RELATIONSHIP BETWEEN CONTRALATERAL INHIBITION OF OTOACOUSTIC EMISSIONS AND SPEECH PERCEPTION IN NOISE: EFFECT OF AGE, SIGNAL TO NOISE RATIO AND LINGUISTIC LOAD

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This Dissertation is submitted as part fulfilment

for the Degree of Master of Science in Audiology

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April, 2018

CERTIFICATE

This is to certify that this dissertation entitled **'Relationship between contralateral inhibition of otoacoustic emissions and speech perception in noise: Effect of age, signal to noise ratio and linguistic load'** is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 16AUD026. This has been carried out under the guidance of the faculty of this institute and 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 **'Relationship between contralateral inhibition of otoacoustic emissions and speech perception in noise: Effect of age, signal to noise ratio and linguistic load'** is the result of my own study under the guidance of Dr. Ajith Kumar U, Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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Dedicated to

My 'Orchidians'

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ABSTRACT

The main aim of this study was to assess the relationship between contralateral inhibition of transient evoked otoacoustic emissions (TEOAE) and speech perception in noise (SPIN) across different age group and speech materials. 72 participants were recruited for the study. The participants of the study were divided into three groups based on their age – young normal hearing group (YNH, with age ranging between 18 – 29 years), middle normal hearing group (MNH, between 30-49 years) and elderly normal hearing group (ENH, with age greater than 50 years). Participants in all the three group had normal peripheral hearing acuity as assessed by pure tone audiometry, immittance and otoacoustic emissions. The speech perception ability in the presence of multi-talker babble was tested using monosyllables, words and sentences and the signal to noise ratios varied between +10 dB to -10 dB (in 5 dB steps). The medial olivocochlear bundle (MOCB) functioning was assessed via contralateral inhibition of transient evoked otoacoustic emissions. Results showed that contralateral inhibition magnitudes did not differ significantly across different age groups. However, speech identification scores reduced significantly with the increasing age. Participants in the YNH group had better speech perception in noise compared to other two groups, especially, at poorer SNRs. Furthermore, correlation analyses suggested that relationship between MOCB functioning and speech perception in noise was significant at poorer SNRs, primarily, in young adults.

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CHAPTER I

Introduction

One of the major and most unique senses in living beings is the sense of hearing. This sense is preliminarily important for distant warning and communication. The sound gets picked up by the ear and is sent to the higher centers through the afferent pathway. The signal received at the ear level (periphery) get processed and modified (fine-tuned) all along the pathway till the auditory cortex. Additionally, there is an efferent or a descending pathway which modulates information in the auditory pathway (central to peripheral control).

Rasmussen was the first one to discover such a top down control of the auditory system (Rasmussen, 1946). The olivocochlear bundle (OCB), which originates from the brainstem forms a major part of this connection. The OCB can be further differentiated into medial OCB (MOCB) and lateral OCB (LOCB). They originate from the medial and the lateral parts of the superior olivary complex respectively. The two pathways varies in terms of their myelination (myelinated and unmyelinated), innervations (contralateral outer hair cells (OHC) and ipsilateral inner hair cell (IHC) respectively), thickness (thick medial fibers and thin lateral fibers) etc. (Guinan, 2006; Warr & Guinan, 1979).

Several studies have been conducted to explore the anatomy, physiology, functions of OCB, especially the medial OCB (Boer & Thornton, 2008; Guinan, 2006; Maruthy, Kumar, & Gnanateja, 2017; Murugasu & Russell, 1996; Rajan, 1992). Some of the proposed functions of medial OCB are

i. Protection of cochlea from loud sounds (Patuzzi & Thompson, 1991; Rajan, 1992).
ii. Perceptual learning (Boer & Thornton, 2008; Nobuo Suga, Xiao, Ma, & Ji, 2002)
iii. Perception in the presence of noise (Giraud et al., 1997; Kawase, Delgutte, & Liberman, 1993)

Speech perception in the presence of noise (SPIN) is a complex phenomenon and the mechanisms underlying it are still not completely understood. Recent studies suggest a cortical involvement for SPIN wherein, an activation is observed in the prefrontal cortex and left posterior superior temporal gyrus while perceiving speech in the presence of babble (Wong, Uppunda, Parrish, & Dhar, 2016). Studies have also suggested of the involvement of phonologic memory in speech in noise perception (Baddeley, 1992). The role of MOCB has also been implicated in speech understanding in the presence of noise in several studies (Kumar & Vanaja, 2004a; Maruthy et al., 2017). There are studies contradicting these findings as well, especially on the role of MOCB in speech perception in noise (Mishra & Lutman, 2014; Mukari & Mamat, 2008; Wagner, Frey, Heppelmann, Plontke, & Zenner, 2009). However, there are many methodological differences among these studies and it is difficult to compare among them. Also, there could be many other variables influencing the relationship between MOCB reflex and SPIN. The above mentioned studies have used speech with different linguistic loads. The complexity of the task may vary between nonsense syllable identification to continuous discourse identification across experiments. Studies report that the speech in noise scores vary with the material that has been used for testing (Anderson & Kalb, 1987; Miller, Heise, & Lighten, 1951). This difference in the linguistic load of the speech material used for testing may also be one of the variables causing the difference in findings. Also, the speech in noise testing may be carried out at different signal to noise ratio (SNR) and it has been noted that there is a decrease in error rate in performance as the SNR increases (Cheesman & Jamieson, 1996; Ellermeier & Hellbrück, 1998). Hence, the relationship between MOCB and speech perception in noise may be modulated by the SNR.

Another factor that may influence the relationship between MOCB reflex and speech perception in noise may be the age of the participants. In children, a developmental trend has been observed in speech perception in noise skills, like other auditory processes (Verônica, Novelli, Carvalho, & Colella-santos, 2017). And, older individuals report of hearing difficulty in the presence of noise despite having normal peripheral hearing (Dubno, Horwitz, & Ahlstrom, 2002). This has been observed in structured research as well (Wong et al., 2009). Similarly, an MOCB activity decline has also been reported in some studies (SungHee Kim, Frisina, & Frisina, 2002; Sunghee Kim, Frisina, & Frisina, 2006). A few other studies does not report of any age related changes in the medial olivocochlear reflex from children till older adults (Abdala, Mishra, & Garinis, 2012; Quaranta, Debole, & Di Girolamo, 2001).

Hence, it is evident that there are lot of controversies about the effect of these variables and about relationship between MOCB and SPIN. Therefore in the current study relationship between MOCB reflex and speech in noise was examined using three different speech materials – varying in linguistic load- at five different SNRs in young, middle and older individuals with normal hearing

Aim of the study

The study aims to elucidate a functional relationship between the speech in noise performance and contralateral inhibition of otoacoustic emissions (OAE) across different testing variables.

Objectives of the study

1. To compare contralateral inhibition of transient evoked otoacoustic emissions (TEOAE) in normal hearing young adults (YNH), adults in the middle aged group with normal hearing sensitivity (MNH) and elderly normal hearing individuals (ENH).
2. To measure the SPIN scores using monosyllables, words and sentences at different SNR (across -10 to +10 dB SNR in steps of 5 dB) in YNH, MNH and ENH.
3. To assess the relationship between SPIN and contralateral inhibition of TEOAE across the three groups.

CHAPTER II

Review of Literature

The auditory system has both afferent and efferent connections. The major efferent connection of the auditory system arise from the superior olivary complex and terminates at the organ of corti (Warr & Guinan, 1979). The efferent system, also known as the olivocochlear system was first explained by Rasmussen (Rasmussen, 1946) and comprises of the medial olivocochlear bundle (MOCB) and lateral olivocochlear bundle (LOCB) (Guinan, 2006; Guinan, Warr, & Norris, 1983; Warr & Guinan, 1979). The MOCB has thick and myelinated fibers, and innervates the outer hair cells, whereas, the unmyelinated, thin lateral olivocochlear fibers innervate the inner hair cells (Guinan, 2006). Of the medial olivocochlear (MOC) fibers, the amount of crossed fibers (contralateral projections) are more than uncrossed fibers (Warr, Guinan, & White, 1986).

The MOC neurons are found to be sharply tuned to preserve tonotopic innervations (Liberman & Brown, 1986). One of the major action performed by the MOC is the inhibition of cochlear responses, which is done by a reduction in the cochlear amplifier gain (Guinan, 2006; Murugasu & Russell, 1996). It has been observed that MOC activation causes a reduction in basilar membrane movement (Cooper & Guinan, 2006) and brings about a reduction in the amplitude of the compound action potential and an enhancement in the cochlear microphonics (Delano, Elgueda, Hamame, & Robles, 2007). Various techniques have been used to study the efferent system. Earlier, techniques such as direct electrical stimulation of olivocochlear bundle (OCB) (Winslow & Sachs, 1988) and transection of OCB (Dewson, 1968; Giraud et al., 1997; Scharf, Magnan, & Chays, 1997) were employed for this purpose. Currently, techniques such as acoustic stimulation of OCB (Collet et al., 1990; Kawase et al., 1993; Moulin, Collet, & Duclaux, 1993) are used.

Effect of age on MOCB functioning

It has been well established that as the age increases, there is an overall decline in performance by the individual, including general cognitive decline (Gordon-Salant & Fitzgibbons, 1997) . Studies have also reported reduced neural efficiency in older individuals with normal hearing sensitivity by measuring speech evoked auditory brainstem responses (Werff & Burns, 2011). Similar effects have been reported with regard to the efferent pathway as well. Studies on effect of age on MOCB reflex are equivocal. Some of the studies have shown that as the age increases, there is a reduction in the strength of the MOC reflex (Castor, Veuillet, Morgan, & Collet, 1994; SungHee Kim, Frisina, & Frisina, 2002; Maruthy, Kumar, & Gnanateja, 2017; Mukari & Mamat, 2008).

Castor et el (1994) recorded transient evoked otoacoustic emissions (TEOAE) and distortion product otoacoustic emissions (DPOAE) with and without contralateral stimulation (at 30 dB SL) in young normal hearing group and older group with some high frequency hearing loss (between 70 – 88 years). The authors found lesser reduction in amplitude of TEOAE in the older group after contralateral stimulation. In DPOAE, this reduction was predominantly in the middle frequency region (2.83 to 5.04 kHz). To check the influence of hearing loss on this effect, the authors compared the older individuals with threshold matched young adults, and the difference was not found to be significant. They conclude that the deterioration in the function could be related to the age linked hearing loss.

Maruthy et al. (2017), in their study to check the association between perception in presence of noise and efferent system functioning, also checked the effect of age on the MOC system. Their participants included 27 adults in the age range of 18-30 and 29 older adults with age ranging between 50-65 years. Both the groups had similar TEOAE amplitude in quiet. Contralateral white noise was presented at 30 dB SL and TEOAE measured again. The reduction in amplitude was noted. The reduction in amplitude was found to be more in the younger group than in the other group.

The study by SungHee Kim et al. (2002) checked how age influences MOC function by measuring the contralateral suppression (CS) of DPOAE on ten normal hearing individuals divided into young, middle and old groups each. White noise (at 30 dB SL) was used as the contralateral stimuli. The authors carried out a frequency specific analysis of the suppression obtained with the contralateral noise in the DPOAE amplitude. Suppression magnitudes were significantly lower in the middle aged and older group. They conclude that MOC decline starts prior to the OHC dysfunction. The MOC is function is found to be maintained best at 1-2 kHz in individuals of all age groups. Mukari and Mamath (2008) also used CS DPOAE to check efferent function across young normal hearing (20-30 years) and older (50-60 years with thresholds within 25 dB) adults, along with other objectives of their study. 30 dB SL was the presentation level of the contralateral noise for CS DPOAE. It was found that the younger group had higher suppression in almost all frequencies.

Some studies also report of no significant differences across younger and older individuals' in MOC functioning (Quaranta et al., 2001). In their study, the authors assessed CS of TEOAE in participants with age varying from 20 to 78 years. All participants had thresholds within 25 dB HL. They found a reduction in mean amplitude of suppression, though it was found to be non-significant across the groups (individuals divided into five groups based on age). Study by Abdala, Dhar, Ahmadi, & Luo (2014) examined MOC functioning across four different age groups (teens, young adults, middle aged adults and older adults) by measuring CS of DPOAE (subtraction of amplitude with and without 60 dB SPL noise in the contralateral ear). They found a mild aging effect (lesser reduction in amplitude than the other groups) for the middle group for DPOAE frequencies below 1.5 kHz. In the elderly group, the authors found significantly higher amount of suppression than the other groups. The authors hypothesize the possible role of middle ear muscles for such an unexpected finding.

Functions of MOCB

The complexity in of the descending feedback system suggests that it plays multiple roles in signal processing – both in central and peripheral auditory systems.

Protective function

From the notion that the stimulation of OCB brings about a change in basilar membrane motion, it may be inferred that the OCB plays a protective role in safeguarding the cochlea from loud sounds. This has been established through structured research as well.

For instance, study by Patuzzi & Thompson (1991), used anesthetized guinea pigs and divided them into four categories

i. Fourteen animals with traumatizing exposure (ipsilateral)
ii. Eight animals with ipsilateral exposure and contralateral sound
iii. Four animals with ipsilateral exposure and MOC transection
iv. Four animals with ipsilateral exposure, contralateral sound and MOC transection

They checked if there's any possible role of MOC in protection from loud sounds. The animals were exposed to 115 dB SPL of 10 kHz tone for durations of sixty seconds and ninety seconds (two exposures). Near field compound action potential threshold was compared pre and post exposure. After exposure, the threshold measured was found to be elevated from 8 kHz to 30 kHz (maximum effect at 14 kHz) for all the groups. However, the elevation was found to be significantly lesser in the protected group (the group with contralateral sound) than the exposed group which depicts a protective role played by the contralateral sound. This protection was absent in the group with transection and contralateral sound, revealing the importance of MOC in the protection.

Such findings have been reported earlier in literature as well (Buño, 1978; Cody & Johnstone, 1982). For example, Cody and Johnstone, recorded electrocochleogram after exposing anesthetized guinea pigs to traumatizing condition like 10 kHz tone at 107 dB SPL (with varying contralateral stimuli parameters) using tone bursts with 2ms rise and fall time and duration of 50ms at a rate of 4/s. Maximum sensitivity loss found was at around 13 kHz. It was found that contralateral stimulation significantly reduced the temporary threshold shift (especially when the stimuli and the contralateral sound were similar in their spectral characteristics) in these animals. The authors assign this effect to the auditory efferent neurons and it is thought to be frequency specific.

However, there are contradictory studies as well (Liberman, 1991). The author did a within subject comparison (across the two ears) to check the protection offered by the efferent system in anesthetized cats. The middle ear muscles of these cats were severed for the experiment to take off any effect of middle ear reflex on the measurement. Also, in every cat, the OCB was transected in one ear. Following this, the animal was exposed to intense pure tone binaurally and the resultant threshold shifts were compared across the two ears. The author found no significant difference between the shifts of the two ears. The contradictory finding in this study may be due to the difference in the species of the participant involved in the studies.

Perceptual Learning

The efferent pathway reflects a top down influence by the central system on the auditory periphery. It forms multiple positive feedback loops (associated with lateral inhibition) which leads to an increase in subcortical auditory nuclei activity, which in turn, fine tunes the auditory information. Xiao and Suga (2002), attributed this to selective corticofugal modulation of individual olivocochlear efferent fibers. In their study, they recorded cochlear microphonics with electrode in the cochlea and by stimulating the auditory cortex electrically. These findings are supported by other studies as well (Palmer et al., 2007; Winer, 2005).

When a sound is presented, small, short term changes (specific to sound characteristics) are brought about in the subcortical auditory nuclei in response to it. Through conditioning and associative learning, these small changes are augmented in the auditory cortex (reorganizations takes place) and becomes more long term. The process is modulated by the descending auditory pathway. This modulation for reorganization of central auditory system is multi-parametric and occurs in frequency, time and amplitude domains (Suga et al., 2002). Thus, the corticofugal system plays a role in plasticity of the central auditory system (Suga, Gao, Zhang, Ma, & Olsen, 2000)

A study investigated the involvement of the efferent system (MOCB) in perceptual learning after auditory training on normal hearing adult listeners (Boer & Thornton, 2008). The participants underwent a five day training program on a speech in noise (SIN) discrimination task. During the training sessions, continuous uncorrelated broadband noise was presented in the contralateral ear to activate the MOCB. CS of evoked OAE was administered on all the participants after every training session as a measure for MOCB functioning. The authors found a significant improvement in phoneme in noise discrimination post the training sessions behaviourally. Additionally, they also found that the MOCB activity measured on the first day of training strongly predicted the amount of improvement in the participants (weaker MOCB activity was associated with greater improvements). There was also an overall enhancement of MOCB activity after the training. This shows that the central auditory system is flexible and the descending feedback pathway has a role in long and short term plasticity. Similar results have been reported in other studies as well (Perrot, Micheyl, Khalfa, & Collet, 1999; Veuillet, Magnan, Ecalle, Thai-Van, & Collet, 2007).

Perception in noise – anti-masking function

Amongst the multiple proposed functions of MOCB comes its role in speech perception in noise. Several studies have been conducted in this lines. However, the results of the studies are highly variable and the debate still exists. One of the initial studies discussing the anti-masking function of MOCB was carried out by Kawase, Delgutte, & Liberman (1993). The study was carried out on anesthetized or decerebrate cats and single nerve response to tone burst stimuli in quiet and continuous noise was checked. They conclude that there's a difference in response and function of OCB in quiet and noise conditions. In quiet, the MOCB majorly gives a suppressive response, whereas, in noise, the response to transient stimuli is enhanced.

Another study in similar lines used operant conditioning techniques and checked F2 discrimination threshold for vowel Ɛ in cats with bilateral olivocochlear lesions. It was checked in quiet as well as in continuous broadband noise (BBN) presentation at varying signal to noise ratios (SNR) -23, 13 and 3 dB. Pre sectioning of the OCB, thresholds were obtained for comparison. Post cut, it was found that there was a significant increase in the discrimination threshold. Also, this increase was found to be more for those individuals with more severe cuts (Hienz, Stiles, & May, 1998). The results suggest that OCB plays a role in speech perception in noise, especially at lower SNRs.

This finding was originally reported by Dewson, who studied monkeys post olivocochlear lesions (Dewson, 1968). These monkeys also had focused cortical lesions. They were trained to discriminate changes in F2 in vowels. The testing involved a similar task in the presence of low pass filtered noise. He found that, there was a change in the level of noise tolerance (lower values) after the surgical sectioning was done. However, since the monkeys used in this study had other cortical lesions, the reliability or the generalizability of the finding is questionable.

Winslow & Sachs (1988), did electrical stimulation of MOC fibers in cats. They studied responses to brief tone stimuli in the presence of noise using micropipettes. For analysis, base frequency near 8 kHz (no phase locking) were taken in quiet and background noise condition with and without electrical stimulation of OCB. The authors found that when OCB was stimulated, there was a reduction in the discharge rates of the nerve fibres. This decreases adaptation of the fibre, leading to saturation (which increases with increasing levels of noise). Therefore, OCB stimulation restores dynamic ranges of nerve fibres to those seen in quiet, thus enhancing signal detection in the presence of noise.

In a 1997 study, the authors explored the presence of efferent involvement in understanding signals in the presence of noise (SNR's varying from -20 dB to +25 dB) in humans. They compared the speech intelligibility in noise using monosyllabic words from Fournier list in healthy individuals and vestibular neurectomized patients. They found that there was an improvement in the SIN scores in conditions with contralateral noise in the healthy participants which was almost nil in the neurectomized patients. The study concluded that the efferent system plays an anti-masking role in speech perception in noise (Giraud et al., 1997).

Kumar and Vanaja (2004), attempted to correlate effect of contralateral acoustic stimuli on speech perception and CS of TEOAE. The participant group included ten normal hearing children. The authors used speech identification test for Indian English speaking children (Rout, 1996) in the presence of BBN at +10, +15 and +20 dB SNRs in the ipsilateral ear. Testing was done in different conditions such as quiet, various ipsilateral noise conditions, low level contralateral noise (30 dB SL) and both ipsilateral BBN and contralateral low level BBN. They found that contralateral stimuli enhanced speech perception at ipsilateral SNR's of +10 dB and +15 dB, which correlated with the magnitude of CS of OAE. The result suggests the possible role of MOCB in hearing in noise.

In a study, the authors tried to examine associations with aging MOC and speech perception in noise skills. The study included 118 individuals separated into four age groups (teenagers, young adults, middle aged adults and elderly adults). CS of DPOAE was done on these individuals. The speech perception tasks included consonant and vowel identification at SNRs varying from -21 to +12 dB in 3 dB steps. The Hearing in Noise Test (HINT) was also administered on them. Performance-intensity function was plotted. The authors found moderate correlations between speech and MOC reflex. The authors report that with greater MOC reflex, there is enhanced transmission of place and manner cues, which in turn leads to better performance (Abdala et al., 2014).

Other authors carried out studies, where they checked the MOC efferent functioning via contralateral inhibition of TEOAE in normal hearing children categorized into three groups

i. Typically developing children
ii. Children with poor speech in noise performance
iii. Children with specific language impairment (SLI) and poor speech in noise performance.

The results indicates significantly reduced inhibition in children having poor performance in speech in noise measures (Rocha-muniz, Mota, Carvallo, & Schochat, 2017).

Another study (Sunghee Kim et al., 2006) explored the MOC efferent effects using contralateral suppression of DPOAE and speech perception in noise (SPIN) using the HINT (Nilsson, Soli, & Sullivan, 1994). The study included normal hearing adults in the age range of 18-75 years and SNR-50 was estimated. They found significant correlations between CS of DPOAE and SPIN at narrow band range of 4-6 kHz (higher speech frequency region). The authors conclude that the descending system may act like a non-linear adaptive filter for speech perception in background noise. The efferent activity in individuals having difficulty in speech in noise perception versus those who don't was checked in another study. CS of DPOAE was administered on all these individuals. They found absence of suppression at certain frequencies (especially in the middle frequency region) in right and left ears of individuals who complained of speech understanding difficulty, again suggestive of a link between role of MOCB in speech in noise condition (Lautenschlager, Tochetto, Julio, & Doctoral, 2011).

Maruthy, Kumar, & Gnanateja (2017), carried out a study where they checked for efferent functioning (both LOCB and MOCB) and their correlation with SPIN in younger and older normal hearing adults. SNR-50 using Kannada sentence from SIN-Kannada (Avinash, Meti, & Kumar, 2009) was the measure utilized to check the performance. It was correlated with CS of TEOAE (as a measure for MOCB functioning) and context dependent brainstem encoding of speech (as a measure of LOCB function). They found a negative correlation between the CSOAE magnitude and SIN in older individuals. This trend was not seen in the younger group. They proposed that both MOCB and LOCB fine tunes the neural encoding of input speech, and this is done independently.

Similar findings have been reported by other authors as well (Bidelman & Bhagat, 2015). They assessed the relation between magnitude of OAE suppression and SPIN (Killion, Niquette, & Gudmundson, 2004) at SNR's varying from 25 to 0 dB using materials from Quick-SIN. The participants were normal hearing adults. An across ear comparison was done as well. A negative correlation between OAE suppression and SIN in right ear was found. This suggests better speech in noise recognition at lower SNRs. Also, no correlations were found in the left ear, suggestive of a laterality in SIN skills. This is also in par with findings from other studies (de Boer, Thornton, & Krumbholz, 2012). These authors also went ahead with checking the anti-masking function of MOCB by correlating between consonant-vowel (CV) discrimination in presence of broadband Gaussian noise at an SNR of 10 dB and suppression of TEOAE. The participants with stronger OAE suppressions were found to perform poorer in presence of noise suggesting a detrimental effect. The authors explain the contradictory finding by saying that the direction of correlation between these two parameters may vary depending on the acoustic properties of the signal.

In another set of studies, no correlations have been found across the two phenomena, like the one by Mukari & Mamat (2008). In their experiment, they compared medial efferent system functioning (assessed through CS of DPOAE) in SIN perception (through HINT) in younger and older individuals. Even though they found an age related deterioration in DPOAE amplitude and SIN performance, it wasn't attributed to MOCB functioning. These findings are reported in other studies as well (Wagner et al., 2009). These authors found no statistically significant relation between SIN intelligibility and CS of DPOAE. In their study, non-meaningful sentences in the presence of background noise were used to determine the SNR-50 (in free field condition).

In similar lines, Mishra & Lutman (2014), checked the MOC unmasking effects in normal hearing listeners. The four alternative auditory feature test (Foster & Haggard, 1987) in the presence of steady noise filtered to be similar to that of the long term average speech spectrum of the target word was administered on 18 adults (18-30 years). They could not find any significant relations between magnitude of suppression in these individuals and their speech perception in noise.

In a study by Narne and Kalaiah (2018), involvement of efferent system in hearing in noise was assessed in 20 adults (between 18-28 years). Phonetically balanced sentences in Kannada (Avinash et al., 2009) in the presence of speech spectrum shaped noise was administered on the participants. CS of TEOAE was used as a measure for assessing the MOCB functioning. It was found that there was no significant relation between strength of MOC reflex at any level of stimulation and speech reception threshold in noise (Narne & Kalaiah, 2018).

From the collection of studies discussed, it is clear that there is no consensus about the role and the extent to which the MOCB functions. This is especially true for the speech in noise function. Table 2.1 summarizes the studies that have explored the relationship between contralateral inhibition of OAEs and SPIN.

Table 2.1

Review of studies which investigated the relationship between MOCB and perception in noise

Author(s), year	Participant	Stimuli/test used	Results	Conclusions
Kawase, Delgutte, & Liberman (1993)	Decerebrate cats	Tone burst in continuous masking noise ipsilaterally with and without contralateral noise	Addition of the contralateral elicitor increased the maximum discharge rates to the masked tone bursts and decreased the rates to the ipsilateral masker.	The detection of transient stimuli is enhanced in the presence of noise and suppressed in quiet by the OCB.
Hienz, Stiles, & May (1998)	Cats with bilateral olivocochlear (OC) lesions	Change in vowel discrimination thresholds in the presence of noise	Discrimination threshold increased after the sectioning (when compared to baseline threshold – before the sectioning)	The olivocochlear system enhances speech perception in the presence of noise.
Dewson (1968)	Monkeys pre and post OC lesions	F2 discrimination in vowels in the presence of noise	Change in level of noise tolerance post sectioning for the discrimination task	OCB may be playing a role in speech perception in the presence of noise.
Winslow & Sachs (1988)	Cat	Electrical stimulation of the OCB	Electrical stimulation of the OCB enhances sensitivity of tone level in noise backgrounds	OCB enhances encoding of signals by opposing the background noise.
Giraud et al. (1997)	Normal hearing humans (NHH) and vestibular neurectomized patients (VNP)	Monosyllabic words (from Fournier list)	In NHH, strong OC feedback gave greater phoneme recognition improvement with contralateral noise. In VNP, there was weak amplitude reduction and weak phoneme recognition improvement.	The OC plays an antimasking role in perceiving speech in noise.
Kumar & Vanaja (2004)	Normal hearing children	50 English monosyllabic words and CS TEOAE	Significant correlation across the shift in speech identification with contralateral acoustic stimulation at +10 and +15dBSNR, and CS TEOAE.	OCB constitutes one of the physiological mechanisms that augment speech perception in noise.

Abdala, Dhar, Ahmadi, & Luo (2014)	Individuals in four age groups (teens, young, middle aged and older adults)	CS DPOAE and vowel, consonant and word identification	Moderate correlation between MOC reflex and SPIN performance	Activation of MOC enhances place and manner cues and this in turn enhances SPIN
Rocha-muniz, Mota, Carvallo, & Schochat (2017)	Normal hearing children (typically developing, with poor SPIN, SLI and poor SPIN– 3 groups)	CS TEOAE	CS TEOAE amplitude was found to be the least in those children having SPIN difficulties	The role of MOCB in speech perception is described.
Kim, Frisina, & Frisina (2006)	Young and older adults	Hearing in Noise Test (HINT), CS DPOAE	Weak correlations between SPIN and CS DPOAE (correlations appeared only in certain frequency bands)	Auditory efferent system might function as a non-linear adaptive filter for speech processing in background noise
Lautenschlager, Tochetto, Julio, & Doctoral (2011)	Normal hearing adults	CSDPOAE	Individuals who complained of SPIN difficulties had poorer or absent DPOAE amplitude at some frequency	There is a link between role of MOCB in SPIN.
Maruthy, Kumar, & Gnanateja, (2017)	Young and older adults	Qucik SIN – Kannada, CS TEOAE	Negative correlation between activation of the efferent system and speech in noise skills in the older group	The efferent mechanism function to fine tune afferent signal and refine auditory system in degraded listening conditions.
Bidelman & Bhagat (2015)	Young adults	Quick SIN, CS TEOAE	Correlation found only in right ear. No correspondence was observed between QuickSIN and OAE suppression in the left ear	Results suggest a rightward asymmetry in SIN processing. They posit that the observed right-ear laterality in cochlear feedback and its correspondence with SIN perception might be an early precursor to the left-hemispheric bias for language processing found in the cerebral cortex.

de Boer, Thornton, & Krumbholz (2012)	Adults	Consonant vowel (CV) discrimination in noise Auditory brainstem response in noise	Participants with stronger otoacoustic emission (OAE) suppression showed poorer CV discrimination-in-noise performance and larger ABR latency shifts.	The acoustic properties of the stimuli used for testing may have an effect on the scores obtained and the relationship between MOC system and SPIN.
Mukari & Mamat (2008)	Young and older adults	HINT, CS DPOAE	No significant relationships between any of the speech perception measures and the CS DPOAE suppression measures in total-group and within-group analyses.	MOCB does not necessarily play a role in SPIN and the age related deterioration in SPIN cannot be attributed to MOCB functioning.
Wagner, Frey, Heppelmann, Plontke, & Zenner (2009)	Adults	Word recognition in presence of noise, CS DPOAE	No correlation between intelligibility in background noise and MOC functioning	Clarification of role of OCB in impairments in speech understanding needs to be done.

Mishra & Lutman (2014)	Adults	Computerized version of the Four Alternative Auditory Feature (FAAF) test (binary and minimally paired words), CS TEOAE	The MOC inhibitory effect is repeatable; The magnitude of MOC inhibition(from CEOAEs), is not related to SIN performance without contralateral acoustic stimulation (CAS); MOC reflex magnitude positively correlated with CAS-induced change in SIN acuity (average improvement of 2.45 dB SNR).	Individuals do not necessarily use the available MOC unmasking characteristic while listening to speech in noise. MOC mediated mechanism play a role only in specific listening conditions (which are yet to be discovered)
Narne & Kalaiah (2018)	Young adults	QUICK SIN- K, CS TEOAE	No significant relation between strength of MOC reflex at any level of stimulation and speech reception threshold in noise	Utility of MOC reflex related mechanisms in extracting signals from noise may vary with the stimulus and the listening conditions in a complex way and needs to be studied further

Speech Perception in Noise

Communication in the natural situation usually occurs in a background of some interfering noises. Normal peripheral hearing sensitivity does not warrant good speech in noise skills. The process of SIN perception happens in humans by using a variety of resources – by integrating sensory, cognitive and neural aspects of the stimuli. One of the reasons for poor performance in such situation has been attributed to poor auditory processing skills in children and elderly population (Chermak & Musiek, 1997; Gates & Cooper, 1991)

A developmental trend has been observed in performance of children in speech in noise test. Children between the age range of 8-10 years with no ear related problems or history of same were recruited and HINT- Brazil test administered. It was found that the 10 year olds performed better than the 8 year olds. Age 9 children performed intermediately and had no significant difference between either the 8 or the 10 years olds (Verônica et al., 2017)

In another experiment, Abdala et al., 2014, also compared the difference in performance across teenagers, young adults, middle aged adults and older adults in a task involving vowel, consonant and word in sentence identification in the presence of noise. They found deterioration in performance with increase in age. They also found that there was no correlation between speech scores and age in individuals greater than 60 years of age.

In another study, the authors compared across SPIN (sentence identification) performance in young and older adults (perception of IEEE sentences in the presence of speech shaped noise). The older group was further divided into a hearing impaired group (mild to severe sloping sensorineural hearing loss) and a normal group. They reported that the older group had significantly lower scores when compared to adults (Billings, Penman, McMillan, & Ellis, 2015). In the same study, the authors also checked the effect of varying SNR on speech perception. They varied SNR from -10 dB to 35 dB and reported a significant main effect of SNR for both the groups. Other studies have also taken up similar objective and the findings of the studies are equivocal (Ellermeier & Hellbrück, 1998).

The linguistic load of the material with which the speech testing is done also has an impact on the total correct scores (Miller et al., 1951). The more redundant the information, the more easy it is to decipher, even in the presence of noise. The difference in intelligibility scores across different speech materials that can be used for testing have been reported by several authors [eg,(Anderson & Kalb, 1987)].

CHAPTER III

Method

Participants

A total of 72 participants participated in the study. All participants recruited for the study were native speakers of Kannada, a south Indian language, spoken mainly in the state of Karnataka. The participants in the study were divided into three groups based on their age. The first group consisted of young normal hearing adults (YNH) (n= 30) in the age range of 18-29 years (mean age: 22.1, SD: 2.56). The second group (n = 20) included middle aged participants (MNH) with age ranging between 30-49 years (mean age: 38, SD: 6.14) and the third group (n =22) had elderly normal hearing (ENH) individuals in the age range of 50-80 years (mean age: 57.82, SD: 7.83). A structured interview was carried out to ascertain that none of the participants had any history of middle ear pathology, noise exposure, ototoxic drug usage etc. Through the interview it was also ascertained that none of the participants had any gross neurological or cognitive dysfunction.

Inclusion Criteria

Participants of the YNH and MNH groups had thresholds within 15 dB HL at octave frequencies from 250 Hz to 8 kHz. Participants of ENH group had thresholds within 15 dB HL at octave frequencies 250 Hz to 2 kHz and within 20 dB HL at 4 kHz and 8 kHz. All participants had ‘A’ type tympanogram (Jerger, 1970). All participants showed ipsilateral and contralateral acoustic stapedial reflexes at normal sensation levels at 500 Hz and 1 kHz. All the participants had clinically normal transient evoked otoacoustic emissions (TEOAE) for 80 dB SPL clicks. A written informed consent was taken from all participants prior to the commencement of the experiment and the study adhered to ethical guidelines for bio-behavioural research involving human subjects, All India Institute of Speech and Hearing, Mysuru (Venkateshan, 2009).

Equipment and test environment:

The testing was carried out in a sound treated, double room set up with appropriate lighting and ventilation. The room specifications were as per the ANSI S3.1-1999-R2013 (American National Standard Institute, 1999). The participants were made to sit comfortably on a chair and instructions were given in their native language.

A calibrated dual channel, diagnostic audiometer - MAICO MA 53 (MAICO Diagnostics, Berlin, Germany) with TDH 39 headphones and Radio Ear B71 bone vibrator was used for the evaluation of hearing status of the participant. A calibrated GSI Tympstar (Grason-Stadler, Minneapolis, USA) middle ear analyzer with default probe assembly was used for analyzing the middle ear status (both tympanometry and reflexometry). Otoacoustic emissions and its inhibition were recorded and analyzed using Otodynamics ILO V6 software. For the speech perception in noise test, recorded speech material was delivered through a calibrated Sennheiser HD 280 pro headphones connected to a Dell Inspiron i3 core Laptop.

Experimental Procedure

Basic Audiological Evaluation

Pure tone Audiometry was carried out using modified Hughson and Westlake procedure (Carhart & Jerger, 1959) at octave frequencies between 250Hz to 8000Hz for air conduction and between 250Hz to 4000Hz for bone conduction. Speech reception threshold, speech identification scores and the uncomfortable levels were assessed using standard procedures. For tympanometry, probe frequency of 226 Hz was used. Acoustic reflex threshold was obtained at 500Hz and 1000 Hz ipsilaterally and contralaterally. TEOAEs were measured by presenting 260 sweeps of nonlinear clicks at 80 dB SPL (±0.5 dB) using the Otodynamics ILO V6 instrument.

Contralateral Inhibition of TEOAE

The participants were seated comfortably on a chair and a probe of appropriate size was inserted in to the ear canal of the right ear. In the left ear, an E-A-RTONE 5A insert earphone connected to a MAICO MA 53 diagnostic audiometer was placed. Placement of insert receiver and probe was undisturbed till the end of testing. TEOAEs were obtained for 260 linear clicks presented at 65 dB SPL (±0.5 dB). After this recording 60 dB SPL of calibrated white noise was presented to left ear through the insert ear phones and TEOAEs were recorded again using the same protocol mentioned above. During the entire measurement, the participants were made to read a book of their choice. This reduced participants movements and also controlled attention as it has been shown that attention can influence the contralateral inhibition of TEOAEs. Magnitude of contralateral inhibition was measured as the difference in TEOAE amplitude with and without noise in the contralateral ear.

Speech Perception in Noise

The speech perception in the presence of noise (SPIN) was assessed using monosyllables, words and sentences at different SNRs. The eight talker speech babble of Quick SIN – Kannada (Avinash et al., 2009) served as the noise. Speech perception in noise was assessed using following material

i. phonemically balanced (PB) monosyllables (Mayadevi, 1974), which includes 20 consonants in the context of /a/ vowel.
ii. PB word lists – Kannada (Manjula, Antony, Kumar, & Geetha, 2015), which has 21 equivalent lists for speech in noise testing. Each list had 25 disyllabic Kannada words that were balanced phonemically.
iii. Sentences from Sentence Identification Test (SIT), Kannada (Geetha, Kumar, Manjula, & Pavan, 2014), which consisted of 30 equivalent sentence lists. Each list was made of ten sentences and 40 key words. The sentences were made of familiar words of equal difficulty level. All the sentences had low predictability level.

Two lists were presented per SNR across all the materials. The presentation level for speech was maintained at 70 dB SPL. The order of presentation of lists were randomized across participants. The speech stimuli used was mixed with the eight talker babble using a MATLAB code (Gnanateja, 2017). Verbal responses were obtained from the participants and the responses were recorded using Audacity software, 2.1.3 version for offline analyses. A score of one was given for every correct response (repetition of the correct monosyllable, whole word or key words of sentences) and zero for any incorrect or partially correct response.

Analyses

The parameters analyzed were

i. The amplitude of contralateral inhibition of TEOAE across the three groups (univariate analysis of variance).
ii. The difference in normalized SPIN scores across the different stimuli (monosyllables *vs.* words *vs.* sentences), SNRs (+10 dB SNR, +5 dB SNR,

0 dB SNR, -5 dB SNR, -10 dB SNR) and groups (YNH *vs*. MNH *vs.* ENH) and any interactions between them (repeated measures ANOVA).

iii. Correlation between the normalized correct scores in SPIN and inhibition amplitude of TEOAE in YNH, MNH and ENH (Karl Pearsons's product moment correlation).

CHAPTER IV

Results

The objectives of this study were three folds and the results will be discussed under the respective headings. The study included 72 participants, out of which 5 were removed, as they were outliers as visualized on box plots. The participants were divided into three groups based on the age. Overall data followed normality on Shapiro-Wilks test and hence parametric tests were used.

Effect of age on contralateral inhibition of TEOAE

Figure 4.1 depicts the mean and one standard deviation (denoted by error bars) of inhibition of transient evoked otoacoustic emissions (TEOAE) amplitudes across three age groups (young, middle and elderly normal hearing individuals – YNH, MNH and ENH respectively). From figure 4.1., it can be seen that YNH group had higher inhibition of TEOAEs compared to MNH and ENH. It can also be noted that, the standard deviations are high for all the three groups, indicating high variability within the inhibition magnitudes. To check for significance of these differences, a univariate analysis of variance (ANOVA) with inhibition amplitude as the dependent variable and groups as between subject factor was run. Results revealed no significant main effect of age on inhibition amplitude [F (2, 62) = 1.74, p = 0.18, η^2 = 0.053].

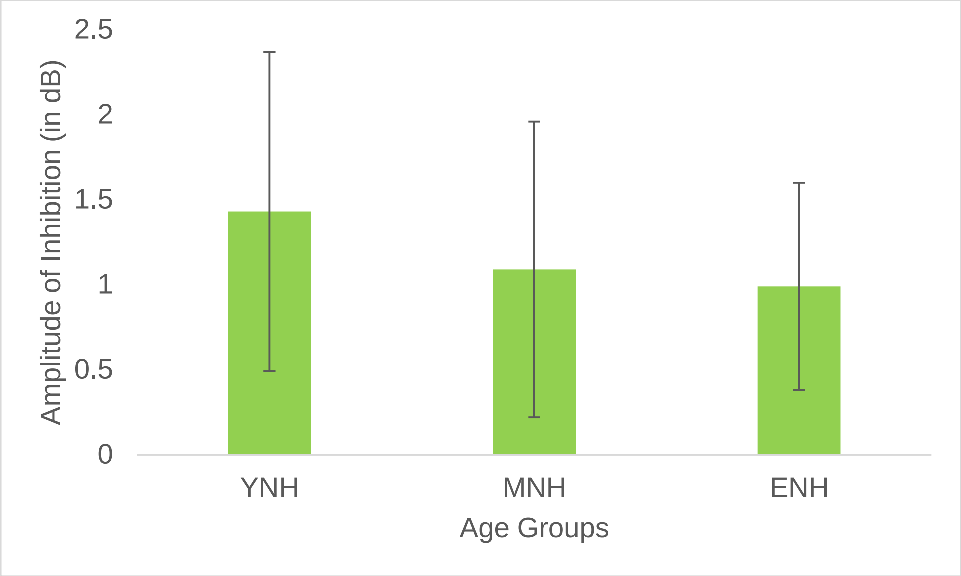

Figure 4.1. Contralateral inhibition of TEOAE as a function of age

Effect of age on speech perception in noise

The data gathered was examined to compare the SPIN scores across the three groups – YNH, MNH and ENH. Figure 4.2. - 4.4. depicts the mean and one standard deviation of normalized speech in noise scores for monosyllables, words and sentences respectively at five different SNRs tested across three groups

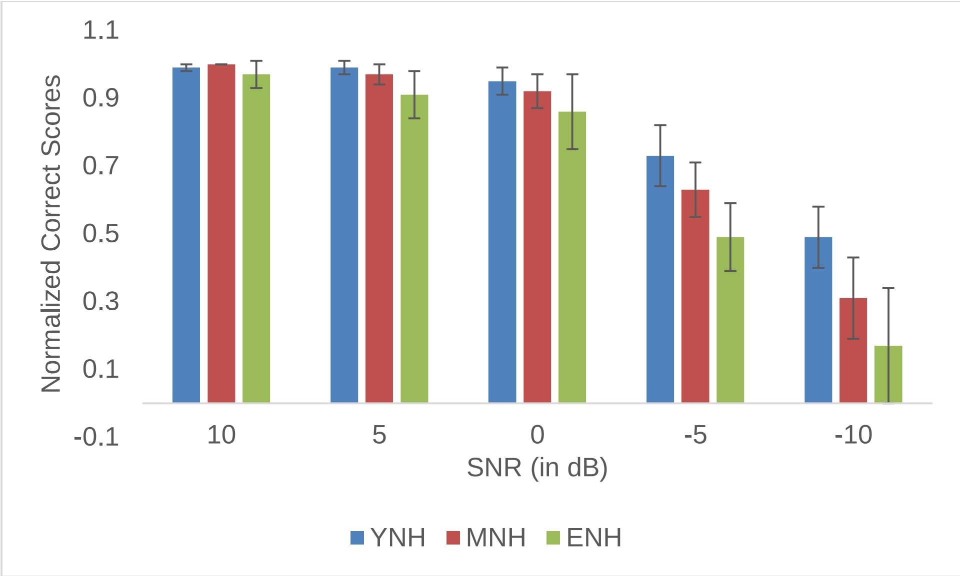

Figure 4.2. Mean and SD of SPIN scores across SNR for monosyllables as a function of age.

From figure 4.2, it can be seen that there was a decrease in correct scores as the SNR decreases and age increases. The effect was more pronounced at lower SNR's.

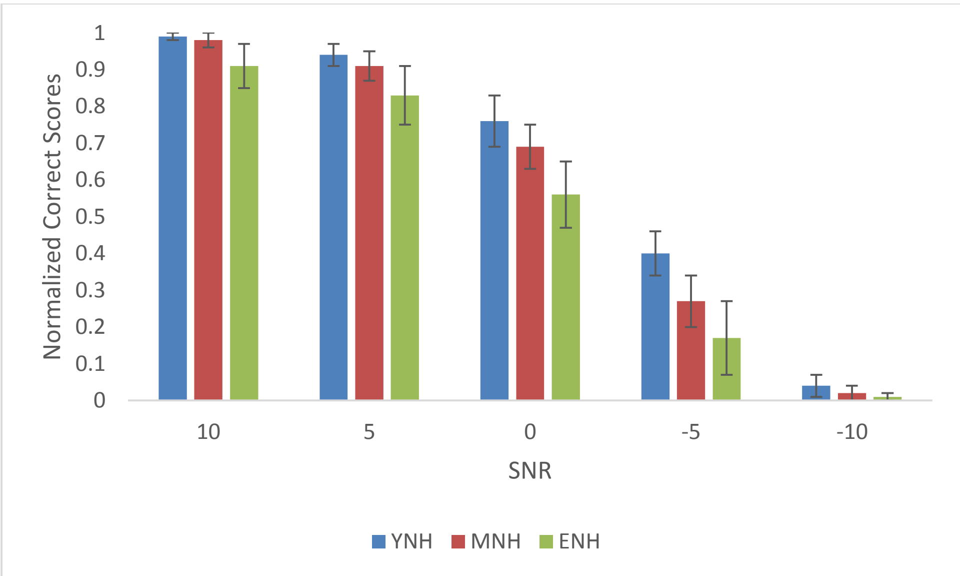

Figure 4.3: Mean and SD of SPIN scores across SNR for words as a function of age

As can be seen in figure 4.3., there is deterioration in performance with decrease in SNR and increase in age. This effect is more pronounced at lower SNRs. A ceiling effect can be clearly observed in the higher SNRs and a floor effect at lower SNR.

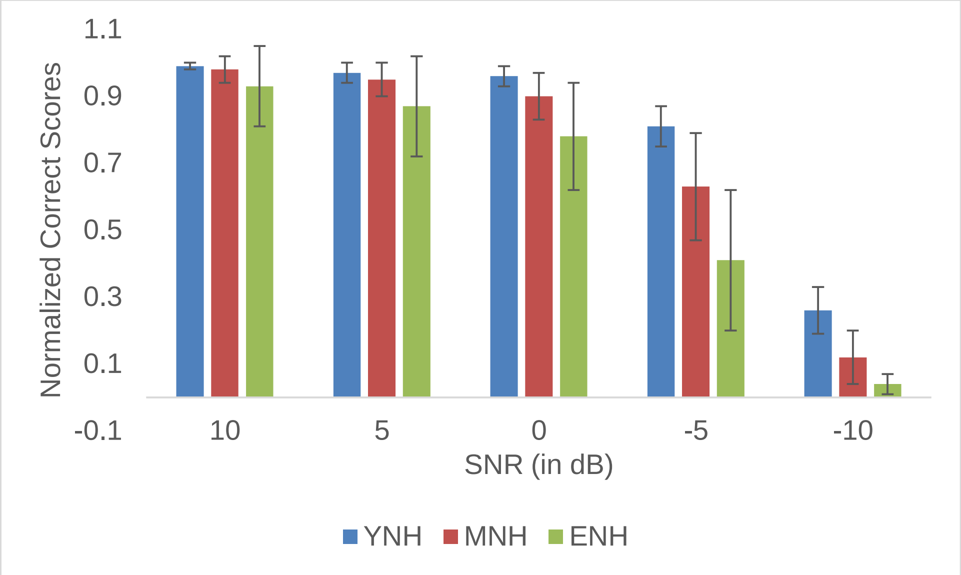

Figure 4.4. Mean and SD of SPIN scores across SNR for sentences as a function of age.

Similar trend can be observed in figure 4.4., for sentences as well. It can be noted that there is more variability in sentence scores (higher standard deviations) when compared to words and monosyllables.

A two way repeated measures analysis of variance with SNR and stimuli as within subject factor and age groups as between subject factor revealed a significant main effect of SNR [F (2.56, 155.87) = 5943.29 , p<0.01, η^2 = 0.997] and stimuli used [F (1.47, 100.47) = 385.87, p<0.01, η^2 = 0.966]. A significant interaction between the two variables (SNR and stimuli) was also observed [F (2.91, 100.47) = 4.19, p<0.01, η^2 =0.683]. A significant main effect of age was also noticed [F (2, 69) = 68.22, p = 0.01, η^2 = 0.664]. A significant interactive effect of age with SNR [F (4.52, 155.87) = 41.21, p<0.01, η^2 = 0.474] and stimuli [F (2.91, 100.47) = 4.19, p < 0.01, η^2 = 0.117] was also observed.

Since an interactive effect was found to be present across stimuli and SNR, a one way repeated measures ANOVA was carried out with SNR as the within subject variable and groups as between subject variable for each of the stimuli conditions. The result revealed a significant main effect of SNR [F (2.53, 174.38) = 1344.55, p<0.01, η^2 = 0.951] and age [F (2, 69) = 0.74, p<0.001, η^2 =0.637] for monosyllable identification scores. Interactive effect between age and SNR was also found to be significant [F (5.05, 174.38) = 24.74, p<0.001, η^2 = 0.418]. Similarly, a significant effect of SNR [F (3.12, 214.99) = 4819.45, p<0.01, η^2 = 0.986] and age [F (2, 69) = 68.34, p<0.001, η^2 =0.665] was observed on word identification scores as well. A significant interaction effect across group and SNR was found as well [F (6.23, 214.99) = 15.96, p<0.001, η^2 = 0.316]. Also, a significant main effect of SNR [F (2.36, 162.96) = 2000.05, p<0.01, η^2 = 0.967] and group [F (2, 69) = 35.78, p<0.001, η^2 = 0.509] was observed on sentence identification scores. An interaction effect across group and SNR was also found, which was statistically significant [F (4.72, 162.96) = 27.38, p<0.001, η^2 = 0.443]. Table 4.1 -4.3 shows the results of follow up independent samples t tests on each stimuli between age groups. From the Tables 4.1-4.3., it can be see that there is a difference in performance for SPIN across different SNRs in all the three groups. Significant differences (denoted by the shaded boxes) were found consistently in the lower SNRs for all the groups. One may say that the probable effect of age is more pronounced at lower SNRs than higher SNRs. The differential effect of the material across SNRs can also be noticed from tables 4.1-4.3. For example, sentence perception is relatively similar at higher SNRs across the three age groups, whereas, there is a difference in monosyllable and word scores at higher SNRs itself. Overall, it is clear that age related deterioration in SPIN skills starts by 30-49 years, despite having normal hearing.

Table 4.1

Results of independent t test within monosyllables across different conditions

	YNH *vs.* MNH					MNH *vs.* ENH					YNH *vs.* ENH				
dBSNR	10	5	0	-5	-10	10	5	0	-5	-10	10	5	0	-5	-10
't' value	1.249	0.976	2.024	3.899	6.055	3.536	4.097	2.436	5.294	3.705	2.935	4.821	3.661	9.07	10.418,

Note: shaded box indicates significant difference ($p < 0.003$) between the two groups

Table 4.2

Results of independent t test within words across different conditions

	YNH *vs.* MNH					MNH *vs.* ENH					YNH *vs.* ENH				
dBSNR	10	5	0	-5	-10	10	5	0	-5	-10	10	5	0	-5	-10
'*t*' value	3.07	2.596	3.815	6.538	3.754	4.53	3.925	3.696	3.797	2.254	6.088	6.56	7.082	10.078	6.877

Note: shaded box indicates significant difference ($p < 0.003$) between the two groups

Table 4.3

Results of independent t test within sentences across different conditions

	YNH *vs.* MNH					MNH *vs.* ENH					YNH *vs.* ENH				
dBSNR	10	5	0	-5	-10	10	5	0	-5	-10	10	5	0	-5	-10
'*t*' value	1.899	2.107	3.628	4.874	6.334	1.597	2.208	3.122	3.783	4.114	2.422	3.047	5.004	8.575	12.546

Note: shaded box indicates significant difference ($p < 0.003$) between the two groups

Relationship between contralateral inhibition of TEOAE and SPIN scores

For this objective, correlation between contralateral inhibition of TEOAE magnitudes and speech perception in noise scores were computed separately for each age group.

Identification of monosyllables in the presence of noise

The results of the correlation analysis revealed a significant correlation between contralateral inhibition of OAEs and monosyllable identification scores at two SNR's (+10 dB SNR and 0 dB SNR) only in YNH group (r = .56, p<0.001 and r = .66, p<0.001 respectively). Figures 4.5a and 4.5b depicts the scatter plots for the same. No significant correlations were observed in the MNH and ONH groups at any SNR.

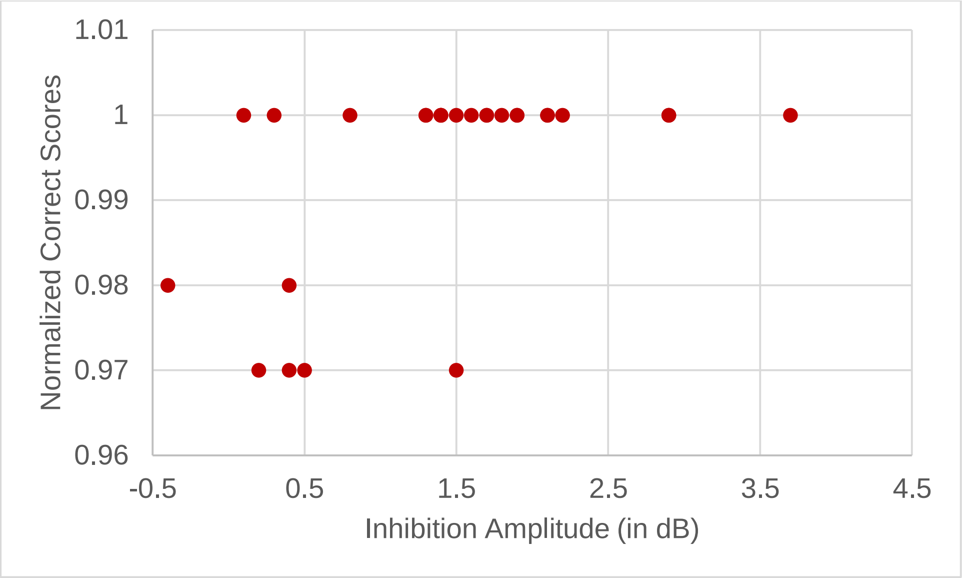

Figure 4.5a: Plot representing relation between inhibition magnitude and monosyllable in noise scores at +10 dB SNR in the YNH group

However, from figure 4.5a, it can be understood that there is no true correlation observed between the two variables and the relation obtained in the statistical test is spurious. Hence, this wasn't considered for further analysis.

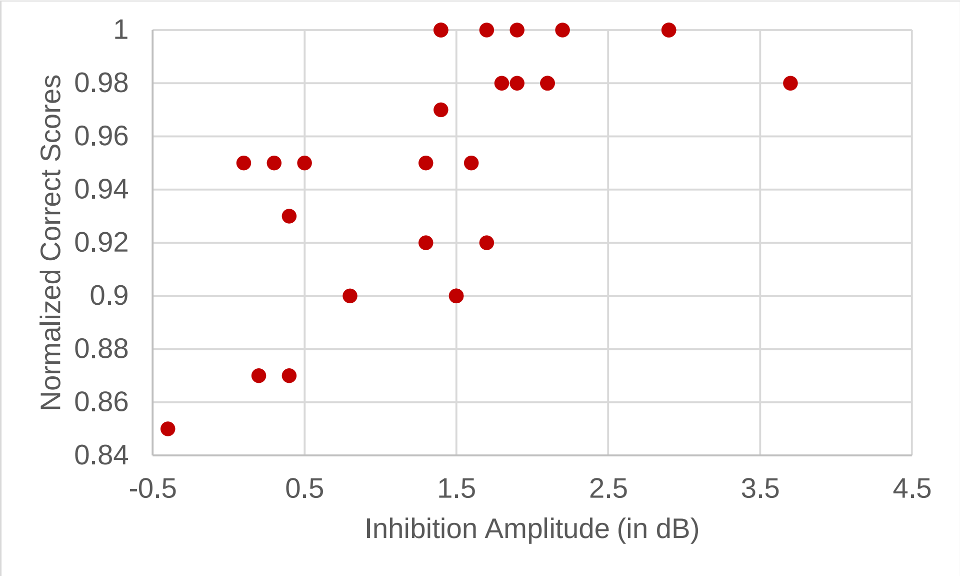

Figure 4.5b: Plot representing relation between inhibition magnitude and monosyllable in noise scores at 0 dB SNR in the YNH group.

Identification of words in the presence of noise

The Spearman's correlation revealed a significant correlation between the contralateral inhibition amplitude and word identification in noise at -5 dB SNR only (*r* = .39, *p*=0.04) in the YNH group. The scatter plot for the same has been depicted in figure 4.6. Significant relations were not obtained for the MNH and ENH groups at any SNR.

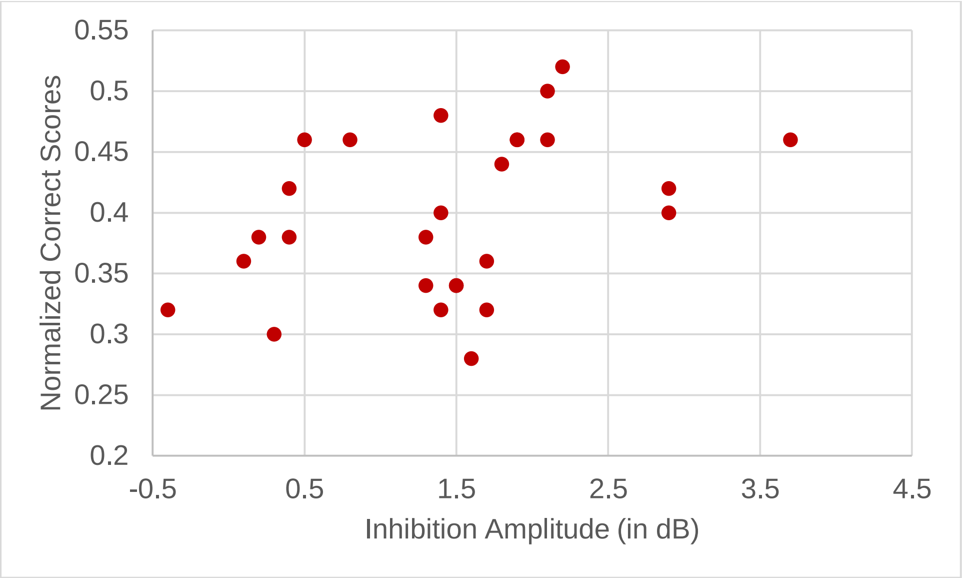

Figure 4.6. Plot representing relation between inhibition magnitude and word in noise scores at -5 dB SNR in the YNH group.

Identification of sentences in the presence of noise

Significant correlation between two variables were found to be significant at -10 dB SNR in the YNH (r = .42, p = 0.03) and MNH (r = 0.55, p = 0.01) groups for sentence speech material. Scatter plots for the same are represented as figures 4.7a and 4.7b. No other correlations were significant.

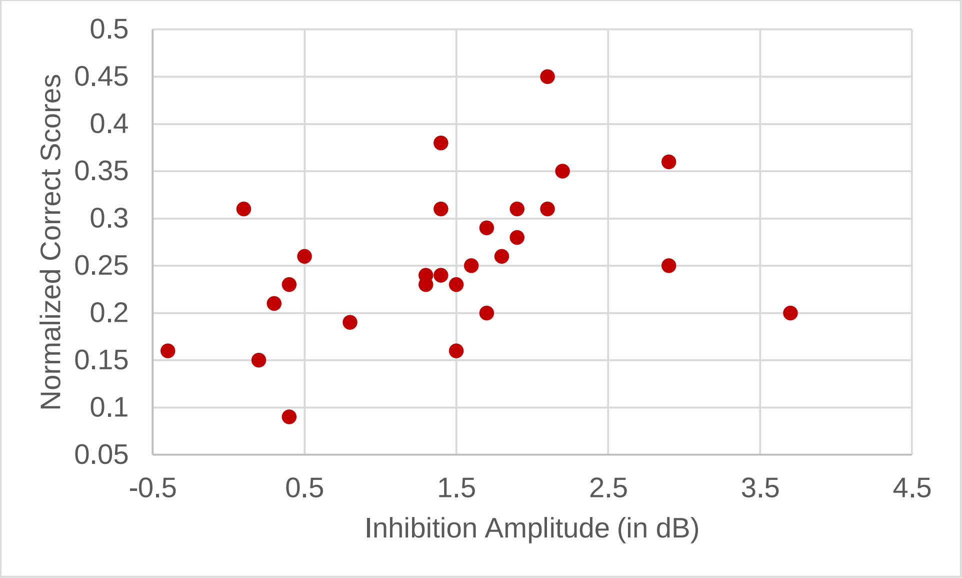

Figure 4.7a. Plot representing relation between inhibition magnitude and sentence in noise scores at -10 dB SNR in the YNH group.

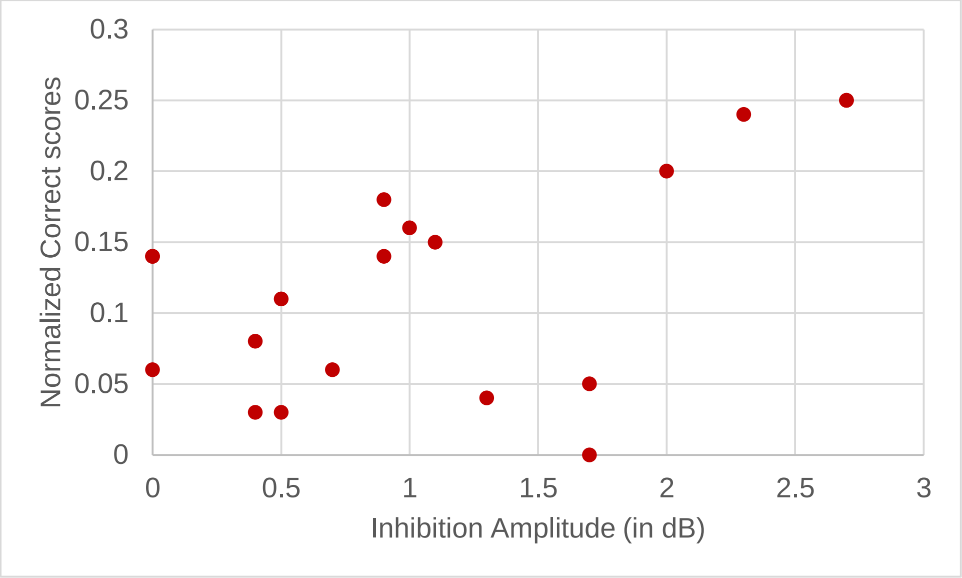

Figure 4.7b. Plot representing relation between inhibition magnitude and sentence in noise scores at -10 dB SNR in the MNH group.

CHAPTER V

Discussion

Effect of age on contralateral inhibition of TEOAE

To check the effect of age on contralateral inhibition of transient evoked otoacoustic emissions (CI-TEOAE), TEOAE was measured in individuals belonging to three age groups – young normal hearing (YNH), middle aged normal hearing (MNH) and elderly normal hearing (ENH) individuals and the global amplitude was compared. The mean of CI-TEOAE was found to be more in the YNH group, when compared to MNH and ENH groups. However, this difference was not statistically significant ($p > 0.05$).

There are a few studies reported in literature which has checked the CI-TEOAE variation with respect to age. Findings of the current investigation is in consensus with that of Quaranta, Debole, & Di Girolamo (2001). In their study, the authors examined the inhibition in five groups of individuals, with age ranging from 20-78 years. Magnitude of the inhibition of TEOAEs did not vary depending on the age.

In the study by Maruthy, Kumar, & Gnanateja (2017), the click stimuli for TEOAE was presented at 70 dB SPL and white noise in the opposite ear at 40 dB SPL. The experimenters also matched the TEOAE global amplitude in quiet across the two groups (no statistical difference), which suggests equivalence in cochlear function across the two groups. The results of their study indicate a negative correlation of suppression amplitude with age, contradictory to the present study. The methodological variations across the two studies may have brought about the difference in the finding to some extent. Also, in the present study, the standard deviation for inhibition amplitude was very high, which could be another reason for the difference in result across the two studies.

Other studies, (Parthasarathy, 2001), which checked age effects of CI-TEOAE also reported the magnitude of inhibition decreased with the increasing age. However, this reduction in the inhibition amplitude was noticed only in the two groups with mean age greater than 60 years. In these groups, a rapid decline in the amplitude of suppression was noticed when compared to the other younger groups. In the present study, however, the mean age of older individuals was much lesser and therefore, the effect of age on magnitudes of inhibition were not observed. Most of the other studies which report of a decline in medial olivocochlear (MOC) functioning with age have also been done on groups of individuals with mean age greater than the current study (Castor et al., 1994; SungHee Kim et al., 2002)

The CI-TEOAE is a measure for MOC functioning. Another test which can be used to check the MOC status is the contralateral suppression of distortion product otoacoustic emissions (CS-DPOAE). The DPOAE is more frequency specific and is a nonlinear phenomenon. A few studies have been done checking the relation between CSDPOAE and age (SungHee Kim et al., 2002; Mukari & Mamat, 2008). These studies report of a negative correlation with age. Even though the two tests checks for the same process, there are differences in findings between these studies and the present study. Most studies that have used DPOAE have found an age related decline in the inhibition magnitudes at high frequency. For example, the age effect in CS-DPOAE was found in the higher frequency band (3-8 kHz) only, when compared across young and old individuals (Mukari & Mamat, 2008). There was no significant difference in the other frequency bands. Similar findings have been reported by Kim et al., as well, who reported that the function of the MOC system is maintained better in 1-2 kHz region (as indicated by greater suppression) than in the 4-6 kHz region as age increases. However in the current study we measured the TEOAEs using a broadband click. The upper frequency of standard TEOAE is around 4 kHz (Probst, Lonsbury-Martin, & Martin, 1991). Therefore, it is probable that the higher frequency effects may not be evident in a TEOAE recording, which may be another factor causing the discrepancy in findings on effect of age on MOC operation as a function of age.

Also, in the present study, the global CI-TEOAE amplitudes were used for the comparison. It may be noted that a global value may be less susceptible (as it is more robust) to subtle changes in the efferent system, and especially if the changes to be recorded falls in a narrow range.

Effect of age on speech perception in noise

The next objective of the study was to compare the speech perception in noise (SPIN) scores across the different material (monosyllables, words and sentences) and signal to noise ratios (SNR) used in the study. The results of the study indicate that there is a significant effect of age on SPIN. The SPIN scores were significantly poorer in the ENH group, followed by the MNH group. The YNH group performed the best at all SNR's and across all the speech materials. The difference between the elderly individuals and young individuals are more evident at poorer signal to noise ratio. This is in consensus with other studies as well (Abdala et al., 2014; Billings et al., 2015). Abdala et al. (2014) found a decrease in speech scores with increasing age up till 60 years of age, beyond which they found no decline. Billings et al. (2015), also found that there is more severe deterioration of SPIN scores at poorer SNRs when compared to better. They found the SNR-50 to be largest in older individuals with hearing impairment, followed by older normal hearing group and then the YNH group.

Reduced temporal acuity in the elderly has been accounted as one of the reasons for the reduction in the SPIN scores with increase in age (Fitzgibbons, Gordon-Salant, & Gordon-salantt, 1996; Pichora-Fuller, Schneider, MacDonald, Pass, & Brown, 2007). To understand speech in noise, it is usually the temporal modulation cues that play a major role (for example, 'listening in dips' phenomena in the presence of noise). Invariantly, reduction in temporal abilities will lead to performance deterioration in perceiving stimuli in the presence of noise as the noise will mask the temporal cues and exaggerate the difficulty further (Assmann & Summerfield, 2004).

Studies also report of presence of a general cognitive decline in the elderly individuals (Gordon-Salant & Fitzgibbons, 1997) which also plays a role in speech in noise perception, especially in more difficult situations. Studies have reported that with increasing amount of background noise, the cognitive load for perception increases, owing to greater effort from the listener. Zekveld, Kramer, & Festen (2011), checked text reception threshold (a test of processing speed and word vocabulary) across 38 individuals having mean age of 55 years and normal hearing ability. They found the threshold to deteriorate with increasing age, suggesting a reduction in processing speed, even though their vocabulary was intact. This may have an implication in adverse listening situations, like in presence of noise, but not so much in quiet environments, similar to what is reported in older individuals. The poor scores could also be attributed to reduced neural efficiencies reported in elderly normal hearing individuals as estimated through speech evoked auditory brainstem responses (Werff & Burns, 2011).

Also Wong et al. (2009) did an MRI on normal hearing elderly individuals to check for neuroanatomical variations, if any. They found a reduction in volume of pars triangularis and cortical thickness of left frontal gyrus in older individuals, which was found to be a significant predictor in speech in noise performance. Those with larger volumes were found to perform better in SPIN than the rest (probably a compensatory mechanism to take over for the decline in the peripheral sensory system). Hence, cortical decline in elderly may also lead to SPIN difficulties in them.

Relationship between contralateral inhibition of TEOAE and SPIN scores

The study also aimed to re-examine the relation between contralateral suppression of OAE and SPIN by considering various factors (age, linguistic load and SNR) that may affect the findings. A significant correlation was found only in a few conditions

i. Monosyllable identification in babble at 0 dB SNR in the YNH group
ii. Word identification in babble at -5 dB SNR in YNH group
iii. Sentence identification in babble at -10 dB SNR for YNH and MNH groups

It can be observed that the correlation is present only at lower SNRs, suggesting that the medial olivocochlear bundle (MOCB) is effective in enhancing speech primarily at poorer SNRs. This positive correlation between SPIN scores and MOCB functioning in adults have been reported in other studies as well (Abdala et al., 2014; Giraud et al., 1997; Sunghee Kim et al., 2006).

Since the correlation was obtained at different SNRs for the different materials, it may be hypothesized that the MOCB functions differently depending on the kind of stimulus that it receives. It is not within the scope of the current study to pinpoint how exactly the role changes. It is however, possible that the durational aspect (monosyllables have shorter duration when compared to sentences) or the linguistic load of the information or both may have played a role in this. For the longer duration stimuli and stimuli with more linguistic load, like sentence in the present study, the effect of

MOCB (correlation) was at a lower SNR than when compared to a short duration stimuli like monosyllable, suggesting a possible interplay between these factors.

In older adults, no correlation was found across SPIN and MOCB functioning in the study for any material. Probably, the role of MOCB in speech perception deteriorates with age. This is also consistent with other studies (Mukari & Mamat, 2008), where they observed age related deterioration in DPOAE, but no correlation between CSDPOAE and SPIN scores.

CHAPTER VI

Summary and Conclusions

The medial olivocochlear bundle is one of the major and the longest efferent connection of the auditory system (Cooper & Guinan, 2006). Several studies have been carried out to understand the role played by MOCB in speech perception in the presence of noise (SPIN). However, the findings have been equivocal. Thus, the main aim of this study was to elucidate the relationship of contralateral inhibition of transient evoked otoacoustic emissions (TEOAE) with SPIN across different testing variables. 72 participants were recruited for the study. The participants of the study were divided into three groups based on their age – the young normal hearing group (YNH- with age ranging between 18 – 29 years), middle normal hearing group (MNH in the age range of 30-49) and the elderly normal hearing group (ENH with age greater than 50 years). Participants in all the three groups had normal peripheral hearing acuity as assessed by pure tone audiometry, immittance and otoacoustic emissions. Contralateral inhibition of TEOAE was calculated as the difference in the global TEOAE amplitude with and without noise in the contralateral ear for 65 dB SPL clicks. Speech perception in the presence of babble was assessed at different signal to noise ratios varying from +10 to -10 dB SNR (in 5 dB steps) for monosyllables, words and sentences. The eight talker speech babble of Quick SIN – Kannada served as the noise. The SPIN performance was determined using

i. Phonemically balanced (PB) monosyllables (Mayadevi, 1974), which includes 20 consonants in the context of /a/ vowel.

ii. PB word lists – Kannada (Manjula, Antony, Kumar, & Geetha, 2015), which has 21 equivalent lists for speech in noise testing. Each list had 25 disyllabic Kannada words that were balanced phonemically.

iii. Sentences from Sentence Identification Test (SIT), Kannada (Geetha, Kumar, Manjula, & Pavan, 2014), which consisted of 30 equivalent sentence lists. Each list was made of ten sentences and 40 key words. The sentences were made of familiar words of equal difficulty level. All the sentences had low predictability level.

Two lists were presented per SNR across all the materials. The presentation level for speech was maintained at 70 dB SPL.

Results showed that contralateral inhibition magnitudes did not differ significantly across different age groups. However, speech identification scores reduced significantly with the increasing age. Participants in the YNH group had better speech perception in noise compared to other two groups, especially, at poorer SNRs. Pearson's product moment correlation analyses revealed significant correlations between contralateral inhibition magnitudes of TEOAEs and speech perception in noise scores primarily at poorer SNRs, especially in YNH group. For monosyllables, correlations were significant at 0 dB SNR (only in YNH), for words, correlations were significant at -5dB SNR (only in YNH) and for sentence, correlations were significant at -10 dB SNR (in YNH and MNH). No significant relations were found in the ENH groups. This suggests that the MOCB plays a role in enhancing speech perception in noise only at lower SNRs, primarily, in young adults. Thus, the study reinforces the notion that the MOCB plays a role in speech perception in the presence of noise, though only in young adults at poor SNRs. In younger individuals reporting of difficulty in perceiving speech in presence of noise, an MOCB assessment can be included in the test battery to add on more information.

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