Effect of Age on Fatiguing Characteristics of Efferent Inhibition

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Abstract

Efferent nervous system is reported to protect the cochlea from noise induced damage, improves signal detection in noise and enhances the dynamic range. However, it is not clear as to whether such positive influences remain stable over continuous prolonged stimulations. The present study evaluated the effect of age and fatiguing characteristics of efferent system during prolonged acoustic stimulation. A total of 80 normal hearing subjects who were divided into 4 age groups, participated in the study. From each subject, TEOAEs were recorded four times after different duration of continuous stimulation. In each recording, the overall SNR as well as amplitude at each half-octave frequency were noted. The results showed that efferent fibers do not deteriorate during prolonged stimulation and also these fibers do not degenerate with advancing age. Degeneration of sensory cells and the afferent auditory neurons do not influence efferent inhibition. Hence, it is concluded that unlike afferent neurons, efferent neurons do not evidence degenerative changes in their physiology up to 60 years of age.

***Key words**: TEOAEs, efferent fibers, contralateral noise, efferent inhibition.*

Efferent innervation to the cochlea is from the descending fiber tracts starting primarily from superior olivary complex (Rasmussen, 1946). This descending fiber tract is also called the olivary cochlear bundle (OCB) (Guinan, Warr, & Norris, 1983) as these nerve fibers end at the cochleae. Most studies on the physiology of efferent system have focused on medial efferent neurons as these fibers are myelinated and readily stimulable by extracellular current (Hallin & Torebjork, 1973). Lateral efferent neurons on the contrary are unmyelinated and hence difficult to trigger either electrically or acoustically.

MOC efferents end at outer hair cells (OHCs). These neurons modify the activity of the OHCs which in turn controls the gain of the cochlear amplifier (Warr & Guinan1973). The Activation of MOC is likely to suppress OHC functioning (Galambos, 1956; Warren & Libermann, 1989).

Clinically, contralateral suppression of OAEs has been the most established technique to assess the functioning of efferent system. This is due to its noninvasiveness (Giraud, Collet, Chery-Croze, Magnan, & Chays, 1995; John & Guinan, 2006), objectivity and high sensitivity. In this technique, the strength of efferent inhibition is determined by the difference in the amplitude of OAEs, with and without contralateral noise (Giraud, Collet, Chery-Croze, Magnan, & Chays, 1995). The difference in TEOAE amplitude is termed as suppression amplitude. Across studies, the suppression amplitude is reported to vary between 1 and 3 dB (Hood, Berlin, Hurley, Cecola, & Bell, 1996; Sandeep & Jayaram, 2008). Under equivalent conditions, the amplitude of TEOAEs is suppressed to a greater extent than that of DPOAEs (Hall, 2000).

Past research has reported that the efferent inhibition of OHCs elevates the auditory threshold, reduces the masking effects of noise on signals and protects the cochlea from the negative effects of acoustic overstimulation (Geisler, 1974; Kumar & Barman, 2002; Wiederhold, 1970).

There is strong evidence that the efferent pathway in the mammal can protect the cochlea from damage caused by loud sounds (Cody & Johnston, 1982). This is based on the experimental work on animals (Rajan, 2001). These studies have shown diminution of the permanent threshold shift (PTS) in case of acoustical or electrical stimulation of olivo cochlear bundle during noise exposure and also increase of the PTS after sectioning of the OCB. Cody and Johnstone (1982) demonstrated that whole nerve action potential (N1) in guinea pigs following monoaural acoustic overstimulation was significantly reduced from 12.7 dB to 5 dB, when frequency matched acoustic stimulus at a lower stimulus intensity is delivered to the contralateral ear.

This frequency specific TTS suggested that the activation of medial efferent system reduces the susceptibility of the cochlea to the effects of acoustic trauma. However, the researchers have pointed out that there are certain ambiguities to the mechanism underlying such effects (Libermann, 1999).

Damage to the efferent auditory system is reported to degrade the perception of signal in noise (Muchnik, Roth, Oathman-Jebara, Puter-Katz, Shabtai, & Hildesheimer, 2004) and make the

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cochlea more susceptible to damage from exposure to noise (Liberman & Kujawa, 1999).

It is quite common that industrial workers are exposed to high levels of noise for long durations. Hence, the efferent inhibition which helps to protect the cochlea from the negative effects of acoustic over-stimulation shall ideally be constant throughout the duration of noise exposure. In this regard, it is important to study the effect of prolonged efferent stimulation on the magnitude of inhibition. Sliwinska and Kotylo (2002) measured the suppression of TEOAE in individuals with occupational noise exposure and the results showed that the degree of suppression was decreased in these individuals when compared to that in control group of normal individuals without noise exposure.

Attempts have been made to study the temporal characteristics of the efferent effects in animals and humans using different recording methods, ranging from cochlear compound action potential measurement (Puria, Guinan, & Liberman, 1996), ensemble back ground activity measures of eighth nerve from an electrode implanted on the round window (Da Costa, Jean-Marie, & Aran, 1997) to evoked otoacoustic emissions while delivering contralateral acoustic stimulation (Giraud 1995; Moulin & Carrier, 1998). Sandeep and Jayaram (2008) reported reduction in the efferent inhibition when the efferent system was continuously stimulated beyond 6 minutes. On the contrary, Swanepoel and Hall (2009) reported sustained suppression of TEOAE for 16 min of low level contralateral acoustic stimulation. Similarly, no change in suppression amplitude of DPOAEs for duration of 20 min has been reported by Carrier & Annie (1998).

Collectively, majority of the studies leads to the impression that suppression of MOC neurons (electric or acoustic) is constant up to 20 minutes. But these findings are derived from adults of age below 30 years. Similar to structural and functional afferent neuron degeneration of neurons with aging, there could be degeneration of efferent neurons. Thisnotion is supported by studies which report a reduction in the efferent suppression with age (Kim, Frisina, & Frisina, 2002). Consequently studies (Castor, Veuillet, Morgan & Collet, 1994; Parthasarathy, 2001; Govil & Vanaja, 2002) had shown reduction in contralateral suppression of TEOAEs in the elderly individuals compared to adults, supporting presbycutic changes in efferent fibers. Furthermore, speech perception in noise which is partly regulated by efferent system is also reported to reduce with aging (Varghese & Vanaja, 2004).

One of the early changes in neurophysiology is the increase in fatiguing characteristics of neurons. In fact, the fatiguing behavior of efferent system shall logically be evident earlier than the reduction in efferent inhibition (Castor et al, 1994). Also, as the medial efferent neurons execute their function through OHCs, and afferent neurons, the well established sub-clinical loss of OHCs (Attias, Horovitz, El-Hatib, & Nageris, 2001; Marsshall, Lapsley-Miller, & Heller, 2001) and the degeneration of afferent neurons that is seen with aging, could increase the chances of age related changes in the fatiguing characteristics of efferent inhibition. However, the influence of advancing age on fatiguing characteristics of efferent system is not studied till date. Hence, the present study is taken up to evaluate the effect of age on fatiguing characteristics of efferent system during prolonged acoustic stimulation.

Method

Subjects: A total of 80 subjects participated in the study. Of the 80 subjects, 36 subjects were females and the remaining 44 were males. They were divided into four groups based on their age. All the four groups had 20 participants each. Prior to the audiological screening, an otoscopic examination was done to rule out the presence of structural abnormalities of external ear or tympanic membrane. All participants had normal hearing sensitivity (pure tone thresholds within 15dB HL at octave frequencies between 250 Hz & 8 kHz), normal middle ear functioning as tested on immittance evaluation (all the subjects had 'A' type tympanogram with normal acoustic reflex threshold), more than 90% speech identification scores in speech audiometry, more than 3 dB SPL TEOAEs between 1 kHz and 4 kHz none of them had complaint of difficulty in understanding speech in the presence of back ground noise, and were not exposed to hazardous noise (occupational noise exposure or other).

Instrumentation: A calibrated, two channel diagnostic audiometer (Orbiter 922) with TDH 39 head phones was used for pure tone and speech audiometry. The same was used to present broad band noise (BBN) to the contralateral ear through the insert receiver. A calibrated Immittance meter (Grason-Staddler Tympstar) was used for recording the tympanogram and acoustic reflexes. A Madsen Capella Cochlear Emission Analyzer was used to record click evoked nonlinear otoacoustic emissions. All the testing was carried out in an acoustically treated air-conditioned room with adequate illumination and ambient noise within permissible limit (ANSI S.3, 1991). Pure tone and speech audiometry were carried out in a two room suite while immittance and OAE measurements were done, in a single room situation.

Stimulus & Recording of TEOAEs

Transient evoked otoacoustic emissions (TEOAEs) were recorded for 260 sweeps of clicks. Clicks were presented in nonlinear paradigm. Each sweep contained four clicks where the first three clicks were of same polarity and the fourth click was of opposite polarity but with the amplitude three times the amplitude of earlier three clicks. The duration of click was 80 μsec and acoustical bandwidth was between 500 to 4000Hz +/- 5 dB @ 1000Hz. Intensity of click was between 80 and 85dB peak SPL, depending on external ear canal volume.

The probe with a foam tip was positioned in the external ear canal and was adjusted to give a flat stimulus spectrum across the frequency range. The response was acquired using the standard differential averaging technique to minimize stimulus and other artifacts. The two averaged TEOAE waves of each memory buffer (A & B) composed of 260 accepted click trains. The data of the two buffers were automatically cross correlated and used to determine reproducibility of the measure of TEOAEs. The stimulus stability was more than 90% to consider the recording as valid. The response was considered present, only when the amplitude of OAEs at the individual frequency was more than 3 dB SPL with reproducibility above 80%.

Test procedure

Only the individuals who fulfilled all the aforementioned subject and response criteria were included for the actual experimental procedure. Subjects were instructed to sit in a comfortable position and also to stay steady in the same position till the recording is complete. Only one ear was tested in each subject. The choice of the ear depended on the robustness of the OAEs. A good probe fit was ensured prior to the initiation of all the recordings of TEOAEs. Stimulus spectrum showed a smooth distribution of energy across frequencies ensuring a good probe fit.

In the present experimental procedure, TEOAEs were recorded four times from each subject. First, a baseline recording of TEOAEs was done without contralateral noise (Condition 1). Then, broadband noise (BBN) of 50 dB SPL was presented continuously to the ear contralateral to the probe ear. Figure 1 is a schematic representation of the test procedure.

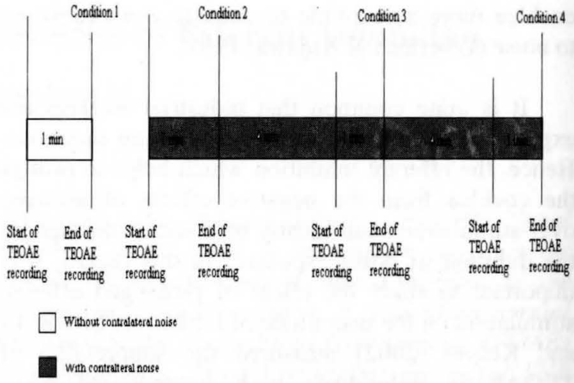

Figure 1. Schematic representation of the test procedure.

TEOAEs were recorded three times in the presence of contralateral noise, as shown in Figure 3.2, once, after exposure to noise for 1 minute (Condition 2), a second time after exposure to noise for 6 minutes (Condition 3), and a third time after exposure to noise for 11 minutes (Condition 4). In each condition, the overall signal to noise ratio as well as amplitude at each half-octave frequency was noted following averaging of 260 sweeps.

The SNR of TEOAEs in each of the four conditions was obtained from 80 subjects. Mean SNR of each age group for condition 2, 3 and 4 was compared with that of condition1. The comparison was also done across age groups. Suppression amplitude was calculated by subtracting the TEOAE amplitude obtained in condition 2, 3 and 4 from that of condition 1. The suppression amplitude thus obtained was compared across conditions and across different age groups, to verify the objectives of the study.

The data obtained from four age groups were analyzed using Statistical Package for the Social Sciences (version 10.0).

Results

Effect of age on signal to noise ratio of TEOAEs

Mean and standard deviation of SNR of TEOAE across frequencies in the four age groups are given in Table 1. The Table 1 shows the mean SNR of TEOAEs only in baseline condition. Comparison across frequencies showed that mean SNR of TEOAEs is lesser at 4 & 5 kHz compared to lower frequencies in all subject groups. Comparison across four age groups showed that mean TEOAE SNR was higher in Group 1 (adults of 20-30yrs) compared

Table 1. Mean and standard deviation of TEOAE SNR (dB SPL) across frequencies in the baseline condition in the four age groups

Frequency	Group 1	Group 2	Group 3	Group 4
	Mean SNR (SD) (dB SPL)	Mean SNR (SD) (dB SPL)	Mean SNR (SD) (dB SPL)	Mean SNR (SD) (dB SPL)
500 Hz	13.46 (4.84)	11.73 (5.04)	11.26 (4.78)	8.61 (6.01)
I K Hz	15.71 (4.43)	12.88 (5.07)	12.19 (6.38)	10.90 (5.40)
2 K Hz	12.31 (4.12)	8.53 (3.60)	7.95 (3.27)	7.75 (6.19)
4 K Hz	10.60 (5.49)	5.59 (2.74)	6.69 (6.36)	4.60 (5.14)
5 K Hz	5.85 (4.26)	2.12 (3.59)	2.65 (3.59)	2.65 (5.91)

Table 2. Results of one way ANOVA on baseline TEOAE SNR with age as independent variable

	SNR at 500 Hz	SNR at 1 KHz	SNR at 2 KHz	SNR at 3 KHz	SNR at 4 KHz	SNR at 5 KHz	Global SNR
df	(3, 76)	(3, 76)	(3, 76)	(3, 76)	(3, 76)	(3, 76)	(3, 76)
F	2.98	2.87	4.68	5.27	4.36	4.13	10.05
p	0.360	0.420	0.005	0.020	0.007	0.008	0.000

to other groups. In general, mean SNR decreased with increase in age. This was true in most frequencies.

One way ANOVA was done to verify whether observed differences in mean were statistically significant. Results (Table 2) showed that there was main effect of age on mean SNR. This was true for global SNR and SNR at 2K Hz and above. Bonferoni post hoc was done to evaluate pair wise comparisons. The results of the post hoc test are depicted in Table 3.

Effect of Contra lateral Noise (broad band noise) on SNR of TEOAE

The mean and standard deviation of TEOAE-SNR of base line condition and condition 2 is shown in Table 2. The Table also gives suppression amplitudes (Baseline SNR-SNR in condition 2) across frequencies in the four groups. Mean values showed that there was a decrease in the TEOAE-SNR in condition 2 compared to condition 1 (Baseline). Also, the mean suppression was more in group 1 & 2 compared to 3 & 4.

Paired t-test was done to evaluate whether these decrease in TEOAE-SNR from baseline to condition 2 was statistically significant. To do this, the data from all the four groups were combined. The results (Table 5) showed that suppression in TEOAE-SNR was significant at 0.01 probabilities in global measure as well as at all the frequencies except 5 kHz.

Effect of age on suppression amplitude

The significant decrease in TEOAE-SNR seen in the previous section could have been different in the four groups of individuals who differed in their age. Hence, it was necessary to verify whether there was a difference in the suppression amplitude across the four age groups. The mean suppression from condition 1 to condition 2 in the four age groups is shown in Table 4.

The data showed that the mean suppression was more in group 1 and 2 compared to group 3 and 4. One way ANOVA was done to evaluate whether these mean differences were statistically significant. The results (Table 6) indicated that there is no statistically significant difference in the suppression amplitude across the 4 groups of subjects differing in their age. This was true for global measure as well as SNR at different frequencies.

Effect of Condition on Suppression Amplitude

Evaluation of the effect of condition on suppression amplitude was the primary aim of this study. To do this, only global SNR of TEOAEs was taken into consideration. This is because; the data would have been enormous and confusing to the readers otherwise.

Table 3. Results of Bonferroni post hoc test pair-wise comparison of TEOAE-SNR across four groups

Measure	Group	1	2	3	4
Global	1				
	2				
	3				
	4				
At 2 kHz	1				
	2				
	3				
	4				
At 4 kHz	1				
	2				
	3				
	4				
At 5 kHz	1				
	2				
	3				
	4				

Table 4. Mean and standard deviation of SNR of TEOAE in baseline and condition 2 and suppression amplitude across frequencies in the four age groups

GROUPS	B 500 (M & SD)	B 1K (M & SD)	B 2K (M & SD)	B 4K (M & SD)	B 5K (M & SD)	B GL (M & SD)	C2 500 (M & SD)	C2 1K (M & SD)	C2 2K (M & SD)	C2 4K (M & SD)	C2 5K (M & SD)	C2 GL (M & SD)	SP 500 (M & SD)	SP 1K (M & SD)	SP 2K (M & SD)	SP 4K (M & SD)	SP 5K (M & SD)	SP GL (M & SD)
1	13.46 4.84	15.7 4.43	12.3 4.12	10.6 5.49	5.85 4.26	12.7 2.17	9.72 5.01	12.5 6.1	11.1 4.87	9.04 5.98	5.06 3.62	10.6 4.37	3.74 6.48	3.17 4.84	1.14 2.37	1.5 2.45	.79 2.84	2.10 3.65
2	11.73 5.04	12.8 5.07	8.53 3.60	5.59 2.74	2.12 3.59	8.86 2.85	7.01 4.76	9.49 4.78	7.6 4.6	5.15 3.16	2.41 3.04	6.47 2.85	4.72 3.2	3.39 4.35	.87 3.08	.44 2.02	-.29 2.98	2.38 1.78
3	11.26 4.78	12.1 6.38	7.95 3.27	6.69 6.36	2.65 3.59	8.29 4.34	8.12 5.40	9.12 5.6	5.26 5.78	4.21 6.9	1.07 4.06	6.29 3.95	3.14 5.74	3.07 7.42	2.69 5.49	2.47 4.66	.06 3.64	1.44 2.76
4	8.61 6.01	10.9 5.4	7.75 6.19	4.60 5.14	2.65 5.91	7.60 3.34	6.71 5.0	8.67 4.87	5.69 6.23	5.18 4.22	3.47 6.04	6.56 3.92	1.89 4.99	2.22 4.18	2.06 2.99	-.57 2.70	-.81 3.67	1.78 3.15

B -Baseline, C-Condition, SP-Suppression amplitude, GL-Global

Table 5. Results of paired t-test

TEOE-SNR	df	t	p
500 Hz	79	5.748	0.000
1 k Hz	79	5.027	0.000
2 k Hz	79	2.656	0.010
4 k Hz	79	1.615	0.010
5 k Hz	79	-0.174	0.862
Global	79	5.345	0.000

Table 6. Results of one way ANOVA with age as independent variable

SNR at	df	F	*p*
500 Hz	3, 76	1.013	0.392
1 kHz	3, 76	0.183	0.908
2 kHz	3, 76	1.127	0.344
4 kHz	3, 76	3.587	0.078
5 kHz	3, 76	0.831	0.481
Overall	3, 76	0.680	0.908

Also, it would not have provided any additional information in understanding the fatiguing characteristics of efferent fibers.

To do this, suppression amplitudes were calculated by independently subtracting the TEOAE-SNR in condition 2, 3 and 4 from that of condition 1 (baseline). The resulting three groups of suppression amplitude were analyzed for their mean and standard deviation and the results are as given in Table 7. Table 7 also gives the suppression amplitudes in 4 different age groups. The mean scores showed that the suppression varied from condition 2 to condition 4.

Repeated measure ANOVA was done to verify whether differences in mean suppression amplitude across the conditions are statistically significant. In this, group (which differed in age of the individuals) was taken as within subject variable. Results of ANOVA showed that there is no significant main effect [$F(3, 75) = 2.348$, $P > 0.05$] of condition on suppression amplitude. Also, age was not an interacting variable in this result [$F(3, 152) = 0.962$ $P > 0.05$].

Table 7. Mean and standard deviation of TEOAE suppression amplitude across different conditions in the four groups

Group	SP Amp 1 (C1-C2)	SP Amp 2 (C1.-C3)	SP Amp 3 (C1-C4)
Group 1	2.10 (3.65)	2.75 (4.09)	3.06 (4.06)
Group 2	2.38 (1.78)	1.99 (4.10)	1.04 (2.58)
Group 3	1.44 (2.76)	1.21 (3.20)	1.93 (3.12)
Group 4	1.78 (3.15)	1.93 (3.12)	1.41 (2.58)

SP-Suppression, C-Condition

Discussion

Effect of age on TEOAE baseline SNR across frequencies: This study clearly demonstrated decrease in the SNR of TEOAE as a function of age. Highest TEOAE SNR was observed in group 1 (20-30 yrs) and the mean SNR for this group is 15.08 and lowest is for group 4 (50-60 yrs) i.e. 9.95. This is similar to the previous findings (Bonfils, Bertrand, & Uziel, 1988, Collet, Kemp, Veuillet, Duclaux, Moulin, 1990 & Martin, 1991). On the contrary, there are studies which reported that the effect of age on cochlea or OAE SNR was unclear (Stover & Norton, 1993). TEOAE SNR across frequencies shows that there is decrease in the amplitude TEOAE at high frequencies especially at 5 kHz region in all age groups. This supports the degeneration of sensory cells with aging, particularly the outer hair cells.

Effect of Contralateral Noise on SNR of TEOAEs: Results showed that there is a reduction in the SNR of TEOAE in the presence of contralateral noise. This may be because of the activity of medial olivo cochlear neurons as reported by earlier studies (Galambos, 1956; Warren & Liberman, 1989). Activation of medial efferent neurons results in the release of Acetylcholine at the synapse which in turn, induces alterations in the shape and/or compliance of outer hair cells. These alterations can damp micromechanical activity, reduce the sensitivity of basilar membrane (Geisler, 1991; Kim, 1986), and thus reduce the amplitude of TEOAEs. The mean amplitude of suppression found in the present study after 1 minute of contralateral noise presentation is similar to that reported by Hood et al, (1996).

The participation of the efferent nerve fibers in the suppression of TEOAEs is further supported by frequency distribution of suppression. Figure 2 shows that there was a significant suppression at 500 Hz, 1k Hz, 2k Hz and 4k Hz. This supports the assumption that suppression is influenced mainly by the activation of uncrossed medial efferent neurons. As these fibers innervate outer hair cells to a greater extent at the center of the cochlea (Guinan, Warr, & Norris, 1983), the degree of suppression was highest between 500 Hz and 2 kHz.

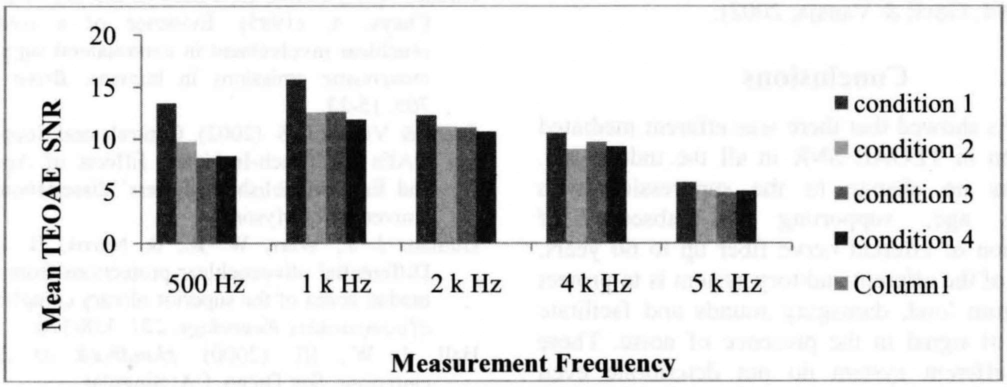

Figure 2. Mean TEOAE amplitude recorded at five different frequencies in four conditions of TEOAE recording in group 1 individuals.

Effect of prolonged contralateral stimulation on efferent inhibition: In the present study suppression was observed even after 11 minutes of contralateral acoustic stimulation. This is in agreement with Sandeep and Jayaram, (2008) who used the same protocol. Also, in the present results, suppression was constant in its magnitude from beginning till 11 minutes.

This sustained contralateral suppression suggests that the neuron of MOC bundle is capable of a sustained inhibitory effect on OHCs for a prolonged duration (up to at least 11 min) in humans. Suppressive effect to prolonged acoustic stimulation may suggest that the MOC is capable of a sustained role in hearing protection against acoustic overstimulation and can help in detection of signals in noise. However, this finding is in contradiction with that of Sandeep and Jayaram (2008) who reported reduction in suppression amplitude after 6 minutes.

Effect of age on efferent inhibition over prolonged stimulation: The present results also showed that age was not an interacting variable while seeing the effects of prolonged stimulation on efferent inhibition. This means that the sustained efferent inhibition is not influenced by age of individuals. This result is in consonance with the earlier studies (Strouse, Ochs, Hall, 1996; Dorn, Piskorski, Keefe, Neely 1998; Parthasarathy, 2001).

This shows that the efferent fibers do not get degenerated with advancing age. Also the degeneration of sensory cells and the afferent auditory neurons degeneration do not influence efferent inhibition. Hence, one can infer that the reduced speech perception in noise with advancing age is not because of reduced efferent inhibition. There could be other issues related to afferent auditory system that could be accounted for reduced speech perception in noise in elderly individuals. However, the finding is in contradiction with some of the earlier studies (Castor, Veuillet, Morgon & Collet, 1994; Govil & Vanaja, 2002).

Conclusions

Results showed that there was efferent mediated suppression in TEOAE SNR in all the individuals. There was no change in the suppression with increasing age, supporting the absence of degeneration of efferent nerve fiber up to 60 years. The roles of the efferent auditory system is to protect cochlea from loud, damaging sounds and facilitate detection of signal in the presence of noise. These roles of efferent system do not deteriorate even during prolonged stimulation.

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