Involvement of the Efferent Auditory System for Improvement in Speech Perception in Noise

Vijaya Kumar Narne[1,*] and Mohan Kumar Kalaiah[2]

[1]*Reader in Audiology, Department of Audiology, JSS Institute of Speech and Hearing, University of Mysore, India*

[2]*Department of Audiology, University of Manipal, India*

Abstract: To investigate the involvement of auditory efferents in hearing-in-noise in humans, Median olivocochlear (MOC) efferent's functioning and speech recognition-in-noise abilities were compared in 19 subjects. MOC efferent's function was assessed in terms of contralateral attenuation of transient evoked otoacoustic emissions (TEOAE): i.e., the reduction in TEOAE amplitude elicited by a 40, 50 and 60-dB SPL contralateral speech spectrum shaped noise. Correspondingly, the speech reception thresholds for sentences embedded in 50-dB SPL speech spectrum shaped noise (SRTn) were measured in the same ear as the TEOAEs, successively in the presence and in the absence of uncorrelated noise in the opposite ear at three different levels (i.e 40, 50, & 60 dB SPL). The results indicated there was no significant statistical correlation between the contralateral attenuation of TEOAEs and SRTn for uncorrelated noise. In addition, there was no change in SRTn for uncorrelated noise at different levels. These results were discussed in line with previous studies.

Keywords: OAE, Contralateral suppression, uncorrelated noise, speech perception.

INTRODUCTION

The role of the efferent auditory system in speech perception in noise, specifically, the medial olivocochlear bundle (MOCB), has been extensively studied. The MOCB originates in the superior olivary complex in the brain stem and projects in to the inner ear. It comprises of lateral and medial parts, and both possess crossed and uncrossed fibers [1]. The medial olivocochlear (MOC) efferents synapse directly with outer hair cells (OHCs). Therefore, activation of the efferent bundle by acoustic stimulation leads to amplitude changes of transient otoacoustic emissions (TEOAE) and distortion product otoacoustic emissions (DPOAE) [2, 3]. The amplitude reduction of TEOAE/DPOAE on the side of stimulation is referred as ipsilateral suppression and that observed on the opposite side of stimulation is termed as contralateral suppression (CS).

It is thought that the inhibitory function of MOC reflex would lead to an improvement in coding of signals embedded in noise [4], suggesting an anti-masking role for the MOC efferents [5, 6]. Physiological studies conducted in animals [4, 5, 7] has shown that MOC activity improves the auditory nerve's response to signals by reducing the response to a noisy background, effectively improving the signal to noise ratio [5, 6].

*Address correspondence to this author at the Reader in Audiology, Department of Audiology, JSS Institute of Speech and Hearing, University of Mysore, India; Tel: 0821 254 8229; Fax: 0821-2548230;
E-mail: vijaynarne@gmail.com

In humans, the functional role of auditory efferents on speech perception has been studied using three approaches Guinan (2010) [8]. One approach has been to study the psycho-acoustical performance of patients who have undergone transection of the olivocochlear bundle (OCB) (in vestibular neurectomy) [9-12]. Two of these studies reported that speech reception in noise was poorer in the operated ear than in the un-operated ear of vestibular neurectomy patients [10, 12]. Scharf *et al.* [9, 11] indicated that vestibular neurectomy had no effect on the thresholds of tones presented either in quiet or in noise, except when the frequency of the tones was unexpected. Morand-Villeneuve *et al*. (2002) [13] have noted similar results in vestibular neurectomy participants. Thus, these studies provide somewhat inconsistent evidence that disruption of the MOC reflex is associated with hearing-in-noise deficits.

Second, the role of MOC efferents, have also been examined by studying the relationship between speech reception threshold in noise and the magnitude of MOC reflex [14, 15]. Kim, Frisina and Frisina [14] investigated the relationship between the CS of distortion product otoacoustic emissions (DPOAE) and sentence recognition thresholds in noise with speech and noise coming from the same frontal direction (Hearing in Noise Test (HINT)), and improvement of sentence perception when speech and noise were spatially separated and emanated from different directions. The authors reported weak correlation between speech reception threshold and CS of DPOAE. In addition, [15] showed that there was no relation between CS of DPOAE and speech reception

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threshold in noise. The lack of correlation between MOC reflex functioning and speech perception in noise in the above studies may be due to the fact that speech perception was measured in the free field with speech and noise delivered binaurally [16].

In the third approach, speech identification scores at different SNRs were measured with and without contralateral noise and these measures were correlated with contralateral suppression of TEOAE [10, 17]. This approach allows direct effects of the contralateral stimulation of the MOC reflex on speech perception in noise to be studied [16, 18]. There was a significant positive correlation between speech identification scores in noise and CS of TEOAE. They attributed the improvement in speech identification to MOC efferent activation. However, noise was presented binaurally in [17] study was from same source (Madsen OB-922 clinical audiometer), indicating the noise in both ears may be correlated. Improvement observed in such stimulus conditions can't be accounted exclusively for MOC mediated effects. Because, improvement observed in such stimulus conditions are majorly dominated by binaural masking level difference [19-21], which reflect a kind of binaural interaction thought to derive from a central mechanism and which may not involve MOC.

The present study sought to clarify the relationship between the contralaterally evoked MOC reflex and speech reception thresholds in noise in normal hearing adult listeners. As in the previous studies, the relation between MOC reflex and speech reception thresholds in noise (SRTn) was measured in presence of contralateral noise. However, unlike the previous studies, the noise used in the contralateral ear was uncorrelated. Further, several studies have reported an increase in the amount of suppression of TEOAE as the level of noise in contralateral ear was increased [22], which indicate increased MOC efferent activity. Hence, increased MOC efferent activity upon increasing contralateral stimulation level should, on average, exhibit a corresponding improvement in speech reception threshold when uncorrelated noise is presented contralaterally. Systematically examining speech reception threshold in noise, when varying the level of uncorrelated noise in the contralateral ear, would provide better understating of the possible anti-masking role of MOC reflex. To address this possibility, the present study examined CS of TEOAE and speech reception threshold in noise (SRTn) at three different levels of uncorrelated contralateral noise (i.e. 40, 50 and 60 dB SPL).

Method

A. Participants

The present study was performed on 20 participants (12 males and 8 females) in the age range of 18 and 28 years with mean age of 20.3 years. All participants had hearing sensitivity with in normal limits in both ears. None of them had a history of ear infections, noise exposure or ototoxicity. All the participants had pure-tone thresholds ≤15 dB HL at octave frequencies between 0.25 kHz and 8.0 kHz (ISO, 389-3, 1994), and bilateral normal middle ear functioning as indicated by a type 'A' tympanogram [23]. The middle-ear muscle reflex (MEMR) threshold was measured using the GSI-TYMPSTAR middle-ear analyzer with a broad band noise elicitor. Contralateral MEMR thresholds ranged from 70 to 90 dB SPL, averaging 77.7 dB SPL.

B. Speech Perception

I. Speech Reception Threshold in Noise (SRTn)

i. Stimulus

The speech stimuli were sentences in Kannada, developed by Avinash, Raksha and Kumar [24]. There was a total of seven lists, each list consisting of 10 sentences. Each sentence carried 4 to 5 target words. All the sentence lists were phonetically balanced and were equally difficult. The sentences were spoken in a conversational style by a male native speaker of Kannada. They were digitally recorded in an acoustically treated room, on a data acquisition system using a 44.1 kHz sampling frequency and 16-bit analog to digital converter.

In the experiment involving background noise, the sentences were individually mixed with a speech-spectrum-shaped noise. The speech-spectrum-shaped noise was produced by randomizing the phase of the Fourier spectrum of the concatenated signal (conversational speech sentences). In the contralateral noise condition, the uncorrelated noise was generated with a similar spectrum and presented to opposite ears.

ii. Procedure

Speech reception threshold in noise (SRTn) was measured, in acoustically treated room, using the custom-made MATLAB program. The program was configured to present target stimuli (sentences) via the one channel and masking stimuli were presented either binaurally (left and right headphone channels) or monaurally. They were routed through a calibrated two channel clinical audiometer (Madsen OB-922) and participants received the signal through TDH-39 headphones. SRTn was measured in 2 test conditions. First, SRTn was estimated without any contralateral noise which acted as the baseline condition (N_mS_m). Next, SRTn was measured at three levels of uncorrelated noise (N_u) (generation of uncorrelated noise is given in APENDIX) in the contralateral ear (N_uS_m). Separate sentence lists were used to obtain SRTn in each of the above conditions and order of the conditions were counter-balanced across the participants.

SRTn for all the conditions is obtained using the following procedure. The beginning intensity level of noise channel for the ipsilateral ear was 50 dB SPL and was kept fixed. Noise onset preceded each sentence by 500 ms and was turned off 500 ms after each sentence was completed. The initial level of the target stimuli was 46 dB SPL and rose by 2 dB, if fewer than two of the four or five words of the sentence are repeated correctly and lowered by 2 dB, if more than 3 of the four or five words are understood. The SNR, at which two of four or three of five words repeated correctly, was considered as SRTn.

C. Transient Evoked Otoacoustic Emission Measurements

TEOAE recordings were performed using an Otodynamics ILO-V6 system. The contralateral speech-spectrum-shaped noise was played on the computer and routed through a calibrated Madsen OB-922 clinical audiometer and presented though ER-3A insert phone.

Following the method developed by Bray and Kemp (1987) [25], OAEs were recorded in linear mode using 80-μs broadband (rarefaction) clicks presented at 60 dB SPL. Linear mode was employed because non-linear mode may over or under estimate contralateral suppression of TEOAE [26]. These clicks were presented at a rate of 50 per second. Responses were acquired during with a 20-ms time window and were alternately accumulated in two separate buffers. The averaging process stopped when 260 responses below the noise rejection threshold had been recorded.

The speech shaped noise was used to obtain CS of TEOAE. Contralateral noise was presented through an ER-3A insert earphone at 40, 50 and 60 dB SPL. The output level of the insert ear phones was measured in an AEC-102 coupler using a Larson and Davis system 824 sound level meter. These levels were chosen because they did not elicit a MEMR. TEOAEs were recorded from the right ear in nine participants while they were recorded from the left ear in remaining ten participants. TEOAEs were recorded in the same ear for which the SRTn was estimated.

RESULTS

A. Contralateral Suppression of TEOAE

In all the participants, amplitude of TEOAE decreased upon contralateral stimulation. Figure **1** shows mean and standard deviation (as error bars) of amount of attenuation of TEOAE amplitude as a function of contralateral stimulus level.

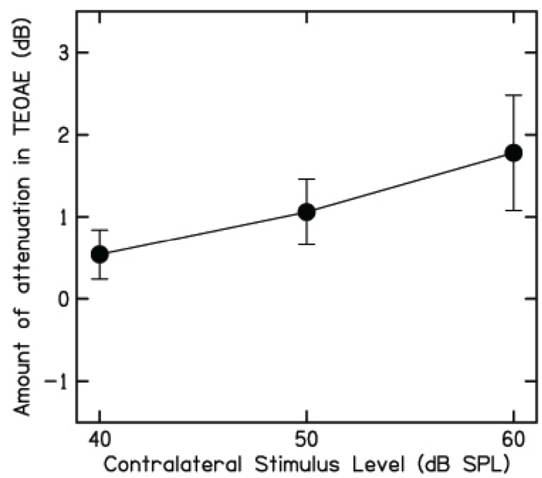

Figure 1: Amount of contralateral suppression of TEOAE as a function of level of contralateral noise (filled circle).

The visual inspection of the Figure **1** shows that mean data of suppression at different contralateral simulation levels. The reduction in TEOAE amplitude was higher for higher level of contralateral stimulation. To evaluate the effect of stimulation level on CS of TEOAE, ANOVA for repeated measures was carried with stimulation level (3 levels) as within subject factors. The analysis showed a significant main effect of stimulation level ($F_{(2,\ 24)} = 27.3$, $p< 0.01$) and Bonferroni Pair wise comparison reveled a significant difference in the mean reduction of TEOAE amplitude across different stimulation levels.

B. Speech Reception Threshold in Noise

The adaptive procedure for the determination of the SRTn converged for all the participants in all conditions. In the N_mS_m condition, mean SRTn was approximately -0.3 dB. The effect of contralateral noise on SRTn was calculated by taking the difference between monaural condition (N_mS_m) and binaural condition (N_uS_m) at each level of noise in contralateral ear. Mean and standard deviation of this difference in N_uS_m condition as a function of level of contralateral noise are presented in Figure **2**. The visual inspections of the data in Figure **2** reveal that mean difference is minimal in N_uS_m condition across the presentation levels. To assess the effect of contralateral noise level, ANOVA for repeated measures was carried with stimulation level (3 levels) as within subject factors. The analysis showed a no significant main effect of stimulation level ($F_{(2, 14)} = 7.3$, $p = 0.21$).

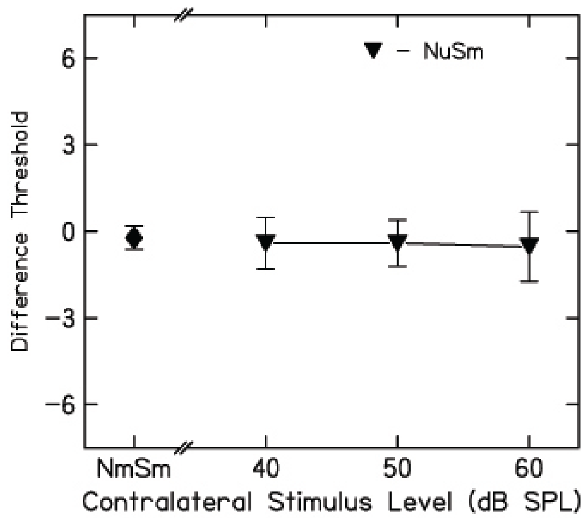

Figure 2: Difference threshold as a function of contralateral stimulus level (i.e deference between SRTn obtained in base line condition (NmSm) and SRTn obtained in uncorrelated contralateral noise (N_uS_m)).

The relationship between SRTn and CS of TEOAE amplitude at all the stimulus levels were assessed using Pearson product-moment correlation. The CS of TEOAE was compared with the NuSm results at corresponding contralateral noise levels. Analysis revealed no significant relation between SRTn and CS of TEOAE.

DISCUSSION

A. Contralateral Suppression of TEOAE

The results of the present study show that the amount of contralateral suppression was dependent on the level of contralateral noise. Maximum suppression of TEOAE was observed for 60 dB SPL noise, and the amount of suppression of OAEs decreased with decreasing the level of contralateral noise. Collet *et al.*, (1990) [27] recorded TEOAEs to clicks in the presence of contralateral noise, and the level of noise was increased from 30 dB SPL to 50 dB SPL in a stepwise fashion. They also observed that as the level of contralateral noise increases more suppression was seen. Similar results have been reported by many other investigators [22, 26]. Contralateral suppression of TEOAE is mediated by MOC efferent system [26] and increasing level of contralateral noise increases the MOC efferent system activity which in turn causes greater reduction in amplitude of TEOAE [22, 26]. Although, the trend was similar, the amount of suppression noted in the present study was 0.2 to 0.3 dB lesser than that reported by other investigators [22, 26] at all the levels of stimulation in the contralateral ear. The difference in suppression noted may be attributed to differences in the type of stimuli used.

B. Speech Reception Threshold in Noise

The goal of this investigation was to examine the relationship between the strength of contralaterally evoked MOC inhibition and speech reception threshold in noise. The original hypothesis was that increased MOC efferent activity upon increasing contralateral stimulation level should, on average, exhibit an improvement in performance of signal detection in the presence of noise. Contrary to expectation, the results revealed that there was no significant difference in SRTn obtained at 40, 50 and 60 dB SPL of uncorrelated contralateral noise condition, while CS of TEOAE amplitude reduced as level of contralateral noise increased. In addition, there was no significant relationship between SRTn and CS of TEOAE (strength of MOC reflex) at any level of contralateral simulation These results seems to run in agreement with some of the previous studies [14, 15] and counter to those reported in few other studies [10, 17].

There are many methodological differences among the studies that have examined the link between MOC reflex strength and detecting signals in noise, including stimuli, OAE type and other procedural variations. These variables are summarized for the four previously published studies and for the current study in Table **1**. One obvious difference found among the studies is the method employed across studies. The current study and some of the previous [14, 15] studies which employed threshold measures have shown no significant relation between strength of MOC reflex and sensitivity to signal detection in noise. This was also noted for tone detection in noise when uncorrelated noise is presented in the contralateral ear [28]. On the other hand, the studies which employed identification scores have demonstrated a significant correlation between Speech perception scores in noise and the

Table 1: Summary of Methods from Five Studies of Relationship between MOC Reflex Strength and Speech Perception in Noise

Study	Subjects (N[a], Age)	Speech perception (Stimuli, masker, task)	Contralateral noise	OAE type[b]	MOC reflex and speech perception relationship [c]
Giraud *et al*., (1997) [10]	20, M = 40 yrs	Monosyllabic words, broadband noise, speech identification scores	Yes	TE	Positive
Kumar & Vanaja, (2004) [17]	10, Age range 10-12 yrs	Monosyllabic words, broadband noise, speech identification scores	Yes	TE	Positive
Kim *et al*. (2006) [14]	25, Age range 18-75 yrs	Sentences, speech spectrum shaped noise, speech reception threshold	Yes	DP	Weak
Wagner *et al*. (2008) [15]	49, Age range 19.7-41.7 yrs	Sentences, speech spectrum shaped noise, speech reception threshold	Yes	DP	None
Narne, Kumar, (Present Study)	19, M = 23.3 yrs	Sentences, speech spectrum shaped noise, speech reception threshold	Yes	TE	None

[a]N= Number of Participants.
[b]TE= transient evoked OAE; DP =distortion product OAE.
[c]Positive = threshold lower or higher scores for larger MOC effect; None = no significant relationship.

CS of TEOAE. Careful observation of results reported in Licklider (1948) [20] study is that presenting uncorrelated noise in the contralateral ear improved identification scores only at very low SNR's (i.e < -8 dB SNR).

The varied results of the studies that examined the relationship between MOC reflex strength and extracting signals from noise may suggest that dependence on this process or mechanism is helpful for detecting masked sounds in specific tasks and conditions. This is further supported by Heinz *et al*., (1998) [29] where they demonstrated that vowel discrimination in cats was adversely affected by bilateral efferent section only at lower SNRs than at higher SNRs. These observations suggest that MOC mediated effects are observed in specific tasks and conditions. Therefore, the task employed in the present study may not have adequately reflected the MOC involvement.

CONCLUSION

In conclusion, the presented study found no significant correlation between the magnitude of MOC reflex (as measured by CS of TEOAE) and SRTn. These results and those of previous studies of the same type suggest that utility of MOC reflex related mechanisms in extracting signals from noise may vary with the stimulus and the listening conditions in a complex way. Additional parametric studies may clarify this issue. Further studies are needed in this direction to 1) explore the effect of different levels of uncorrelated contralateral noise at different SNRs for speech perception and 2) tone detection in noise for different frequencies with varying levels of contralateral uncorrelated noise.

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CONFLICT OF INTEREST

Authors declare no conflict of interest. The present study is not supported by any funding.

APPENDIX: PROCEDURE FOR GENERATION OF UNCORRELATED NOISE

Uncorrelated noise is generated using the Gram–Schmidt's procedure, which allows, in generating another set of functions which are pair wise orthogonal (uncorrelated with each other) and are normalized to have equal energy to the original set of functions. This following procedure is simplified here to the case with only two waveforms in the set. For example, x (t) and y (t) are two independent N-sample nonzero waveforms, and they are not perfectly correlated with each other (two in-dependent samples of noise). There are four steps in generation of uncorrelated noise, outlined next, that result in two orthogonal waveforms x(t) and y(t)', where y(t)' has an identical rms (root mean square) power and zero correlation with, x(t).

Step 1: RMS of for two noises is calculated.

$$x_{rms} = \sqrt{\frac{\sum_{i=1}^{N} X_i^2}{N}} \qquad \text{(Eq.1)}$$

$$y_{rms} = \sqrt{\frac{\sum_{i=1}^{N} y_i^2}{N}} \qquad \text{(Eq.2)}$$

Step 2: The correlation, ρ_{xy} between x and y is calculated

$$\rho_{xy} = \frac{\sum_{i=1}^{N} x_i y_1}{x_{rms} y_{rms}} \qquad \text{(Eq.3)}$$

Step 3: The correlated component of x is subtracted from a scaled version of y. This subtraction yields z, which has zero correlation with x:

$$z_i = \frac{x_{rms}}{y_{rms}} y_i - \rho_{xy} x_i \qquad \text{(Eq.4)}$$

Step 5: The component of z was scaled to get y' which has zero correlation with, and equal power as x:

$$y_i' = \frac{z_i}{\sqrt{1-\rho_{xy}^2}} \qquad \text{(Eq.5)}$$

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