciting OAEs with 80 microsecond pulse at 80-82 dB pe SPL. In the left ear, narrow band noise or pure tones at 20 to 80 dB HL was used as a suppressive stimulus. This study has shown a mean amplitude of 11 dB SPL of overall OAE amplitude and decrease of 2-2.5dB of overall emission amplitude with presence of contralateral noise than OAE amplitude elicited without contralateral suppression. The amplitude decrease was seen with an increase in the contralateral stimulus from 60-80 dB. This study has also stated that narrow band noise was the strongest suppressor compared to the pure tones.

Another experiment on contralateral suppression of TEOAEs in humans were carried out by Hood et al. (1996). In this study the authors have obtained TEOAEs from 48 subjects with normal hearing ranging from 12 to 59 years. At different intensity levels from 55 dB of clicks to 70 dB at 5 dB steps TEOAEs have been recorded for different subjects. Linear clicks have been used to elicit OAEs and a continuous contralateral white noise was presented to the subjects. The results indicated largest amplitude of suppression at or near 60 dB SPL of contralateral white noise.

When arguing on different types of noise for best suppressive effect on MOCB several studies have been done. Out of which recent study done by Kalaiah et al. (2017) explored different noise signals for contralateral suppression of TEOAEs. In this study 19 young adults between 18-23 years of age with normal hearing was included. Variety of suppressor signals such as white noise, amplitude-modulated noise, speech babble, and real-life noise were taken. TEOAEs were recorded at 60 dB pe SPL under different contralateral suppressor stimulus. It has been shown that white noise and amplitude modulated noise have shown to have greatest suppression then followed by environmental noise and the least effect was for speech babble. This study hence concluded the participation of OCB during environmental noise conditions like cafeteria and traffic noise which may further involve in processing speech in presence of noise.

Effect of attention on efferent auditory system suppression

Efferent fibres inhibits or filters irrelevant sensory stimuli at an early stage of sensory processing during a selective attention task (Hernandez-Peon., 1966). Several studies have been done on addressing the effect of human attention on efferent auditory inhibition (Ciuman, 2010; Fuchs & Lauer, 2019; Lauer et al., 2022; Lukas, 1980). One such study done by Lukas (1981), where he examined whether the olivocochlear bundle functions to attenuate irrelevant auditory stimuli during visual attention task. The author took seventeen normal hearing subjects between the age range of 17 and 23 years. The subjects were asked to count 8000Hz 50 dB SL tone pips or count the target letters that flashed on a visual display. Auditory brainstem potentials were recorded for both targeted and non-targeted tone pips. From this study the results revealed that when focused visual attention task was performed, the amplitude of the auditory nerve component reduced significantly by 37.4% and the latency increased by 90 μsecs. Wave V of ABR also showed decrease in the amplitude by 12.9% which was not statistically significant.

Like visual attention's effect on MOCB, auditory attention has also shown its influence on MOCB function. For instance, an experiment was conducted by Michie et al. (1996), where they compared the evoked OAEs (EOAE) with and without an attention task for 70 subjects within the age range of 17 to 48 years. A total of six experiments were carried out, in which the first four experiments used non-linear differential stimulus method, wherein the last two experiments used a single and different frequency tone pips. The results of second, fourth and sixth experiments showed increased emission strength to the ignored stimulus and these were consistently seen at 2000 Hz stimulus. Scharf et al. (1994) have stated that the function of olivocochlear bundle suppresses during the attention task particularly at the frequencies more than half a critical band from the frequency that has been attended.

When assessing MOCB activity is of utmost importance, otoacoustic emissions with contralateral suppression noise is highly used because of its easy, quick and non-invasive procedure. Several research has been carried out in exploring the role of auditory attention on peripheral auditory system through OAEs. In 1994, Meric and Collet reviewed nine papers based on attention and its influence on OAE (Froehlich et al., 1993; Lukas, 1980; Meric & Collet, 1993; Puel et al., 1988, 1989). Among these most of the studies have used nonfiltered clicks as the stimulus. The attention task used was mostly visual and some with both auditory and visual tasks. Auditory attention tasks used non-speech stimuli like tone pips to be identified in presence of another stimulus like clicks etc. The studies have shown ambiguous results of either decreased or increased emissions during an attentive task. Few studies taken for review in this study have also discussed about the role of middle ear with respect to the differences in TEOAE amplitudes. Middle ear pressure variations may affect the amplitude of TEOAEs especially at low frequencies. Between TEOAE and spontaneous OAEs, TEOAE showed shift in amplitudes for attention task compared to SOAE. These results suggest a top-down control of auditory system, which suggest peripheral control by the central system.

De Boer and Thornton (2007) investigated the effect of subject's task on the efferent suppression using contralateral suppression of click evoked OAEs. 12 normal hearing participants were taken in the age range of 18-25 years. OAEs were recorded using linear clicks at 40, 50 and 60 dB SPL. A contralateral broadband noise at 55 dB SL was given for suppression. These OAEs were recorded four times, while the subjects performed different tasks consecutively. The four tasks were: 1. No task, 2. Passive visual task (subjects were asked to watch a silent video with subtitles of their own choice), 3. Active visual task (subjects were given simple mathematical calculation and asked to press true/false in the response pad) and 4. Active auditory task (subjects were asked to detect tone pips given in between a train of clicks). The main effect on the suppression amplitude was seen during performing auditory task than visual. There was no significant difference observed in no task condition and two visual task conditions. This study concluded that MOCB activity is reduced due to top-down influences during selective attention on the ipsilateral ear.

Later studies were carried out to see the effect of auditory attention using speech stimulus unlike tone pips on the suppression effect. Garinis et al. (2011) studied the MOC reflex during active listening condition for speech stimulus in presence of noise. The main hypothesis of this study was that active listening to speech might increase MOC activity. To test this hypothesis, the authors have taken normal hearing females within the age range of 20-33 years. They carried out CEOAE at 60 dB SPL linear mode with three different contralateral noise condition: 1. BBN – 60 dB SPL of continuous BBN was presented in the contralateral ear, 2. BBN+W – Words were embedded in BBN at -3 dB SNR and the task was given to categorize the words into animals or food which was an active listening condition, 3. BBN+BW – The same words were played in reverse along with the continuous BBN noise at -3 dB SNR which was considered as passive listening condition. The study showed more contralateral suppression during active listening condition than other two condition and a laterality effect was seen for greater suppression in the right ear compared to left. They concluded that the cochlear output could be modulated when an active listening task is been done by filtering out irrelevant acoustic signal when attention is directed for that speech stimuli.

Kalaiah et al. (2017) investigated the effect of listening and listening effort on contralateral suppression of transient evoked otoacoustic emissions (CSTEOAEs). The authors have considered two hypotheses wherein, 1st one was the engagement of cortical processing during active listening which might increase the suppression of TEOAEs, and

2nd hypothesis was that the amount of suppression changes with respect to the listening effort. 28 normal hearing female participants between the age range of 18-22 years were taken for the study. Using linear clicks at 60 dB pe SPL in three contralateral noise conditions, CSTEOAEs were recorded. First condition included, recording of TEOAE with contralateral white noise; whereas the second condition of CSTEOAE was recorded with speech stimuli embedded on white noise at -3dB, +3dB and -9dB SNR presented to the contralateral ear. The third condition of CSTEOAE was recorded using speech stimuli being played backwards and embedded in white noise at -3 dB SNR. The active task given for the participants were to categorize. The study found that CSTEOAE was larger in presence of white noise. Also, there was no significant difference of CSTEOAE in both active and passive listening conditions. Various listening efforts had shown increased amount of suppression when the SNR reduced from +3 dB to -3 dB.

Role of MOCB in perception of speech in presence of noise

Among several functions of MOCB, enhancement of speech discrimination ability in presence of noise has been considered one of the important functions. Kawase and Charles (1993) studied on cats for antimasking effects of medial olivocochlear reflex (MOCR). They reported two types of MOC effects in cochlear response, namely direct and indirect effect. Direct effect corresponds to the suppression and indirect effect corresponds to the enhancement of action potential. The direct suppression effect was due to the olivocochlear activation which shifts the dynamic range of auditory nerve fibres to a higher level, hence there will be little or no change. Whereas the indirect enhancement effect was seen because of adaptation of auditory nerve for the continuous masker and becomes less active, but indirectly increases the nerve activity for transients.

Across decades numerous experiments have been done on supporting the antimasking effect of olivocochlear bundle. In 2004, Kumar and Vanaja studied the effect of contralateral acoustic stimuli on speech identification scores and correlation between speech scores and contralateral suppression of evoked otoacoustic emission. In this study ten normal hearing children within the age range of 10-12 years were taken. Speech identification task was carried out in four different conditions: i). In quiet condition, ii). In presence of ipsilateral noise at +10, +15, and +20 dB SNR using broadband noise and no noise in the contralateral ear, iii). Contralateral broadband noise of 30 dB SL with no noise in the ipsilateral ear and iv). In presence of noise in both ears. TEOAEs were recorded with and without contralateral noise at 30 dB SL. The study has proved a significant effect of contralateral noise in improved speech identification scores particularly in +10 dB and +15 dB SNR, as the contralateral acoustic stimulation led to activation of MOCB which has improved speech perception in presence of noise. Also, ear effect for suppression was seen, with greater suppression in the right ear, which might be due to peripheral auditory lateralization. Hence the study concluded that OCB play a significant role in speech perception especially in presence of noise.

To re-investigate the antimasking effect, De Boer et al. (2012), conducted a study to probe into the correlation of MOC activity and speech-in-noise processing for 24 normal hearing individuals. Three experiments were carried out in this study: 1. Discrimination task of CV syllable (/da/ and /ga/) in +10 dB SNR, 2. Contralateral suppression of click-evoked OAE, and 3. ABR for the syllable /da/ in quiet and masking condition at +10 dB and +20 dB SNR. The results were contradictory of the previous study, where it showed strongest suppression associated with poor CV discrimination score and longer latency ABR waveform. Authors elaborated that the findings could be because of stimulus used in this study. The speech perception depends on the existing cues available and using them in adverse listening condition. Hence, complex vs pure tone stimuli and mediating masking mechanism could have resulted in such findings.

Different kinds of SNR have different influence on MOCR. More adverse the condition more effect of efferent system could be seen. In 2021, Hernández-Pérez et al. studied the extent to which MOCR could control the cochlear gain in active vs passive listening situations. The active listening situation included speech identification task and passive listening included watching a silent video non-subtitled. The task difficulty was increased by embedding speech sounds in background noise and used vocoded stimuli that mimics CI processed signal. Physiological recordings were done while the subjects were performing the task. With respect to MOCR click-evoked OAEs with suppression was used. The results of the study showed that the magnitude of CEOAEs were significantly reduced during active task and for all noise-vocoded stimuli. When the effect of efferent system on cochlear gain was compared with natural speech in noise and noise-vocoded stimuli, noise-vocoded speech had better suppression than the natural speech embedded in noise especially task dependent. Wherein in all passive conditions such significance was not observed.

CHAPTER - III

Methods

Participants

A total of 35 participants in the age range of 18-30 years (Mean: 21.17, SD: 2.12) were included in this study. All the participants recruited were native Kannada speakers (knows to read and write Kannada) with a minimum formal education of 12 years. An informal case history was taken to rule out any history or active otological, neurological, neuropsychiatric, or speech – language disorders. The participants were also screened for low noise risk using Johnson screening questionnaire (Johnson et al., 2017) and only subjects with low risk for noise are included in this study. Only right-handed participants were recruited for this study and handedness was assessed using Edinburgh Handedness Inventory (Oldfield, 1971). The history, noise screening questionnaire and handedness questionnaire was assessed using google forms and sent to all the participants through mail and online instant messaging platform like WhatsApp etc. Along with this cognitive decline was ruled out using Montreal Cognitive Assessment test – MoCA (Julayanont & Nasreddine, 2017).

Inclusion criteria:

Apart from the above-mentioned inclusion criteria all participants had,

a) Normal hearing sensitivity (at or below 15dBHL) at octave frequencies from 250 Hz to 8000Hz.
b) More than 85% speech perception scores in quiet for Phonemically Balanced - Kannada words (Yathiraj & Vijayalakshmi, 2005).

c) ‘A’ tympanogram with present ipsilateral and contralateral acoustic reflexes at 500 Hz and 1000 Hz.

d) A transient evoked otoacoustic emissions (TEOAE) amplitude of 6 dB SPL or more for 80 dB pe SPL clicks

A written informed consent was taken from all the participants involved, prior to the commencement of the study. The current study adheres to the bio-behavioural ethical guidelines of All India Institute of Speech and Hearing, Mysore (Venkatesan & Basavaraj, 2009).

Instrumentation

- A calibrated two channel clinical audiometer, Piano Inventis plus (Inventis, Padova, Italy) with TDH 39 supra-aural headphones and Radio ear B71 bone vibrator was used to assess the hearing status of the participants. The same audiometer was also used to present the white noise for the contralateral inhibition of OAEs.
- A calibrated diagnostic immittance meter, GSI Tympstar pro (Gradson-Stadler, USA) was used to perform tympanometry and reflexometry (acoustic reflex thresholds).
- A calibrated Otoacoustic emission analyzer, Otodynamics ILO Version 6 was used to record TEOAE for both preliminary and experimental procedures.
- A laptop with Praat software version 6.3.07 (Boersma et al., 2002) was used to conduct SPiN experiments.

Stimuli used

Speech identification in noise was assessed at +4 dB and 0 dB SNR using two sets of stimuli, varying in their complexity and durational aspects - words and monosyllables.

- Monosyllables (consonant-vowel) (Mayadevi, 1974): Test includes 20 different Kannada consonants with the vowel being constant (/a/) in all consonant-vowel combination (/ma/, /ʤa/, /ʧa/, /sa/, /da/, /ta/, /ra/, /ṇa/, /pa/, /va/, /n̺a/, /ka/, /la/, /ha/, /ḷa/, /ga/, /ʃa/, /ja/, /d̺a/, /t̺a/). The list has been standardized and validated for both normal hearing and for clinical population in quiet and in noise.
- Phonemically-balanced words: Kannada (Manjula et al., 2015): The test contains 21 equivalent Kannada word list that has been standardized for comparable speech identification in quiet and noise conditions. All these 21 lists have phonemically balanced, disyllabic, meaningful Kannada words spoken by female Kannada talker. Two out of these 21 lists are randomly taken and are used for speech identification task in both SNR conditions.

These words and monosyllables were presented in the presence of ipsilateral white noise in two different SNRs (+4 dB and 0 dB SNR). For presenting the stimuli**,** experiments were created in PRAAT separately for the two stimuli. Through laptop, the speech stimuli are routed to the Piano Inventis audiometer and via Etymotic Research ER3C insert earphones, the stimuli were presented in the left ear of the participants. The participants were instructed to pay attention to the stimuli and select the stimulus heard amongst the multiple options displayed on screen

- TEOAE: 65 dB SPL of linear clicks was used as stimuli to measure the TEOAE. 600 and 1000 sweeps of click stimulus was used for monosyllables and PB-word condition respectively. White noise with embedded monosyllables and words (as such and in time-reversed conditions) was the contralateral stimulus. The level of the white noise was held constant at 60 dB HL, whereas the speech was presented such that an SNR of +4 dB and 0 dB was obtained.

Procedure

Before initiating the study, hearing thresholds were assessed for all the participants in both air conduction and bone conduction at frequencies 250Hz to 8000Hz and 250Hz to 4000Hz respectively using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Tympanometry was done at 226Hz probe tone for all participants in both ears. Acoustic reflex thresholds were carried at 500Hz, 1000Hz, 2000Hz and 4000Hz in both ipsilateral and contralateral mode. TEOAE at 80dB SPL using non-linear clicks was measured to ensure normal outer hair cell functioning.

Experimental tests

Transient evoked otoacoustic emissions (TEOAEs). TEOAEs were recorded and analyzed using Otodynamics ILO V6 software (Otodynamics Ltd., London, UK). Participants sat comfortably on a reclining chair. An appropriate-sized probe was inserted in the ear canal of the participants' right ear and sealed using a micropore to prevent falling of probe during testing. An EAR -3C insert earphone connected to a Piano Inventis diagnostic audiometer was placed in the left ear. The probe fit and stimulus levels were monitored throughout the recordings. TEOAEs were recorded in the following conditions:

a. Without contralateral acoustic stimulation
b. White noise presented at 60 dB SPL in the contralateral ear
c. Monosyllables embedded at +4 dB and 0 dB SNRs (active listening) in the white noise – presented at 60 dB SPL in the contralateral ear. During this TEOAE recording participants are required to identify the monosyllables in a closed set speech identification task. TEOAEs were recorded for a total of 600 sweeps in this condition.

d. Words embedded at +4 dB and 0 dB SNRs (active listening) in the white noise – presented at 60 dB SPL in the contralateral ear. Participants are required to identify the words in a closed set speech identification task during this TEOAE recordings. TEOAEs were recorded for a total of 1000 sweeps in this condition.
e. Same as conditions b and c but words and monosyllables are presented in time reversed fashion (passive attention).

In all the recordings linear clicks were presented at 65 dB pe SPL (±0.5 dB) at a rate of 49 clicks/s to record the TEOAEs. The TEOAE stimulus calibration was done as per the procedure recommended by the manufacturer. We set a rejection level of 6 mPa over a time window of 2.5 - 20 ms after the presentation of the click. The rejection rate was at or below 10% for all participants. It was ensured that all accepted TEOAE recordings had response reproducibility of more than 80% and stimulus stability of more than 95%. The magnitude of contralateral inhibition (a measure of the MOCR strength) was measured by subtracting the TEOAE global amplitudes in the CAS+ condition from CAS- condition.

Speech perception in noise (SPiN). SPiN was assessed using a closed-set identification of monosyllables and words at +4 dB and 0 dB SNR simultaneously during contralateral inhibition of OAEs. A multiple forced choice listening experiment was created in Praat software version 6.3.07 using a PRAAT code (Boersma et al., 2002). Speech stimuli was presented to the left ear (contralateral ear) along with white noise. The speech stimuli were routed to one of the external sources of the audiometer (Piano inventis) from the laptop (Lenovo Ideapad i3 core) via an external jack and was presented at required SNRs (+4 dB and 0 dB SNRs) through channel 1, whereas white noise was given to the same ear (left ear) through channel 2 at 60 dB HL constantly. An EAR – 3C insert earphone was placed on the contralateral ear for presentation of the stimuli. The responses were displayed in the laptop screen as soon as the experiment started. Participants were instructed to perform the closed-set speech identification by selecting the appropriate response displayed in the screen. The responses were saved once the experiment is completed. The saved responses were transcribed to a spreadsheet where further analysis was performed.

CHAPTER - IV

Results

The results section will be focused on the three main objectives of this study. Parametric tests were carried out for the statistical analysis as the overall data followed normality in Shapiro-Wilks test and the results are depicted in table 4.1.

Table 4.1

Results of Shapiro-Wilk test of normality

Tested variables		Shapiro-Wilks test		
		Statistic	**df**	***p* value**
Active attention	Suppression – 4 dB SNR monosyllables	0.956	35	0.174
	Suppression – 4 dB SNR words	0.961	35	0.252
	Suppression – 0 dB SNR monosyllables	0.956	35	0.178
	Suppression – 0 dB SNR words	0.964	35	0.296
Passive listening	Suppression – 4 dB SNR monosyllables	0.947	35	0.092
	Suppression - 4dB SNR words	0.956	35	0.176
	Suppression – 0 dB SNR monosyllables	0.985	35	0.898
	Suppression – 0 dB SNR words	0.983	35	0.852
Active attention	Reaction time – 4 dB SNR monosyllables	0.961	35	0.253
	Reaction time – 4 dB SNR words	0.977	35	0.667
	Reaction time – 0 dB SNR monosyllables	0.986	35	0.929
	Reaction time – 0 dB SNR words	0.961	35	0.246
Active attention	Accuracy scores – 4 dB SNR monosyllables	0.950	35	0.116
	Accuracy scores – 4 dB SNR words	0.915	35	0.010
	Accuracy scores – 0 dB SNR monosyllables	0.969	35	0.419
	Accuracy scores – 0dB SNR words	0.945	35	0.082

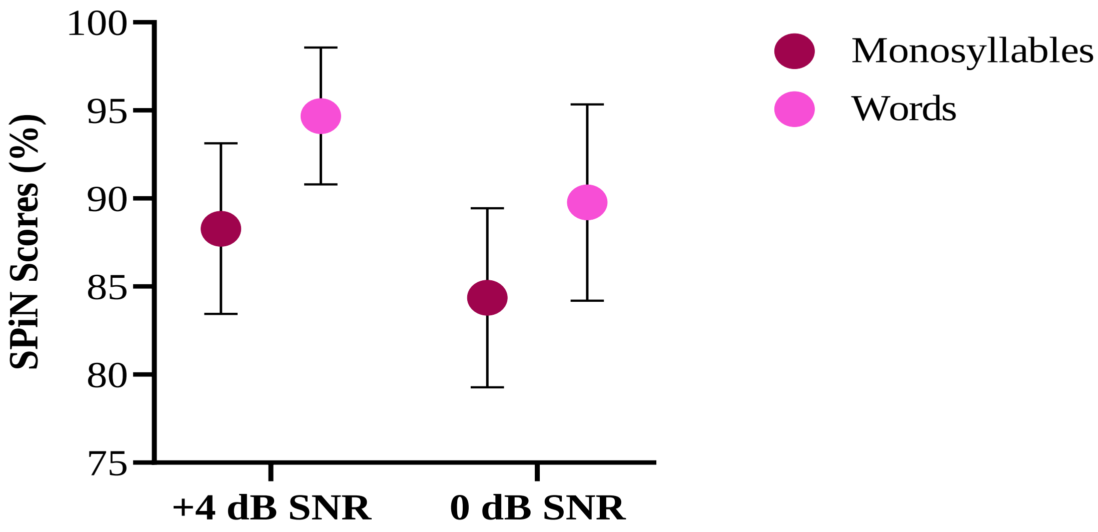
Comparison of speech in noise scores across different SNRs and stimuli

Speech identification scores

Figure 4.1 depicts the mean (in percentage) and one standard deviation (in the error bar) of the speech perception in noise (SPiN) scores across +4 dB SNR and 0 dB SNR for both monosyllables and words. From the Figure 4.1 it can be seen that speech identification scores were better for +4 dB SNR than 0 dB SNR for both words and monosyllables. Between words and monosyllables (+4 dB SNR - mean: 94.69, SD: 3.88; 0 dB SNR – mean: 89.77, SD: 5.57), words were better identified compared to monosyllables. A repeated measures ANOVA was carried out to see the effect of SNR and stimuli on the SPiN scores. There was a statistically significant effect of SNRs [F(1, 34) = 36.572, p<0.001, $\eta_p^2 = 0.518$] and stimuli [F(1, 34) = 38.333, p<0.001, $\eta_p^2 = 0.530$] on the SPIN scores. The interaction between the two was not significant [F(1, 34) = 0.469, p=0.498, $\eta_p^2 = 0.014$].

Figure 4.1

Speech perception in noise scores across different SNRs and speech stimuli. The bar graph depicts the mean accuracy scores of SPiN for monosyllables and words at +4 dB SNR and 0 dB SNR in percentage. Error bars show one standard deviation.

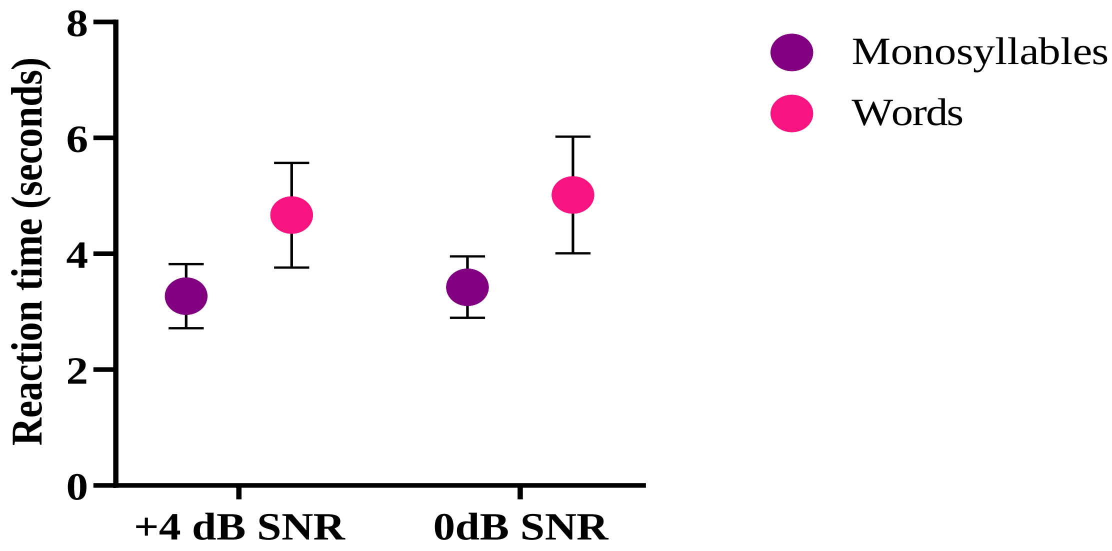


Reaction time

Figure 4.2 depicts the mean (in seconds) and one standard deviation (in the error bar) of the reaction time across +4 dB SNR and 0 dB SNR for both monosyllables and words in Kannada. From figure 4.2 it can be inferred that the poorer SNRs (monosyllable - mean: 3.42, SD: 0.53; words - mean: 5.02, SD: 1) resulted in longer reaction times compared to better SNR. Monosyllables resulted in shorter reaction time compared to words. A repeated measures ANOVA was carried out to see the effect of SNR and stimuli on the reaction time of SPIN task. The results revealed a statistically significant main effect of SNRs [F(1, 34) = 9.371, p=0.004, $\eta_p^2 = 0.216$] and stimuli [F(1, 34) = 134.066, p<0.001, $\eta_p^2 = 0.798$] on the reaction time. Interaction between the two factors were not significant [F(1, 34) = 0.959, p=0.334, $\eta_p^2 = 0.027$].

Figure 4.2

Reaction time across different SNRs and speech stimuli. The bar graph depicts the mean reaction time of SPIN for monosyllables and words at +4dB SNR and 0dB SNR in seconds. Error bars show one standard deviation.



Effect of contralateral acoustic stimulus on TEOAEs

Figure 4.3 and Figure 4.4 shows the mean TEOAE amplitudes and one standard deviation (in the error bars) with and without contralateral acoustic stimulation (CAS) during active attention and passive listening task, respectively. Paired t test showed that all types of CAS significantly reduced TEOAE amplitudes in both the active and passive listening task. Results of pair test are shown in Table 4.2.

Figure 4.3

Mean TEOAE amplitudes with and without CAS in active attention task. The bar graph depicts the mean TOAE amplitudes in two conditions. Condition 1 represents the amplitude of TEOAE without CAS, whereas condition 2 represents the amplitude of TEOAE with different types CAS as indicated by the legend. Error bars show one standard deviation.

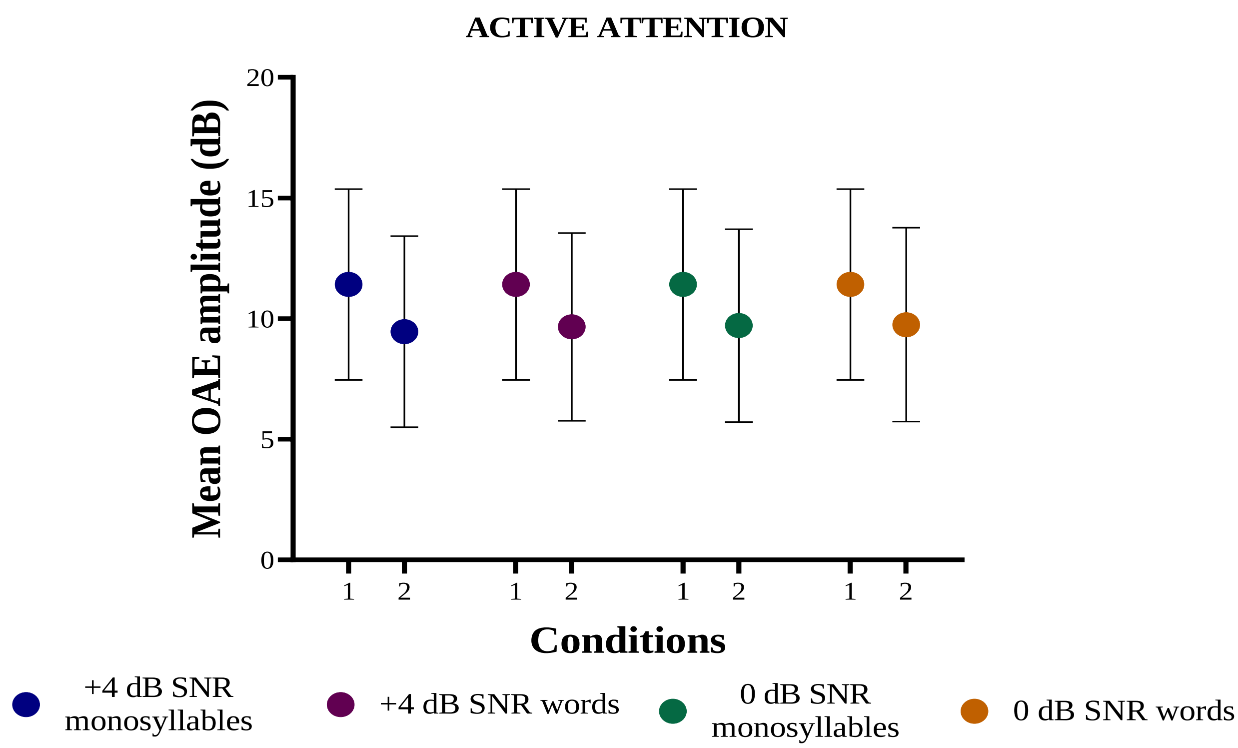


Figure 4.4

Mean TEOAE amplitudes with and without CAS in passive listening task. The bar graph depicts the mean TEOAE amplitudes in two conditions. Condition 1 represents the amplitude of TEOAE without CAS, whereas condition 2 represents the amplitude of TEOAE with CAS as indicated by the legend. Error bars show one standard deviation.

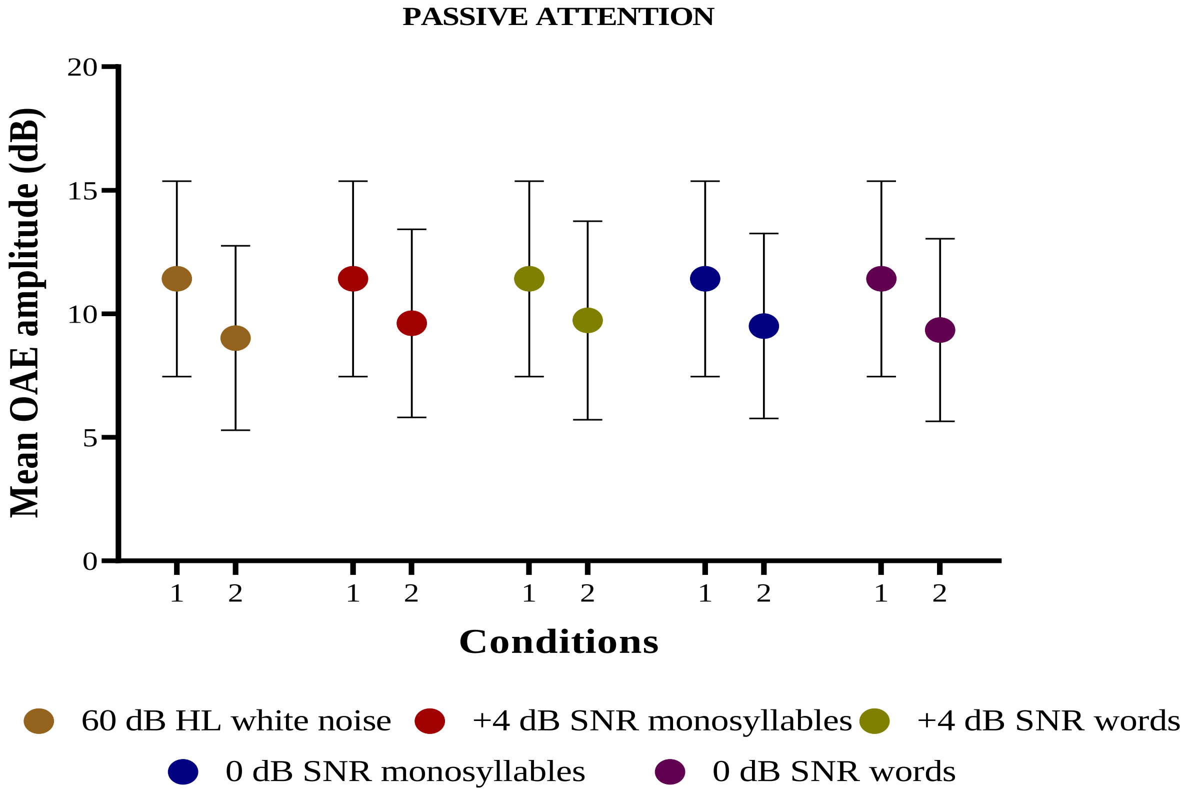


Table 4.2

Results of paired t test across different SNRs and speech stimuli in active attention and passive listening condition

	Compared variables	*t* value	*df*	Sig (2-tailed)	95% Confidence interval of the difference	
					Lower	Upper
Active attention	OAE without CAS – 4 dB SNR monosyllable	11.83	34	<0.001*	1.62	2.3
	OAE without CAS – 4 dB SNR words	15.48	34	<0.001*	1.53	1.99
	OAE without CAS – 0 dB SNR monosyllables	10.57	34	<0.001*	1.38	2.03
	OAE without CAS – 0 dB SNR words	8.76	34	<0.001*	1.28	2.06
Passive listening	OAE without CAS – OAE with CAS (white noise)	21.15	34	<0.001*	2.17	2.63
	OAE without CAS – 4 dB SNR monosyllables	12.3	34	<0.001*	1.5	2.1
	OAE without CAS – 4 dB SNR words	9.07	34	<0.001*	1.31	2.06
	OAE without CAS – 0 dB SNR monosyllables	12.41	34	<0.001*	1.6	2.22
	OAE without CAS – 0 dB SNR words	12.6	34	<0.001*	1.74	2.41

**after Bonferroni's correction for multiple comparisons* $p<0.001$

Effect of attention on magnitude contralateral inhibition

Figure 4.5 represents the mean (in dB) and one standard deviation (in error bar) of the magnitude of contralateral inhibition of TEOAEs for different CAS during active attention and passive listening tasks. From the figure it can be observed that there was no marked difference in the inhibitory amplitudes across different conditions. A two-way repeated measures ANOVA with listening condition (active vs. passive), SNR (+4 dB vs. 0 dB) and stimuli (monosyllable vs. words) was carried out. There was no statistically significant main effect of attention [F(1, 34) = 2.377, p=0.132, $\eta_p^2 = 0.065$], SNR [F(1, 34) = 0.242, p=0.626, $\eta_p^2 = 0.007$], and stimuli [F(1, 34) = 0.308, p=0.583, $\eta_p^2 = 0.009$] on the magnitude of contralateral inhibition of OAE. Furthermore, there was also no statistically significant interaction effect between SNRs and stimuli [F(1, 34) = 1.454, p=0.236, $\eta_p^2 = 0.41$] and attention conditions and stimuli [F(1, 34) = 0.501, p=0.484, $\eta_p^2 = 0.015$]. However, a statistically significant interaction effect was seen between the attention conditions and the SNRs [F(1, 34) = 6.800, p=0.013, $\eta_p^2 = 0.167$] on the amplitude of contralateral inhibition.

Figure 4.5

The graph represents the inhibitory amplitudes of TEOAE under two conditions. Condition 1 and condition 2 depicts the inhibitory amplitudes during active attention and passive listening respectively across +4 dB SNR and 0 dB SNR using both monosyllables and words. The dots represent the mean inhibition amplitude value and the standard deviation is denoted in the error bars

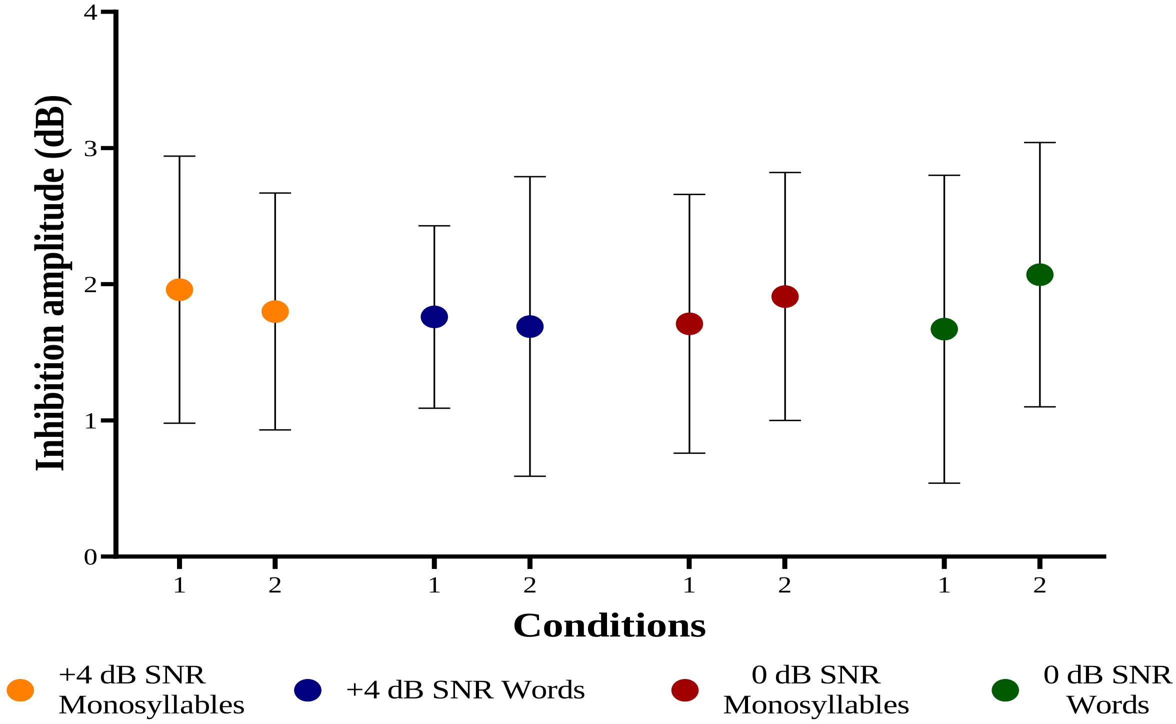


Figure 4.6 and figure 4.7 represents the interaction effects of SNR and attention conditions for monosyllables and words respectively. It can be seen from the figures that at attention and SNR modulated the magnitude of contralateral inhibition of OAEs. When attention was paid to the CAS (in active listening condition), magnitude of contralateral inhibition increased as the SNR improved. However, the opposite was true when participants did not pay attention to CAS. Inhibition magnitude increased when SNR became poor. This was seen for both monosyllables and words. Post-hoc pairwise t tests were conducted to assess the statistical significance of the modulation of magnitude of contralateral inhibition of OAEs with attention. Results are shown in Table 4.3

Figure 4.6

Interaction effect of SNR and attention task for monosyllables on the contralateral inhibition amplitudes. The graph represents the mean inhibition amplitude of TEOAE using CAS at 4dB SNR and 0dB SNR. The circle represents the mean inhibition amplitude during active attention condition and the square represents the mean inhibition amplitude during passive listening condition at both the SNRs using monosyllables

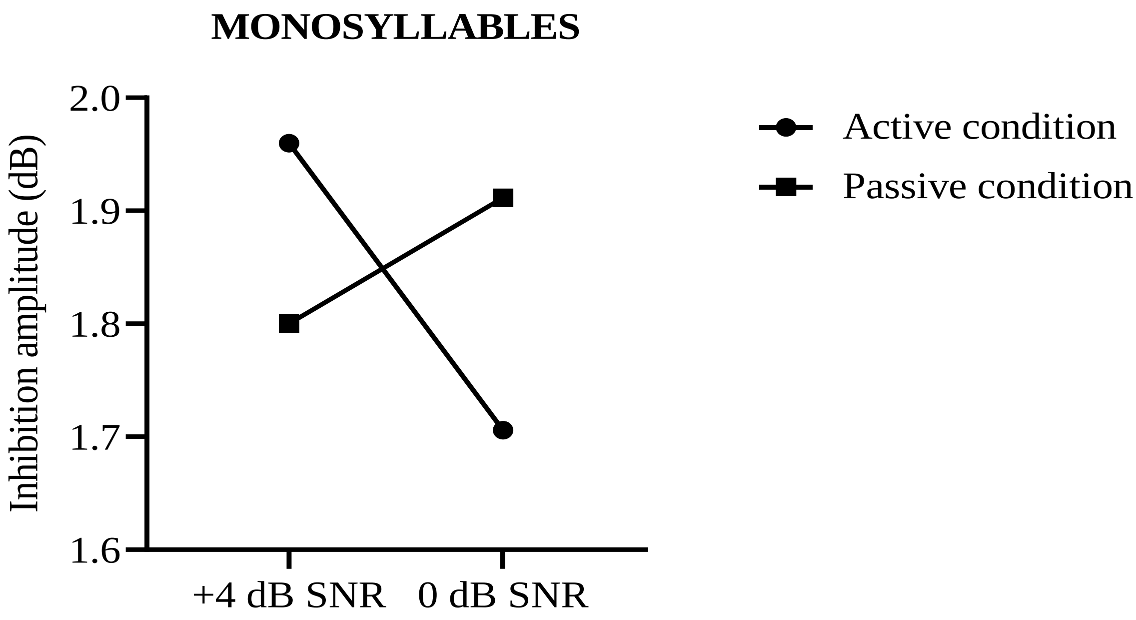


Figure 4.7

Interaction effect of SNR and attention task for words on the contralateral inhibition amplitudes. the graph represents the mean inhibition amplitude of TEOAE using CAS at 4 dB SNR and 0 dB SNR. The circle represents the mean inhibition amplitude during active attention condition and the square represents the mean inhibition amplitude during passive listening condition at both the SNRs using words

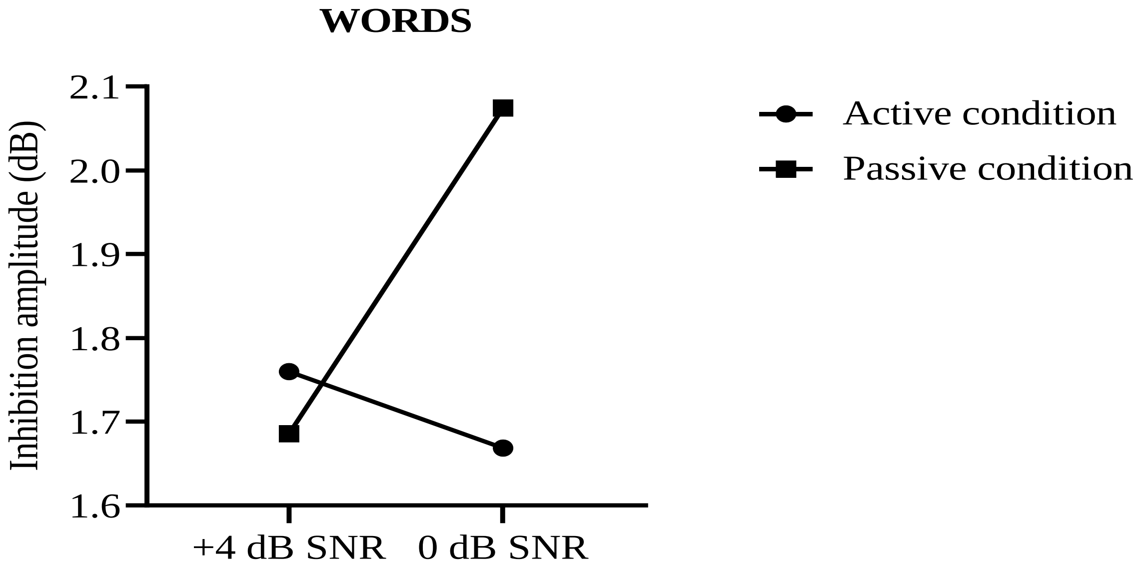


Table 4.3

Student's t test

		t	df	Sig (*p*)
Inhibition magnitude	Active MS 0 dB SNR – Active MS +4 dB SNR	1.840	34	0.074
	Passive MS 0 dB SNR – Passive MS +4 dB SNR	-0.809	34	0.424
	Active words 0 dB SNR – Active words +4 dB SNR	0.486	34	0.630
	Passive words 0 dB SNR – Passive words +4 dB SNR	-2.319	34	0.027

Note. MS – monosyllables

Relationship between different types of stimuli, SNRs on accuracy and reaction time of speech identification and the amplitude of contralateral inhibition of OAEs

Speech identification scores

Pearson's Product-Moment correlation analyses was carried out to find the relationship between magnitude of contralateral inhibition amplitudes and speech identification scores across different SNRs and speech materials (monosyllables and words). Results of correlation test is shown in Table 4.4. There was no statistically significant correlation between the speech identification scores and the inhibition amplitudes at both the SNRs and for both stimuli

Table 4.4

Pearson correlation table for speech identification scores and inhibition amplitude

		SPIN scores							
		Monosyllables +4 dB SNR		Monosyllables 0 dB SNR		Words +4 dB SNR		Words 0 dB SNR	
		r	*p*	r	*p*	r	*p*	r	*p*
Inhibition amplitude	Monosyllables +4 dB SNR	0.117	0.504	0.091	0.605	0.111	0.525	0.343	0.044
	Monosyllables 0 dB SNR	0.370	0.029	0.081	0.643	0.061	0.728	-0.065	0.710
	Words +4 dB SNR	0.134	0.442	0.246	0.154	-0.023	0.896	0.404	0.016
	Words 0 dB SNR	-0.059	0.738	0.203	0.242	0.086	0.624	0.102	0.560

CHAPTER – V

Discussion

The current results of the study were given under the three main objectives:

1. To compare speech perception in noise (SPIN) scores and reaction time across different SNRs (+4 dB SNR and 0 dB SNR) and speech stimuli (monosyllables and words)
2. To compare the medial olivocochlear reflex (MOCR) strength (as measured by contralateral inhibition of TEOAEs) in following conditions
    a. White noise (passive attention).
    b. Participants identifying the monosyllables presented at +4 dB and 0 dB SNRs (active attention)
    c. Participants identifying the words presented at +4 dB and 0 dB SNRs (active attention).
    d. Same as conditions b and c but presented in time reversed fashion (passive attention).
3. To study the relationship between inhibition of OAE and SPIN scores in all the above conditions.

Comparison of SPIN scores and reaction time across different SNRs and stimuli

The SPIN scores were compared across +4dB SNR and 0dB SNR using monosyllables and words. The statistical analysis revealed a significant stimuli effect and SNR effect on the SPIN scores. The accuracy scores were poorer for monosyllables compared to words in both the SNRs. It is evident that identification of monosyllables in presence of noise is more difficult than identification of words (Figure 4.1). One of the main reasons for better identification of words is higher linguistic redundancy present in words compared to monosyllables (Mcardle et al., 2015; Wilson et al., 2008).

Similarly, the reaction time was compared across +4dB SNR and 0dB SNR and using both monosyllables and words. The statistical analysis showed a significant effect of stimuli and SNR on the reaction time. The current study shows that words had longer reaction time than monosyllables in both the SNR conditions (Figure 4.2). Words had longer reaction time compared to monosyllables because words were longer duration stimuli compared to monosyllables. As the reaction time was measured from onset of the stimuli till the participants responded, words resulted in longer reaction time compared to monosyllables.

Effect of contralateral acoustic stimulus on TEOAEs

Across both active attention and passive listening conditions with different speech stimuli and SNRs as contralateral acoustic stimulation (CAS) resulted in the significant reduction in TEOAE amplitudes. The magnitude of the reduction seen was comparable to what is reported in the literature (de Boer & Thornton, 2007; Garinis et al., 2011; Hernández-Pérez et al., 2021; Kalaiah et al., 2017).

Effect of attention on magnitude contralateral inhibition

The current study shows that there is no significant effect of attention on the contralateral inhibition amplitude. The inhibition amplitude did not vary significantly across the stimuli and SNR which are contradictory to the previous findings (de Boer & Thornton, 2007; Garinis et al., 2011; Hernández-Pérez et al., 2021; Kalaiah et al., 2017).

Several investigations have reported increased inhibition amplitudes for passive listening condition than for active attention (De Boer & Thornton, 2007; Hernández-Pérez et al., 2021). dse Boer and Thornton studied the effect of attention on the contralateral suppression. They found least inhibition amplitude during active attention condition involving identification of non-speech stimuli (tone-pips) embedded within the train of click stimulus.

Hernandez-Perez et al (2021) investigated on the brainstem reflex mechanism for degraded signals. They used speech in presence of background noise and vocoded speech stimuli. These two stimuli had shown opposite inhibition effects. Speech in the presence of background noise had increased MOC activity during a passive listening condition at lower SNRs, whereas vocoded stimuli showed greater inhibition amplitudes during an active attention task at degraded SNRs. The authors stated that different neural circuits are responsible for the speech perception and that depends on the specific features of the listening environment. One of the experiments carried out by Kalaiah et al. (2017), reported greater suppression for active attention condition compared to passive listening condition. Also, they reported greater inhibition at -3dB SNR with no significant difference at +3dB and -9dB SNR. Reasons speculated by the authors for this kind of results were reduction in the efferent involvement for an active task in a much more degraded signal (-9dB SNR) and an active involvement of efferent system when the signal was degraded from +3dB to -3dB SNR which caused increase in the inhibition amplitudes. Similar results have also been reported by Garinis et al. (2011). In their study the authors measured TEOAE in an active attention condition at -3dB SNR. They reported an increased inhibition amplitude for active attention conditions compared to the passive listening tasks. Here the authors theorized involvement of cortical mechanism during active listening which yielded higher inhibition amplitude.

In the current investigation we did not find the significant effect of attention on the inhibition amplitudes. However, we observed a significant interaction effect of SNR and listening conditions on the inhibition magnitude. This meant that, inhibition magnitude was modulated by the SNR and attention in a very specific manner. When attention was paid to the CAS (in active listening condition), magnitude of contralateral inhibition increased as the SNR improved. However, the opposite was true when participants did not pay attention to CAS. Inhibition magnitude increased when SNR became poor. One possible explanation for such finding could be the amount of MOC involvement for different attentive conditions. Mishra and Lutman (2014) explained that MOC – induced activity of speech perception as a complex mechanism and listeners may not use the unmasking effect of MOC during all listening situations. The current investigation showed that MOC activation is pronounced for degraded signal but only in specific conditions. Physiological mechanisms behind such effects are unclear at present.

Relationship between different types of stimuli, SNRs on accuracy and reaction time of speech identification and the amplitude of contralateral inhibition of OAEs

The current study did not show significant correlation between speech scores and reaction time on the contralateral inhibition. Recent experiments threw supporting evidence for the current findings. Mertes et al (2023) have studied on the relationship between MOCR and sentence recognition in noise and found no correlation between both. Similarly, Yashaswini et al (2019) have also reported no significant correlation between SNR-50 and CAS of TEOAE

CHAPTER VI

Summary and conclusion

Medial olivocochlear reflex (MOCR) has been hypothesized to play a crucial role in speech perception especially in the presence of noise (SPIN) (Kalaiah et al., 2022; Kumar & Vanaja, 2004; Mishra & Lutman, 2014). Even though there is wealth of research on role of MOCR in SPiN, the results are equivocal. The current study investigated role attention paid to the contralateral stimuli on the relationship between MOCR and SPiN.

The study included 35 normal hearing participants between the age range of 18 to 30 years (mean age range: 21.17 years; SD: 2.12). All the participants had normal hearing sensitivity with no history of conductive component and normal outer hair cell (OHC) functioning. The participants had low noise risk and all the participants were right-handed. TEOAEs were recorded in all the participants in following conditions:

a. Without contralateral acoustic stimulation
b. White noise presented at 60 dB SPL in the contralateral ear
c. Monosyllables embedded at +4 dB and 0 dB SNRs (active listening) in the white noise – presented at 60 dB SPL in the contralateral ear. During this TEOAE recording participants are required to identify the monosyllables in a closed set speech identification task. TEOAEs were recorded for a total of 600 sweeps in this condition.
d. Words embedded at +4 dB and 0 dB SNRs (active listening) in the white noise – presented at 60 dB SPL in the contralateral ear. Participants are required to identify the words in a closed set speech identification task

during this TEOAE recordings. TEOAEs were recorded for a total of 1000 sweeps in this condition.

e. Same as conditions b and c but words and monosyllables are presented in time reversed fashion (passive attention).

Results showed no main effect of attention, SNR or the type speech material used on the inhibition magnitudes. However, there was a significant interaction between inhibition SNR and attention on the inhibition magnitudes. As the participants attended to speech stimuli, the inhibition magnitude improved at only at specific SNR. But there was no significant relationship between inhibition magnitudes and SPiN scores in both the listening conditions, for both SNRs and stimuli.

Implications

- Understanding how the efferent auditory system contributes to speech perception in noisy environments can lead to the development of more effective hearing aid technologies. Researchers can explore ways to enhance efferent system function in hearing aids, potentially improving speech understanding in challenging acoustic conditions
- Investigating modulated attention in the context of speech perception and the efferent system can shed light on the cognitive aspects of hearing. This research can provide insights into how attention affects our ability to filter out noise and focus on relevant speech signals.

References

Berlin, C. I., Hood, L. J., Wen, H., Szabó, P., Cecola, R. P., Rigby, P. L., & Jackson, D. F. (1993). Contralateral suppression of non-linear click-evoked otoacoustic emissions. *Hearing Research*, *71*(1–2), 1–11. https://doi.org/10.1016/0378-5955(93)90015-s

Boersma, P. (2002). Praat, a system for doing phonetics by computer. *Glot International 5*, 341–345. https://hdl.handle.net/11245/1.200596

Ciuman, R. R. (2010). The efferent system or olivocochlear function bundle - fine regulator and protector of hearing perception. *PubMed*, *6*(4), 276–288. https://pubmed.ncbi.nlm.nih.gov/23675203

De Boer, J., Thornton, A. R. D., & Krumbholz, K. (2012). What is the role of the medial olivocochlear system in speech-in-noise processing? *Journal of Neurophysiology*, *107*(5), 1301–1312. https://doi.org/10.1152/jn.00222.2011

De Boer, J., & Thornton, A. R. D. (2007). Effect of subject task on contralateral suppression of click evoked otoacoustic emissions. *Hearing Research*, *233*(1–2), 117–123. https://doi.org/10.1016/j.heares.2007.08.002

Ferry, R., & Meddis, R. (2007). A computer model of medial efferent suppression in the mammalian auditory system. *Journal of the Acoustical Society of America*, *122*(6), 3519–3526. https://doi.org/10.1121/1.2799914

Froehlich, P., Collet, L., & Morgon, A. (1993). Transiently evoked otoacoustic emission amplitudes change with changes of directed attention. *Physiology & behavior*, *53*(4), 679–682. https://doi.org/10.1016/0031-9384(93)90173-d

Fuchs, P. A., & Lauer, A. M. (2019). Efferent Inhibition of the Cochlea. *Cold Spring Harbor perspectives in medicine*, *9*(5), a033530. https://doi.org/10.1101/cshperspect.a033530

Galhom, D. H., Nada, E. H., Ahmed, H. A. E., & Elnabtity, N. M. (2022). Evaluation of Auditory Efferent System using Speech Auditory Brainstem Response with Contralateral Noise. *Egyptian Journal of Hospital Medicine*, *87*(1), 2064–2071. https://doi.org/10.21608/EJHM.2022.232817

Garinis, A. C., Glattke, T., & Cone, B. K. (2011). The MOC reflex during active listening to speech. *Journal of Speech, Language, and Hearing Research*, *54*(5), 1464–1476. https://doi.org/10.1044/1092-4388(2011/10-0223)

Geisler, C. D. (1974). Hypothesis on the function of the crossed olivocochlear bundle. *Journal of the Acoustical Society of America*, *56*(6), 1908–1909. https://doi.org/10.1121/1.1903532

Guinan, J. J. (2006). Olivocochlear efferents: anatomy, physiology, function, and the measurement of efferent effects in humans. *Ear And Hearing*, *27*(6), 589–607. https://doi.org/10.1097/01.aud.0000240507.83072.e7

Guinan, J. J., & Gifford, M. L. (1988). Effects of electrical stimulation of efferent olivocochlear neurons on cat auditory-nerve fibers. II. Spontaneous rate. *Hearing Research*, *33*(2), 115–127. https://doi.org/10.1016/0378-5955(88)90024-x

Hernández-Pérez, H., Mikiel-Hunter, J., McAlpine, D., Dhar, S., Boothalingam, S., Monaghan, J. J. M., & McMahon, C. M. (2021). Understanding degraded speech leads to perceptual gating of a brainstem reflex in human listeners. *PLoS biology*, *19*(10), e3001439. https://doi.org/10.1371/journal.pbio.3001439

Hood, L. J., Berlin, C. I., Hurley, A., Cecola, R. P., & Bell, B. (1996). Contralateral suppression of transient-evoked otoacoustic emissions in humans: intensity effects. *Hearing Research*, *101*(1–2), 113–118. https://doi.org/10.1016/S0378-5955(96)00138-4

Huffman, R. F., & Henson, O. W. (1990). The descending auditory pathway and acousticomotor systems: connections with the inferior colliculus. *Brain Research Reviews*, *15*(3), 295–323. https://doi.org/10.1016/0165-0173(90)90005-9

Johnson, T. A., Cooper, S., Stamper, G. C., & Chertoff, M. (2017). Noise exposure questionnaire: A tool for quantifying annual noise exposure. *Journal of the American Academy of Audiology*, *28*(1), 14–35. https://doi.org/10.3766/jaaa.15070

Julayanont, P., & Nasreddine, Z. S. (2017). Montreal Cognitive Assessment (MoCA): Concept and Clinical Review. In A. J. Larner (Ed.), *Cognitive Screening Instruments: A Practical Approach* (pp. 139–195). Springer, Cham. https://doi.org/10.1007/978-3-319-44775-9

Kalaiah, M. K., Nanchirakal, J. F., Kharmawphlang, L., & Noronah, S. C. (2017). Contralateral suppression of transient evoked otoacoustic emissions for various noise signals. *Hearing, Balance and Communication*, *15*(2), 84–90. https://doi.org/10.1080/21695717.2017.1311504

Kalaiah, M. K., Mishra, K., & Shastri, U. (2022). The Relationship between Contralateral Suppression of Transient Evoked Otoacoustic Emission and Unmasking of Speech Evoked Auditory Brainstem Response. *International archives of otorhinolaryngology*, *26*(4), e676–e682. https://doi.org/10.1055/s-0042-1742774

Kalaiah, M. K., Theruvan, N. B., Kumar, K., & Bhat, J. S. (2017). Role of Active Listening and Listening Effort on Contralateral Suppression of Transient Evoked Otoacousic Emissions. *Journal of audiology & otology*, *21*(1), 1–8. https://doi.org/10.7874/jao.2017.21.1.1

Kawase, T., & Liberman, M. C. (1993). Antimasking effects of the olivocochlear reflex. I. Enhancement of compound action potentials to masked tones. *Journal of neurophysiology*, *70*(6), 2519–2532. https://doi.org/10.1152/jn.1993.70.6.2519

Kumar, U. A., & Vanaja, C. S. (2004). Functioning of Olivocochlear Bundle and Speech Perception in Noise. *Ear and Hearing*, *25*(2), 142–146. https://doi.org/10.1097/01.AUD.0000120363.56591.E6

Lauer, A. M., Jimenez, S. V., & Delano, P. H. (2022). Olivocochlear efferent effects on perception and behavior. *Hearing research*, *419*, 108207. https://doi.org/10.1016/j.heares.2021.108207

Liberman, M. C. (1988). Physiology of cochlear efferent and afferent neurons: Direct comparisons in the same animal. *Hearing Research*, *34*(2), 179–191. https://doi.org/10.1016/0378-5955(88)90105-0

Liberman, M. C. (1988). Response properties of cochlear efferent neurons: monaural vs. binaural stimulation and the effects of noise. *Journal of neurophysiology*, *60*(5), 1779–1798. https://doi.org/10.1152/jn.1988.60.5.1779

Lukas, J. H. (1980). Human auditory attention: the olivocochlear bundle may function as a peripheral filter. *Psychophysiology*, *17*(5), 444–452. https://doi.org/10.1111/j.1469-8986.1980.tb00181.x

Lukas, J. H. (1981). The role of efferent inhibition in human auditory attention: an examination of the auditory brainstem potentials. *The International journal of neuroscience*, *12*(2), 137–145. https://doi.org/10.3109/00207458108985796

Maison, S. F., & Liberman, M. C. (2000). Predicting vulnerability to acoustic injury with a non-invasive assay of olivocochlear reflex strength. *The Journal of neuroscience: the official journal of the Society for Neuroscience*, *20*(12), 4701–4707. https://doi.org/10.1523/JNEUROSCI.20-12-04701.2000

Manjula, P., Antony, J., Kumar, K. S. S., & Geetha, C. (2015). Development of phonemically balanced word lists for adults in the kannada language. *Journal of Hearing Science*, *5*(1), 22–30. https://doi.org/10.17430/893515

Maruthy, S., Kumar, U. A., & Gnanateja, G. N. (2017). Functional Interplay Between the Putative Measures of Rostral and Caudal Efferent Regulation of Speech Perception in Noise. *Journal of the Association for Research in Otolaryngology: JARO*, *18*(4), 635–648. https://doi.org/10.1007/s10162-017-0623-y

May, B. J., Budelis, J., & Niparko, J. K. (2004). Behavioral studies of the olivocochlear efferent system: learning to listen in noise. *Archives of otolaryngology--head & neck surgery*, *130*(5), 660–664. https://doi.org/10.1001/archotol.130.5.660

Mayadevi, (1974). Development and Standardization of A Common Speech Discrimination Test For Indians. University of Mysore.

McArdle, R. A., Wilson, R. H., & Burks, C. A. (2005). Speech recognition in multitalker babble using digits, words, and sentences. *Journal of the American Academy of Audiology*, *16*(9), 726–764. https://doi.org/10.3766/jaaa.16.9.9gaf

Meric, C., & Collet, L. (1993). Comparative influence of repeated measurement and of attention on evoked otoacoustic emissions. *Acta oto-laryngologica*, *113*(4), 471–477. https://doi.org/10.3109/00016489309135848

Meric, C., & Collet, L. (1994). Attention and otoacoustic emissions: a review. *Neuroscience and biobehavioral reviews*, *18*(2), 215–222. https://doi.org/10.1016/0149-7634(94)90026-4

Mertes, I. B., Johnson, K. M., & Dinger, Z. A. (2019). Olivocochlear efferent contributions to speech-in-noise recognition across signal-to-noise ratios. *The*

Journal of the Acoustical Society of America, *145*(3), 1529. https://doi.org/10.1121/1.5094766

Michie, P. T., LePage, E. L., Solowij, N., Haller, M., & Terry, L. (1996). Evoked otoacoustic emissions and auditory selective attention. *Hearing research*, *98*(1-2), 54–67. https://doi.org/10.1016/0378-5955(96)00059-7

Mishra, S. K (2010). *Otoacoustic emission (OAE)-based measurement of the functioning of human cochlea and the efferent auditory system*. [Doctoral Thesis, University of Southampton, Human Sciences Group]

Mishra, S. K., & Lutman, M. E. (2014). Top-down influences of the medial olivocochlear efferent system in speech perception in noise. *PloS one*, *9*(1), e85756. https://doi.org/10.1371/journal.pone.0085756

Narne, V. K., & Kalaiah, M. K. (2018). Involvement of the efferent auditory system for improvement in speech perception in noise. *International Journal of Speech & Language Pathology and Audiology*, *6*, 1–7. https://doi.org/10.12970/2311-1917.2018.06.01

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Puel, J. L., Bonfils, P., & Pujol, R. (1988). Selective attention modifies the active micromechanical properties of the cochlea. *Brain research*, *447*(2), 380–383. https://doi.org/10.1016/0006-8993(88)91144-4

Puel, J. L, Rebillard, G., Bonfils, P., & Pujol, R. (1989). Effect of visual selective attention on otoacoustic emissions. In *Springer eBooks* (pp. 315–321). https://doi.org/10.1007/978-1-4684-5640-0_36

Rasmussen, G. L. (1946). The olivary peduncle and other fiber projections of the superior olivary complex. *Journal of Comparative Neurology*, *84*(2), 141–219. https://doi.org/10.1002/cne.900840204

Robertson, D. (1984). Horseradish peroxidase injection of physiologically characterized afferent and efferent neurones in the guinea pig spiral ganglion. *Hearing research*, *15*(2), 113–121. https://doi.org/10.1016/0378-5955(84)90042-x

Scharf, B., Magnan, J., Collet, L., Ulmer, E., & Chays, A. (1994). On the role of the olivocochlear bundle in hearing: a case study. *Hearing research*, *75*(1-2), 11–26. https://doi.org/10.1016/0378-5955(94)90051-5

Sewell, W. F. (1984). The relation between the endocochlear potential and spontaneous activity in auditory nerve fibres of the cat. *The Journal of physiology*, *347*, 685–696. https://doi.org/10.1113/jphysiol.1984.sp015090

Siegel, J. H., & Kim, D. O. (1982). Efferent neural control of cochlear mechanics? Olivocochlear bundle stimulation affects cochlear biomechanical nonlinearity. *Hearing research*, *6*(2), 171–182. https://doi.org/10.1016/0378-5955(82)90052-1

Smith, B., Harkrider, A., Burchfield, S., & Nabelek, A. (2003). Relation between measures of speech-in-noise performance and measures of efferent activity. *The Journal of the Acoustical Society of America*, *113*(4_Supplement), 2289–2289. https://doi.org/10.1121/1.4780616

Venkatesan, S., & Basavaraj, V. (2009). Ethical Guidelines for Bio-behavioral Research Involving Human Subjects. 1–23. https://doi.org/10.1017/CBO9781107415324.004

Walsh, K. P., Pasanen, E. G., & McFadden, D. (2015). Changes in otoacoustic emissions during selective auditory and visual attention. *The Journal of the Acoustical Society of America*, *137*(5), 2737–2757. https://doi.org/10.1121/1.4919350

Warr, W. B., & Guinan, J. J., Jr (1979). Efferent innervation of the organ of corti: two separate systems. *Brain research*, *173*(1), 152–155. https://doi.org/10.1016/0006-8993(79)91104-1

Wilson, R. H., McArdle, R., & Roberts, H. (2008). A comparison of recognition performances in speech-spectrum noise by listeners with normal hearing on PB-50, CID W-22, NU-6, W-1 spondaic words, and monosyllabic digits spoken by the same speaker. *Journal of the American Academy of Audiology*, *19*(6), 496–506. https://doi.org/10.3766/jaaa.19.6.5

Yashaswini, L., & Maruthy, S. (2019). The Influence of Efferent Inhibition on Speech Perception in Noise: A Revisit Through Its Level-Dependent Function. *American journal of audiology*, *28*(2S), 508–515. https://doi.org/10.1044/2019_AJA-IND50-18-0098

Yathiraj, A., & Vijayalakshmi, C. S. (2005). Phonemically balanced word list in Kannada: developed in department of audiology. *Mysore: AIISH*