OTOLARYNGOLOGY

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-131

Research

*Corresponding author
Himanshu Kumar Sanju
Research Officer
Department of Audiology
All India Institute of Speech and Hearing, Mysuru-6, Karnataka, India
Tel. +91-740-609-3279
E-mail: himanshusanjuaiish@gmail.com

Volume 2 : Issue 5
Article Ref. #: 1000OTLOJ2131

Article History
Received: September 12th, 2016
Accepted: October 19th, 2016
Published: October 21st, 2016

Citation
Sanju HK, Mishra R, Kumar P. Temporal modulation transfer function (TMTF) in individuals with diabetes mellitus type 2. *Otolaryngol Open J*. 2016; 2(5): 150-155. doi: 10.17140/OTLOJ-2-131

Temporal Modulation Transfer Function (TMTF) in Individuals With Diabetes Mellitus Type 2

Himanshu Kumar Sanju[1*]; Rajkishor Mishra[2]; Prawin Kumar, PhD[1]

[1]*Department of Audiology, All India Institute of Speech and Hearing, Mysuru-6, Karnataka, India*
[2]*Consultant Audiologist, Bloom Senso Hearing Centre, Kolkata, West Bengal, India*

ABSTRACT

Introduction: Diabetes mellitus is a collection of metabolic disorders characterized by elevated blood sugar and abnormalities in insulin secretion and action. Previous studies have shown the link between hearing impairment and diabetes. But, there is a lack of literature on patients with diabetes mellitus type 2 for auditory temporal resolution skills.
Aim and Objective: The aim of the current research is to assess auditory temporal resolution skills using Temporal Modulation Transfer Function (TMTF) in persons with diabetes mellitus type 2 (elevated blood sugar level) having high frequency hearing loss.
Methods: Fifteen individuals between the age of 30 to 40 years having diabetes mellitus type 2 with high frequency hearing loss recruited for the study as a clinical group. Fifteen age matched normal hearing subjects with no diabetes were taken as control group. To assess the temporal resolution ability, TMTF tests were administered. Research design used in this study was between group design.
Result: The 2 groups were compared using independent *t*-test. It showed that in TMTF task the diabetic group with high frequency hearing loss (clinical) performed significantly poorer when compared to non-diabetic group having normal hearing (control).
Overall Conclusion: It can be concluded that the reasons for having poorer performance in temporal resolution task in subjects with diabetes mellitus type 2 may be the changes in the central auditory nervous system and widening of auditory filter. The finding of the current study revealed that the processing at the level of central auditory system there is a deterioration due to impact of diabetes mellitus type 2.

KEYWORDS: Auditory temporal resolution; Auditory processing disorder; Diabetes complication.

ABBREVIATIONS: TMTF: Temporal Modulation Transfer Function; GDT: Gap Detection Threshold.

INTRODUCTION

Diabetes mellitus is a carbohydrate metabolism disorder which happens due to relative or absolute deficiency in insulin, including metabolic disturbance and various pathological changes in our body. It is characterized by increased sugar level in the blood, abnormalities in insulin action and secretion. Because of these abnormalities there is an alteration in carbohydrate, protein and fat metabolism. These nutrients acts as structural components and nourishes the cell. When these nutrients remain in the bloodstream, eventually damages micro and macrovascular system. Previous researchers have reported that in individuals with diabetes mellitus, a progressive sensory neural hearing loss bilaterally with gradual onset in which high frequencies are mainly affected as it is seen in presbycusis.[1] It was also observed that there can be sudden and unilateral hearing loss with and without vestibular disorder. Researchers

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-131

have shown that the vasculature of endolymphatic sac has a significant role in pathogenesis of sensorineural hearing loss.[2,3] The vascular insufficiency of cochlea in diabetic patient is the main reason for hearing loss. Uncontrolled diabetes may be caused due to vasculopathy in stria vascularis of the cochlea. Previous studies have showed that, in the vascular endothelium there is a diffused thickening of basilar membrane which is known as microangiopathy.[4,5] Literatures have also shown that microangiopathy is the main cause for hearing loss in subjects with diabetes mellitus[6,7] and involvement of minute vessels in the inner ear causes hypoxia which in turn leads to hearing loss.[7,8] Maia et al[9] concluded that high frequency hearing loss can be caused by diabetic neuropathy and microangiopathy. It was also found that in diabetic patients hearing loss was present at frequencies from 250 Hz to 8000 Hz.[8] Studies have shown mild to moderate high frequency hearing loss and higher thresholds at all the frequencies in individuals with diabetes mellitus.[9,10] Studies have observed no changes in speech discrimination outcome among normal population and subjects with diabetes mellitus.[11] Previous study by Bajaj et al[12] in 2014 showed that in diabetic patients there is poor perception of speech in noise. Researchers have also reported that, individuals with high frequency hearing loss have poor speech perception in noise.[13,14] In patients with hearing loss at higher frequencies, there is loss of audibility and poor frequency selectivity because of which there is a poor auditory processing at a given signal and poor perception of speech in noise.[15] Various researchers have investigated the effect of cochlear lesion on frequency and intensity coding.[16,17] Earlier studies have been done to check hearing and speech perception ability in diabetes mellitus individuals but there is a shortage of studies on evaluating their temporal resolution skill with high frequency hearing loss. Temporal resolution is the capability of the human hearing and listening system to track fast changes in the envelop of a stimulus over a period of time.[18] The Temporal Modulation Transfer Function (TMTF) is a worthy test and cost effective measure to investigate auditory temporal resolution skill. TMTF is psychophysical method which is defined as the depth of modulation required to just allow discrimination between a modulated and an unmodulated waveform. The identfication of amplitude modulation (fluctuations) over time is a measure of temporal acuity i.e. temporal resolution ability. The modulation of the signal depends on the modulation rate or frequency (number of modulations per second). Whereas, modulation depth gives information about the amplitude modulation. This gives the information on listening sensitivity of a person to detect the amplitude modulation. Modulation depth can be expressed in terms of decibels or percent i.e., 0 dB corresponds to 100%. The Gap Detection Threshold (GDT) is another test for temporal resolution. GDT is the ability of an individual to detect the shortest duration of gap in the given signal.[19] Previous researchers have used GDT to study cortical lesion.[20] Musiek et al[21] showed that GDT is an important measure in the evaluation of temporal resolution deficit in cortical as well as brainstem lesions. Therefore, current study is aimed at comparing auditory temporal resolution skill in subjects with diabetes mellitus with high frequency hearing loss and age matched normal hearing subjects. The foremost objective of the current study is to investigate TMTF in individuals with diabetes with high frequency hearing loss (experimental group) and age matched normal hearing individual (control group).

MATERIALS AND METHODS

Participants

Totally there were 30 participants participated in this study. Prior to the test administration all the participants were informed orally and written consent was taken. The participants were divided into 2 groups (experimental and control). There were 15 participants (10 males and 5 females) with diabetic mellitus in the experimental group with the age range of 30 to 40 years (mean age of 36.2 years). Research design used in this study was between group design. All the subjects of experimental group were having diabetic mellitus type 2 for minimum of 5 years (mean duration of 6.92 years). The subjects those who had a complaint of hearing loss after diabetes mellitus type 2 were taken as an experimental group. The subjects in experimental group were having decreased hearing sensitivity (mild to moderate degree) in both ears and the pure tone thresholds were higher than 15 dBHL at 2 kHz, 4 kHz and 8 kHz with normal hearing sensitivity at 250 Hz, 500 Hz and 1000 Hz. Normal middle ear functioning was indicated by 'A' type of tympanogram with no of acoustic reflexes at 2000 Hz and 4000 Hz for both the stimulation (ipsilateral and contralateral).

The diagnosis of diabetes mellitus was confirmed by a physician based on the blood glucose measurements including average blood sugar level over the previous three months (HbA1C testing), along with fasting plasma glucose and oral glucose tolerance test of all subjects as shown in Table 1.

Whereas control group consists age matched 15 non-diabetic individuals (10 males and 5 females) in the age range of 30 to 40 years (mean age of 35.3 years). The reason for taking participants in the age range of 30 to 40 years was to avoid the effect of age related hearing loss on outcomes. Control group consists the subjects with normal hearing sensitivity at all octaves in both air conduction (250 to 8000 Hz) and bone conduc-

	HbA1C (%)	Fasting Plasma Glucose (mg/dL)	Oral Glucose Tolerance (mg/dL)
Diabetes Mellitus Type 2	7.3	156.4	219.7
Non-Diabetic	4.2	80.2	103.7

*HbA1C-Hemoglobin A1c

Table 1: Average blood sugar level over the previous three months (HbA1C testing), fasting plasma glucose and oral glucose tolerance test of all subjects.

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-131

tion (250 to 4000 Hz) mode. All the participants in this group should must have normal middle ear functioning with A type tympanogram with presence of acoustic reflex at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Both the groups exhibited absence of other otological, neurological and neuromuscular symptoms. The data collection was done at All India Institute of Speech and Hearing, Mysuru, Karnataka within a period of 6 months. All procedures performed in studies involving human participants were in accordance with the ethical standards of the All India Institute of Speech and Hearing ethical committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Environment

All the psychophysical tests were carried out in a sound treated room, as per the standards of ANSI S3.1 (1991).

INSTRUMENTATION

Pure tone audiometry was done using a calibrated double channel clinical audiometer (Madsen MA-53). Calibrated GSI-TympStar Immittance meter was used for tympanometry and reflexometry. A personal laptop with Matlab software was used for TMTF.

Procedure

Pure tone thresholds air conduction (250 Hz to 8000 Hz) and bone conduction (250 Hz to 4000 Hz) were obtained using modified Hughson and Westlake procedure given by Carhart and Jerger in 1959.[22] Using a calibrated middle ear analyzer (GSI-Tympstar), tympanometry at 226 Hz probe frequency and acoustic reflexes thresholds (ipsilateral and contralateral) at 500 Hz to 4000 Hz were obtained.

In TMTF, 2 types of stimuli were used in the study i.e. sinusoidal amplitude modulated and unmodulated white noise bursts of 500 ms duration with 20 ms ramp. Stimuli were prepared using a 32 bit digital to analog converter having a sampling frequency of 44.1 KHz and cut off frequency of 220 Hz. The stimuli were then filtered using low pass filter. Variation in the amplitude of modulating sine wave was used to control the depth of modulation. The range of modulation depth was varied from 0 to -30 dB (-30 dB represent 0% modulation and 0 dB represent 100% modulation) with different modulation frequencies (4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz, and 128 Hz). Test stimuli were presented through a calibrated headphone routed from double channel audiometer which was connected with personal laptop having Matlab 2011 software. The stimuli was presented at 40 dBSL (comfortable level) for all participants. The subject task was to identify the modulated stimuli from a group of 3 stimuli which includes 2 unmodulated and one modulated noise bursts. Three interval forced choice method was used. In each trial, unmodulated and modulated stimuli were presented with an interstimulus interval of 500 ms. Feedback was given after every correct or wrong response on the computer screen. Modulation depth was changed into decibels 20 log 10(m), where 'm' refers to modulation depth. Initially 4 db step size was used and later it was decreased to 2 db steps after first two reversals. This method gives an estimate value of amplitude modulation necessary for 70.7% estimate of correct responses. The mean of eight reversals in a block of 14 was taken as threshold.

STATISTICAL ANALYSIS

Descriptive statistics was done to find mean and standard deviation for TMTF for both the groups. The 2 groups (experimental and control) were compared using independent *t*-test for TMTF.

RESULTS

In the present study, all the participants underwent Temporal Modulation Transfer Function test. The data was analyzed using SPSS software (Version 18).

Temporal Modulation Transfer Function (TMTF) Test

TMTF test was done for both the groups. Mean and standard deviation (SD) of TMTF threshold is shown in Table 2. Descriptive statistical analysis revealed that TMTF threshold was better (lower) for group-2 when compared to groups-1. Figure 1 represent graphical presentation of the outcome.

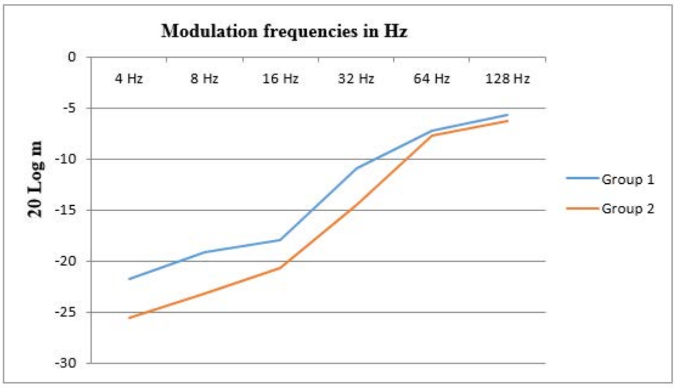

Figure 1: Graphical representation of mean values of temporal modulation transfer function (TMTF) for group 1 (Experimental) and groups 2 (Control).

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-131

Modulation frequencies	Groups			
	Group 1 (Experimental)		Group 2 (Control)	
	Mean	SD	Mean	SD
4 Hz	-21.81	1.23	-25.54	1.33
8 Hz	-19.15	1.03	-23.14	1.59
16 Hz	-17.96	1.18	-20.66	1.34
32 Hz	-10.97	1.04	-14.42	1.04
64 Hz	-7.01	0.45	-7.54	0.95
128 Hz	-6.02	0.51	-6.65	0.38

Table 2: Mean and SD of temporal modulation transfer function (TMTF) for group 1 (Experimental) and group 2 (Control).

To compare TMTF thresholds between these 2 groups independent *t*-test was administered. The statistical analysis revealed significant difference between the 2 groups (t=-7.82; df=28; $p<0.05$).

TMTF was assessed for 6 different modulation frequencies (4 Hz, 8Hz, 16 Hz, 32 Hz, 64 Hz, and 128 Hz), for both the groups i.e. experimental and control. Table 2 showed the descriptive statistics (mean & SD) of the TMTF for all the six modulation frequencies across the two groups. The same are graphically depicted in Figure 1. It was observed from the graph that the experimental group performed poorer in TMTF task compared to control group. Both the groups modulation detection thresholds were worsened as the modulation frequency increased.

Independent *t*-test was administered to compare the parameters across two groups. It revealed statistically significant difference for 4 Hz (t=-4.70; df=28; $p<0.05$), 8 Hz (t=-3.55; df=28; $p<0.05$), 16 Hz (t=-4.59; df=28; $p<0.05$), 32 Hz (t= -3.63; df=28; $p<0.05$), 64 Hz ((t=-7.15; df=28; $p<0.05$) and 128 Hz(t=-5.22; df=28; $p<0.05$).

The results showed that there is statistically significant difference between the scores of the 2 group at all modulation frequencies i.e.4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz and 128 Hz. Group-1 (experimental) showed poorer performance compare group-2 (control) at 5% level of significance.

DISCUSSION

The result of the current study showed poor auditory temporal resolution ability in individuals with diabetes mellitus type 2 having high frequency hearing loss when compared to their age-matched non-diabetic subjects having normal hearing. The results of sent TMTF threshold across the 2 groups showed statistically significant difference for the modulation frequencies like 4 Hz, 8Hz, 16 Hz, 32 Hz, 64 Hz and 128 Hz. However, present study showed an increased magnitude of deterioration in temporal resolution as modulation frequency increased. In the present study, it was also observed that as the modulation frequencies increase it requires more modulation depth to complete the task in both Group-1 and Group-2. But overall threshold on the TMTF was elevated for the diabetic individual with high frequencies sensorineural hearing loss compared to age matched non-diabetic subjects having normal hearing. Elevated threshold on TMTF at higher modulation frequencies could be because the task is more challenging at high frequencies and as band pass filter at high frequencies region uses requires more depth in the signal spectrum to detect.

Current study showed that, in temporal resolution task the patients with diabetes mellitus performed poor which revealed certain degeneration in the central auditory processing system. Earlier literature on rats and diabetic patients showed hearing disorder mainly because of edema in stria vascularis, decrease in number of outer hair cells and spiral ganglion.[23-25] Increased thresholds at high frequencies revealed that the cochlear regions may have been damaged due to angiopathy in the stria vascularis and spiral ligament, edema of stria vascularis which in turn leads to reduced intensity and frequency coding.[16,26,27] A study on auditory brainstem response in individuals with diabetes revealed poor response with prolonged latencies of wave III, V and also prolonged latencies of inter-peak III-V, I-III and I-V at 90 dB presentation level[28] which showed that there is a participation of the relay station of different order neuron in the central auditory nervous system. The current study results are in support with the study done by McCrimmon et al[29] in 1997 in which they have also found poor temporal resolution skill in diabetes mellitus patients. Sommerfield in 2003 also revealed significantly poor results in the tests of immediate visual and verbal memory at the time of hypoglycemia.[30] The impact of hypoglycemia was found to be more profound on working and delayed memory. Present study also supported by Strachan et al[31] 2003 reported adverse effects of acute hypoglycaemia on sensory information processing in adults with diabetes. McAulay in 2006 investigated attention functioning in individuals with diabetes mellitus type 1. The result showed hypoglycemia caused a significant damage in tests sensitive to visual and auditory selective attention.[32] An experiment done by Gold et al[33] reported significant reduction in cognitive function in individuals with hypoglycemia. It was also observed that hypoglycemic seizures had reduce in scores on tests assessing memory skills including short term memory and memory for words.[33] The finding of current study revealed poor temporal resolution ability in individuals with diabetes mellitus may due to broadening of auditory filter and changes in the central auditory nervous system. Sanju and Kumar[34] also suggested annual audiological evaluation in indi-

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-131

vidual with diabetes mellitus. Recently, Mishra et al[35] in 2015 also reported poor temporal resolution skill in individual with diabetes mellitus. Less number of participants is the limitation of the present study. Lack of a group of diabetes mellitus without hearing loss is another limitation of the current study. In future, researchers can compare temporal resolution ability in individuals with diabetes mellitus with and without hearing loss.

CONCLUSION

Current study outcome revealed poor temporal resolution ability in subjects with diabetes mellitus type 2. Because of poor temporal resolution skill, there may be poor speech perception in quiet as well as noise in these individuals. It is not the work of an audiologist or otolaryngologist to diagnose and treat diabetes. But, audiologist and otolaryngologist should give time to take detail case history of diabetic patient and medication they are taking. Annual evaluation by other professionals like podiatrist, cardiologist, ophthalmologist and others are considered to be a standard care for individuals with diabetes mellitus. To add on to this list an audio logical evaluation should be done annually. The findings of the current study reveal that there is an adverse effect of diabetes mellitus type 2 on the central auditory processing, especially on temporal processing. So, it can be recommended to screen all the individuals with diabetes mellitus for temporal resolution test to understand the underlying mechanism of speech perception in noise. In future further research should be conducted by researchers to study the effect of other central auditory processing abilities on diabetes mellitus as auditory discrimination in background noise, speech perception in noise, binaural integration, binaural separation, auditory attention and memory.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCE

1. Jorgensen MB, Buch NH. Studies on the sense of smell and taste in diabetics. *Acta Otolaryngol*. 1961; 53(2): 539-545. doi: 10.3109/00016486109126521

2. Leone CA, Feghali JG, Linthicum FH. Endolymphatic sac: Possible role in autoimmune sensorineural hearing loss. *Ann Otol Rhinol Laryngol*. 1984; 93(5): 208-209. doi: 10.1177/000348948409300303

3. Gussen R. Vascular mechanisms in Meniere's disease. Theoretical considerations. *Arch Otolaryngol*. 1982; 108(9): 544-549. doi: 10.1001/archotol.1982.00790570010003

4. Malpas S, Blake P, Bishop R, Robinson B, Johnson R. Does autonomic neuropathy in diabetes cause hearing deficits? *N Z Med J*. 1989; 102(874): 434-435.

5. Konrad-Martin D, Austin DF, Griest S, Mcmillan GP, Mcdermott D, Fausti S. Diabetes-related changes in auditory brainstem responses. *Laryngoscope*. 2010; 120(1): 150-158. doi: 10.1002/lary.20636

6. Makishima K, Tanaka K. Pathological changes of the inner ear and central auditory pathway in diabetics. *Ann Otol Rhinol Laryngol*. 1971; 80(2): 218-228.

7. Costa OA. Inner ear pathology in experimental diabetes. *Laryngoscope*. 1967; 77(1): 68-75. doi: 10.1288/00005537-196701000-00005

8. Wackym PA, Linthicum FH. Diabetes mellitus and hearing loss: Clinical and histopathologic relationships. *Am J Otol*. 1986; 7(3): 176-182.

9. Maia CA, Campos CA. Diabetes mellitus as etiological factor of hearing loss. *Braz J Otorhinolaryngol*. 2005; 71(2): 208-214.

10. Celik O, Yalçin S, Celebi H, Oztürk A. Hearing loss in insulin-dependent diabetes mellitus. *Auris Nasus Larynx*. 1996; 23(8): 127-132. doi: 10.1016/S0385-8146(96)80019-8

11. Cullen JR, Cinnamond MJ. Hearing loss in diabetics. *J Laryngol Otol*. 1993; 107(3): 179-182. doi: 10.1017/S0022215100122571

12. Bajaj G, Puthuchery S, Bhat J, Ranjan R. Effect of type 2 diabetes on speech perception in noise. *Int Journ Innov Res Dev*. 2014; 3(4): 50-54.

13. Dubno JR, Dirks DD, Morgan DE. Effects of age and mild hearing loss on speech recognition in noise. *J Acoust Soc Am*. 1984; 76(1): 87-96. doi: 10.1121/1.391011

14. Stuart A, Phillips DP. Word recognition in continuous and interrupted broadband noise by young normal-hearing, older normal-hearing, and presbyacusic listeners. *Ear Hear.* 1996; 17(6): 478-489. doi: 10.1097/00003446-199612000-00004

15. Moore BC. Perceptual consequences of cochlear hearing loss and their implications for the design of hearing aids. *Ear Hear.* 1996; 17(2): 133-161. Web site. https://www.ncbi.nlm.nih.gov/pubmed/8698160. Accessed September 11, 2016.

16. Florentine M, Reed CM, Rabinowitz WM, Braida LD, Durlach NI, Buus S. Intensity perception. XIV. Intensity discrimination in listeners with sensorineural hearing loss. *J Acoust Soc Am*. 1993; 94(5): 2575-2586. doi: 10.1121/1.407369

17. Simon HJ, Yund EW. Frequency discrimination in listeners with sensorineural hearing loss. *Ear Hear.* 1993; 14(3): 190-201. Web site. http://journals.lww.com/ear-hearing/Abstract/1993/06000/Frequency_Discrimination_in_Listeners_with.6.aspx. Accessed September 11, 2016.

18. Plack CJ, Viemeister NF. Suppression and the dynamic range of hearing. *J Acoust Soc Am.* 1993; 93(2): 976-982. doi: 10.1121/1.405403

19. Lister J, Besing J, Koehnke J. Effects of age and frequency disparity on gap discrimination. *J Acoust Soc Am*. 2002; 111(6): 2793-2800. doi: 10.1121/1.1476685

20. Efron R, Yund EW, Nichols D, Crandall PH. An ear asymmetry for gap detection following anterior temporal lobectomy. *Neuropsychologia*. 1985; 23(1): 43-50. Web site. http://www.ebire.org/hcnlab/papers/1985aEfron.pdf. Accessed September 11, 2016.

21. Musiek FE, Shinn JB, Jirsa R, Bamiou DE, Baran JA, Zaida E. GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear Hear.* 2005; 26(6): 608-618. Web site. http://journals.lww.com/ear-hearing/Abstract/2005/12000/GIN__Gaps_In_Noise__Test_Performance_in_Subjects.7.aspx. Accessed September 11, 2016.

22. Carhart R, Jerger J. Preferred method for clinical determination of pure-tone thresholds. *J Speech Hearing Disord.* 1959; 24(4): 330-335. doi: 10.1044/jshd.2404.330

23. Raynor EM, Carrasco VN, Prazma J, Pillsbury HC. An assessment of cochlear hair-cell loss in insulin-dependent diabetes mellitus diabetic and noise-exposed rats. *Arch Otolaryngol Head Neck Surg.* 1995; 121(4): 452-456.

24. Fukushima H, Cureoglu S, Schachern PA, et al. Cochlear changes in patients with type 1 diabetes mellitus. *Otolaryngol Head Neck Surg*. 2005; 133(1): 100-106.

25. Lee HS, Kim KR, Chung WH, Cho YS, Hong SH. Early sensorineural hearing loss in ob/ob mouse, an animal model of type 2 diabetes. *Clin Exp Otorhinolaryngol.* 2008; 1(4): 211-216. doi: 10.3342/ceo.2008.1.4.211

26. Nelson DA, Freyman RL. Psychometric functions for frequency discrimination from listeners with sensorineural hearing loss. *J Acoust Soc Am*. 1986; 79(3): 799-805. doi: 10.1121/1.393470

27. Schroder AC, Viemeister NF, Nelson DA. Intensity discrimination in normal-hearing and hearing-impaired listeners. *J Acoust Soc Am.* 1994; 96(5): 2683-2693.

28. Gupta R, Aslam M, Hasan S, Siddiqi S. Type-2 diabetes mellitus and auditory brainstem responses-a hospital based study. *Indian J Endocrinol Metab*. 2010; 14(1): 9-11. Web site. http://www.ijem.in/article.asp?issn=2230-8210;year=2010;volume=14;issue=1;spage=9;epage=11;aulast=Gupta. Accessed September 11, 2016.

29. Mccrimmon RJ, Deary IJ, Frier BM. Auditory information processing during acute insulin-induced hypoglycaemia in non-diabetic human subjects. *Neuropsychologia*. 1997; 35(12): 1547-1553.

30. Sommerfield AJ, Ewing FM, Strachan MW, Deary IJ, Aitken G, Frier BM. Self-treatment of mild symptomatic hypoglycaemia by people with insulin-treated diabetes. *Diabet Med.* 2003; 20(8): 686-687. doi: 10.1046/j.1464-5491.2003.09281.x

31. Strachan MW, Ewing FM, Frier BM, Mccrimmon RJ, Deary IJ. Effects of acute hypoglycaemia on auditory information processing in adults with type I diabetes. *Diabetologia*. 2003; 46(1): 97-105. doi: 10.1007/s00125-002-0950-2

32. Kaufman FR, Epport K, Engilman R, Halvorson M. Neurocognitive functioning in children diagnosed with diabetes before age 10 years. *J Diabetes Complicat.* 1999; 13(1): 31-38. doi: 10.1016/S1056-8727(98)00029-4

33. Gold AE, Deary IJ, Macleod KM, Thomson KJ, Frier BM. Cognitive function during insulin-induced hypoglycemia in humans: Short-term cerebral adaptation does not occur. *Psychopharmacology (Berl).* 1995; 119(3): 325-333. doi: 10.1007/BF02246299

34. Sanju HK, Kumar P. Annual audiological evaluations should be mandatory for patients with diabetes. *Hearing Review*. 2016; 23(1): 14. Web site. http://www.hearingreview.com/2015/12/annual-audiological-evaluations-mandatory-patients-diabetes/. Accessed September 11, 2016.

35. Mishra R, Sanju HK, Kumar P. Auditory temporal resolution in individuals with diabetes mellitus type 2. *Int Arch Otorhinolaryngol.* 2016; 20(4): 327-330. doi: 10.1055/s-0035-1571207