Effect of repetition rate on speech evoked auditory brainstem response in younger and middle aged individuals

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Abstract

Speech evoked auditory brainstem responses depicts the neural encoding of speech at the level of brainstem. This study was designed to evaluate the neural encoding of speech at the brainstem in younger population and middle-aged population at three different repetition rates (6.9, 10.9 and 15.4). Speech evoked auditory brainstem response was recorded from 84 participants (young participants=42, middle aged participants=42) with normal hearing sensitivity. The latency of wave V and amplitude of the fundamental frequency, first formant frequency and second formant frequency was calculated. Results showed that the latency of wave V was prolonged for middle-aged individuals for all three-repetition rates compared to the younger participants. The results of the present study also revealed that there was no difference in encoding of fundamental frequency between middle aged and younger individuals at any of the repetition rates. However, increase in repetition rate did affect the encoding of the fundamental frequency in middle-aged individuals. The above results suggest a differential effect of repetition rate on wave V latency and encoding of fundamental frequency. Further, it was noticed that repetition rate did not affect the amplitude of first formant frequency or second formant frequency in middle aged participants compared to the younger participants.

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Key words: speech evoked auditory brainstem response, middle-aged individuals, Fast Fourier transform.

Contributions: AKN, study design, data collection, data analysis and manuscript preparation; KG, study design, data collection, data analysis and manuscript preparation; GM, data collection, data analysis; SKS, study design, data analysis, manuscript preparation.

Conflict of interests: the authors report no conflict of interests.

Acknowledgements: the authors would like to thank the Director of the Institute for granting the permission to carry out the study. The authors also thank all the participants who came to take part in the study. The authors also thank the reviewers of the paper for their suggestions on earlier version of this manuscript. The authors are also thankful to Prof. Nina Kraus and Erika Skoe for providing the brainstem toolbox for carrying out the FFT analysis.

Received for publication: 3 April 2014.
Revision received: 3 July 2014.
Accepted for publication: 23 July 2014.

Audiology Research 2014;4:106
doi:10.4081/audiores.2014.106

Introduction

Elderly individuals have been shown to have greater difficulty with speech understanding than young listeners.[1] This difficulty of understanding speech in elderly listeners has been attributed primarily to a high frequency sensorineural hearing loss. However, there are studies which demonstrate that in adverse listening conditions, older individuals with normal peripheral hearing sensitivity also have difficulty in understanding speech.[2-9] This may lead-to conclude that age-related changes occur beyond the peripheral auditory system *i.e.*, the central auditory nervous system, may play a role in this difficulty.[10-13]

One of the most important noticeable aspects in most of these studies is the age range of the subjects who participated in these studies. These studies have a group of subjects in the middle age range *i.e.* in the age range of 40-60 years.[2-6,8] There are some other research studies which also suggest that certain auditory abilities begin to decline in middle aged group. For example, Barr and Giambra[14] reported that middle-aged subjects perform poorly than younger listeners (but better than older individuals) on tasks such as perception of dichotically presented speech. Bergman[15] reported a significant decline in perception of interrupted speech in middle-aged individuals, whereas Vaughnan and Letowski[16] reported a significant decline in understanding of time-compressed speech in middle-aged individuals as compared to the young individuals.

Thus, it is clear that the middle aged individuals with normal hearing may also have a decline in understanding speech in adverse listening conditions, although this decline may be lesser as compared to the older individuals. As we understand that the difficulty in speech understanding in older individuals arises from the central auditory nervous system, the decline in speech understanding in middle-aged individuals also may arise from the central auditory nervous system itself. One form of central auditory processing that has been attributed to part of this difficulty in older individuals is the temporal processing.[17-23]

One way to assess the temporal processing elctrophysiologically is to study the stimulus complexity by examining the effects of stimulus rate on speech evoked auditory brainstem responses.[24,25] Recently, speech evoked auditory brainstem responses measures have been introduced as a means to study the brainstem encoding of speech sounds.[26-28] It has been established as a valid and reliable means to assess the integrity of the neural transmission of speech stimuli at the brainstem. After the introduction, speech auditory brainstem response (ABR) has brought an insight into the diagnosis of children with learning disability,[29-31, 27] developmental plasticity of human brainstem to speech sounds;[32] understanding tonal language processing skills,[33,34] studying temporal encoding of amplitude modulations [35] and understanding different aspects of brainstem processing.[36-37] It has also shown to be a means for evaluating training related improvements in children with learning disability.[38]

The aim of this study was to investigate the effect of stimulus repetition rate on encoding of speech sound at the brainstem in middle aged and younger individuals. We hypothesized that variation in presentation rate has a greater effect on the encoding of speech sound /da/ in middle aged individuals compared to the younger individuals. To test these hypotheses, speech ABR were recorded to speech stimulus /da/ at three presentation rates: 6.9, 10.9 and 15.4 Hz in young and middle aged adults. To the best of our knowledge this is the first report examining the speech evoked ABR at different repetition rates in middle aged individuals.

Materials and Methods

Participants

Forty-two young individuals in the age range of 18 to 30 years and 42 middle-aged individuals in the age range of 40 to 60 years participated in the study. The basis of selecting the group (40-60 years) as middle aged individuals is based on some previous studies where middle aged individuals were defined as individuals in the age range of 40-60 years or 45-60 years.[39-42] All the individuals had normal hearing sensitivity in both the ears as defined by air conduction and bone conduction thresholds of <15 dBHL. Participants had normal middle ear function as revealed by *A* type tympanogram and presence of ipsilateral and contralateral reflexes for both the ears. Additionally, participants did not have any history or presence of any other otological and neurological problem. All the participants had presence of click evoked ABR normally in both the ears. All the participants were tested in the right ear only.

Instrumentation

A calibrated two channel clinical audiometer GSI-61 with TDH-39 headphones housed in Mx-41/AR ear cushions with audio cups were used for pure tone audiometry with radio ear B-71 bone vibrator was used for measuring bone conduction threshold. A calibrated middle ear analyzer (GSI Tympstar) using 226 Hz probe tone was used for tympanometry and reflexometry. Auditory brainstem responses to both click and speech stimulus were recorded using Biologic Navigator Pro evoked potential system with Biologic insert receiver. Biologic Navigator Pro has a default program *BIOMARK* which was utilized to record speech ABR.

Speech stimulus utilized in the study

The stimulus is a 40 ms synthesized speech syllable produced using KLATT synthesizer,[43] developed first by Cunningham *et al.*[44] It has been extensively used in studies carried out at Northwestern University. The characteristic of the stimulus has been described in previous studies.[45,46] The stimulus waveform of /da/ stimulus is given in Figure 1.

Procedure

Pure-tone audiometry: Pure-tone audiometry was carried out using modified Hughson and Westlake procedure.[47] Air conduction thresholds were obtained from 250 Hz to 8000 Hz and bone conduction thresholds were obtained from 250 Hz to 4000 Hz.

Immittance: Tympanometry was done to rule out middle ear pathology using 226 Hz probe tone. Immitance was carried out by sweeping the pressure from +200 to -400 dapa. Reflexometry was carried out for both the ipsilateral as well as contralateral stimuli at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

ABR click stimulus: ABR to click was recorded from all the participants using click stimulus presented at 90 dB nHL in rarefaction polarity with 11.1 and 90.1 repetition rate. A non-inverting electrode was placed on vertex, an inverting electrode was placed on mastoid of the stimulus ear and a ground electrode was placed on the opposite ear mastoid. It was ensured that each electrode impedance was <5 k Ω and inter electrode impedance was within 2 k Ω. The click evoked ABR was recorded twice to ensure the replicability of the response. Responses were filtered from 100-3000 Hz and were analyzed in 12 ms time window. A total of 1500 stimuli were used to record click ABR. ABR to click stimulus was done only for selection of the participants. The absolute latency of wave I, III and V and also interpeak latency between I~III, III~V and I~V was considered to determine the normalcy of the click evoked ABR.

ABR to speech stimulus: An auditory brainstem response to speech stimulus was recorded using /da/ stimulus. The recording protocol of speech evoked ABR used in this study is almost similar to that used by Krizman *et al.*[46] The speech evoked ABR was acquired using a single channel recording, with band pass filter of 100-3000 Hz. The gain given was 100,000 and the notch filter was kept on to eliminate electrical artifacts. Responses were recorded by placing the non-inverting electrode on vertex, inverting electrode on the mastoid of the recording ear and ground electrode on lower forehead. The stimulus used was the syllable /da/ of 40 ms presented with alternating polarity. The intensity of the stimulus presentation was at 80 dB SPL and recorded at three repetition rates, 6.9/s, 10.9/s and 15.4/s. The speech ABR was averaged to 2000 stimuli.

Data analysis

Latency of wave V for speech evoked ABR was analysed for all the participants. Additionally, to know the encoding of the first formant frequency and higher harmonics, a Fast Fourier transform (FFT) of the waveform was done. FFT was analysed from 16 ms to 44 ms of the waveform. To do the FFT analysis, activity occurring in the frequency range of the response corresponding to the fundamental frequency of the speech stimulus (103-121 Hz), and first formant frequencies of the stimulus (220-720 Hz) and higher harmonics (721 Hz to 1200 Hz) was measured for all the subjects. This was done as per the guidelines given in earlier studies.[44,26,32] The raw amplitude value of the F0 or F1 frequency component of the response FFR were then noted. All FFT analysis was done using a custom-made programme using MATLAB software. Brainstem Toolbox developed at Northwestern University was also utilized along with MATLAB, to get the FFT information.

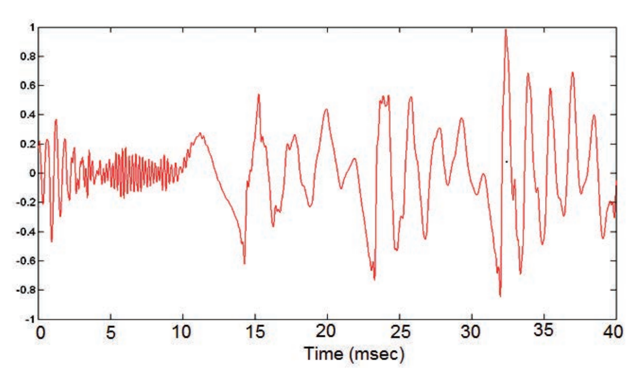

Figure 1. Stimulus waveform of/da/stimulus.

Results

Latency of wave V

Wave V to speech stimulus was present in all the participants in both the groups. The speech evoked ABR waveforms recorded from younger and the middle-aged participants for all the three repetition rates are shown below in Figure 2.

Descriptive statistics was done to calculate mean and standard deviation of latency of wave V for both younger and middle aged participants. The details of the mean and standard deviation of wave V latency are shown in Table 1. It can be seen from Table 2 that as the repetition rate is increasing the latency of wave V is also increasing for both the younger and the middle aged group. Also, when compared across the group, the latency of wave V for the middle-aged participants is more compared to the younger group for all the three repetition rates. The same can be seen in Figure 3.

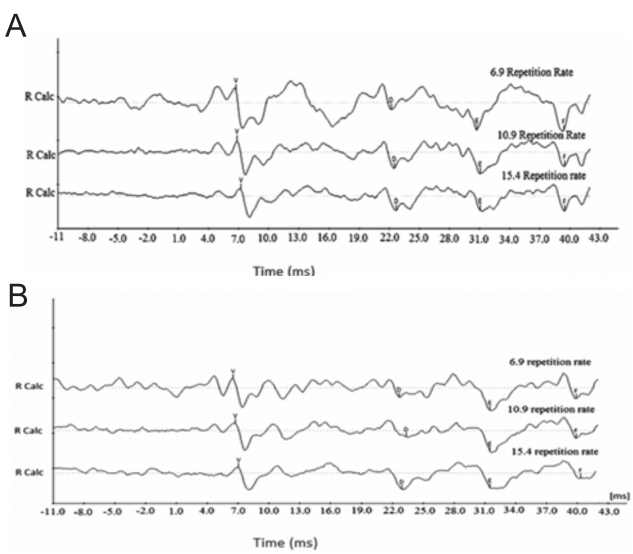

Figure 2. Speech evoked auditory brainstem response at three repetition rates in one of the participants in (A) younger adults and (B) middle aged individuals.

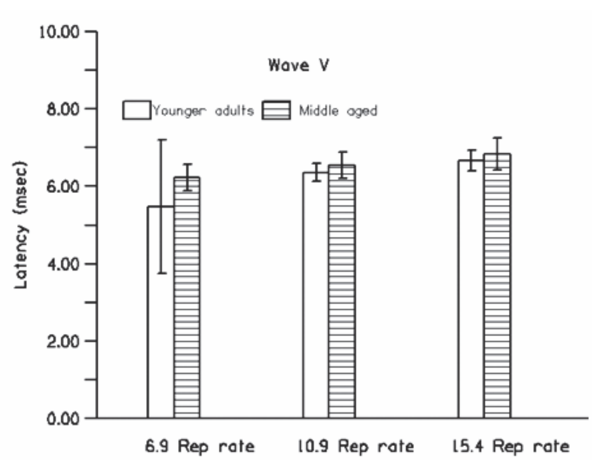

Figure 3. Mean latencies for the repetition rate 6.9, 10.9 and 15.4 in younger and middle-aged adults respectively.

Repeated measure ANOVA (2 groups X 3 repetition rates) was administered to see the significant main effect of age and repetition rate and also significant interaction across the variables on wave V latency. Repeated measure ANOVA showed significant main effect for the repetition rate [F (2,164)=634.03, P=0.00] and groups [F (1,82)=8.48, P=0.00]. But Repeated measure ANOVA failed to show any interaction between groups and repetition rate [F (2,164)=1.753, P=0.17].

To further understand the effect of repetition rate within each group, one-way ANOVA was done for each group separately. One way ANOVA showed a significant main effect for the repetition rate, for the middle aged group [F (2,123)=28.45, P<0.05], also for the younger group [F (2,123)=69.69, P<0.05]. Bonferroni pairwise comparison showed significant difference within each group for three repetition rates [P<0.05]. To understand the group differences for wave V latency at each repetition rate an independent sample *t* test was done. It showed a significant difference between the two groups for 6.9 repetition rate [t (82)=3.46, P<0.05], for 10.9 repetition rate [t (82)=2.74, P<0.05] and for 15.4 repetition rate [t (82)=2.23, P<0.05].

Amplitude of fundamental frequency

The amplitude of F0 varies with increase in the repetition rate in the younger as well as the middle-aged participants. Descriptive statistics was done to find out the mean and standard deviation (SD) for the amplitude of fundamental frequency for both groups separately, at all three repetition rates. The mean and SD of amplitude of fundamental frequency is given in Table 2.

From the above table, it can be seen that as the repetition rate increases, the amplitude of the fundamental frequency decreases for both groups. It is also observed that the amplitude reduction is more for the middle-aged group compared to the younger group. The same can be seen in Figure 4.

Repeated measure ANOVA with group as between subject factors was done to understand the main effect. It showed significant main effect for the repetition rate [F (2,164)=7.489, P=0.001], but no significant main effect for the groups could be observed [F (1,82)=2.734, P=0.127]. Also, no interaction between the groups and repetition rate was observed [F (2,164)=1.385, P=0.253].

Table 1. Mean and standard deviation of wave V latency in younger and middle-aged participants.

Groups	Repetition rate	Mean latency (ms)	SD
Younger	6.9	5.47	1.72
	10.9	6.36	0.24
	15.4	6.67	0.27
Middle aged	6.9	6.23	0.35
	10.9	6.54	0.34
	15.4	6.84	0.42

SD, standard deviation.

Table 2. Mean amplitude and standard deviation of F0 for younger and middle aged participants.

Groups	Repetition rate	Mean amplitude (V)	SD
Young	6.9	3.96	1.73
	10.9	3.42	1.38
	15.4	3.45	1.67
Middle aged	6.9	3.98	2.19
	10.9	3.16	1.78
	15.4	2.65	1.13

SD, standard deviation.

To see the effect of repetition rate within each group, one-way ANOVA was done for each group separately. It showed no significant main effect for the repetition rate, for the younger group [F (2,123)=1.360, P=0.261], but showed significant main effect for the middle aged group [F (2,123)=6.039, P=0.003]. Bonferroni pairwise comparison showed significant difference in middle-aged group between 6.9 and 15.4 repetition rates [P<0.05].

Amplitude of first formant frequency (F1)

Descriptive statistics was done to find out the mean amplitude and standard deviation of F1 for both the younger and middle aged group. The mean and the standard deviation for first formant amplitude for both the groups are shown in Table 3.

It can be seen from Table 3 that there is minimum variation in the amplitude of the first formant frequency with increase in repetition rate for both the groups. The same can be seen in Figure 5.

To understand the significant differences between the different variables for both the groups, repeated measure ANOVA was done. Repeated measure ANOVA test failed to show any significant main effect for the repetition rate [2,164=0.377, P>0.05], for the groups [1,82=2.07, P>0.05] and any interaction between the repetition rate and groups [2,164=0.748, P>0.05]. Since none of the variable showed any main effect or interaction effect, further statistics was not done.

Amplitude of higher harmonics (F2)

Higher harmonics (721 Hz to 1200 Hz) was measured for all the participants. For the ease of reading the higher harmonics has been written as F2 throughout the text. Descriptive statistics was done to find the mean amplitude and standard deviation of F2. The details of the mean and standard deviation of amplitude are given in Table 4.

It can be seen from table that the repetition rate has minimum effect on the amplitude of second formant in both the groups. The same can be seen in Figure 6.

Repeated measure ANOVA with group as between subject factors was done to understand the main effect. Repeated measure ANOVA

Table 3. Mean and standard deviation of first formant of 6.9, 10.9 and 15.4 repetition rate in younger and middle aged participants.

Groups	Repetition rate	Mean amplitude (μV)	SD
Young	6.9	0.58	0.17
	10.9	0.54	0.18
	15.4	0.52	0.24
Middle aged	6.9	0.50	0.22
	10.9	0.51	0.16
	15.4	0.49	0.14

SD, standard deviation.

Table 4. Mean amplitude and standard deviation of second formant for 6.9, 10.9 and 15.4 repetition rate for younger and middle aged participants.

Groups	Repetition rate	Mean amplitude (μV)	SD
Young	6.9	0.32	0.11
	10.9	0.28	0.08
	15.4	0.27	0.13
Middle aged	6.9	0.28	0.11
	10.9	0.23	0.07
	15.4	0.23	0.08

SD, standard deviation.

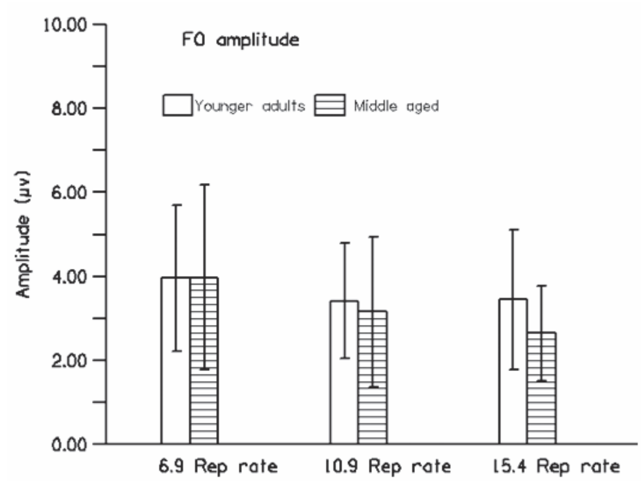

Figure 4. Fundamental frequency amplitude for younger and middle aged participants for 3-repetition rate.

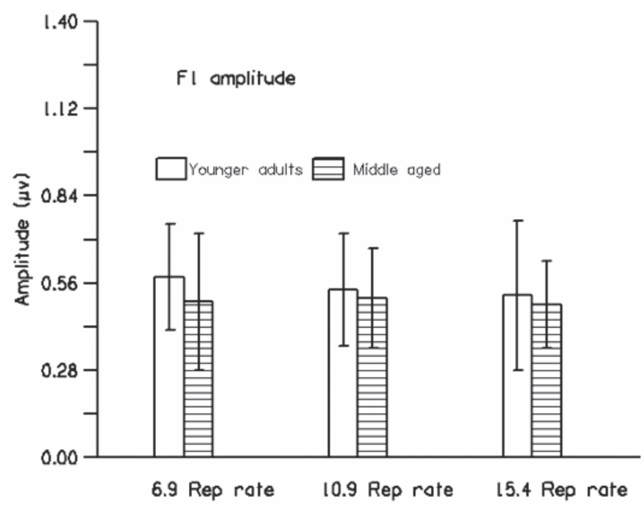

Figure 5. Mean amplitude of F1 for 6.9, 10.9 and 15.4 repetition rate for younger and middle aged participants.

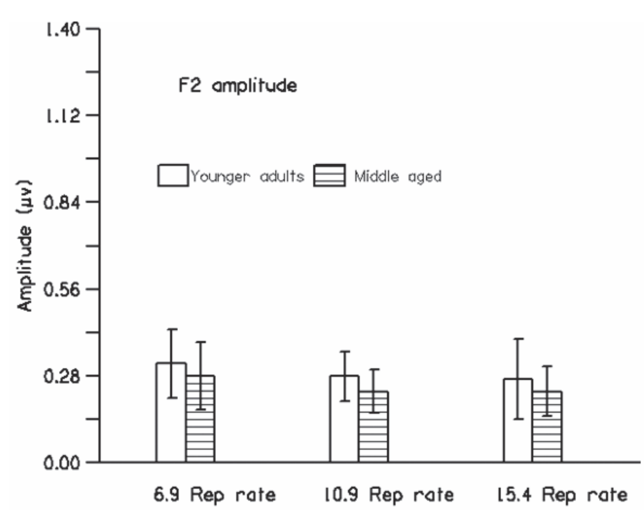

Figure 6. Mean amplitude of F2 for 6.9, 10.9 and 15.4 repetition rate for younger and middle aged participants.

showed significant main effect for the repetition rate [F (2,164)=12.0821, P=0.00], showed main effect for the groups [F (1,82)=6.835, P=0.01]. But Repeated measure ANOVA failed to show any interaction between groups and repetition rate [F (2,164)=0.160, P=0.852].

To further see the effect of repetition rate within each group, one-way ANOVA was done for each group separately. One-way ANOVA showed a significant main effect for the repetition rate for the middle-aged group [F (2,123)=3.698, P<0.05], but not for the younger group [F (2,123)=2.311, P=0.103]. Bonferroni pairwise comparison showed significant difference in middle-aged group for repetition rate 6.9 and 10.9 [P<0.05].

To understand the group differences for second formant frequency amplitude at each repetition rate an independent sample *t* test was done. It showed a significant difference between the two groups only for 10.9 repetition rate [t (82)=3.045, P<0.05] and no significant difference between the groups for 6.9 and 15.4 repetition rates.

Discussion

Latency of wave V

In the present study a delay in wave V latency was noted in middle-aged individuals compared to the younger individuals. The delay in latency of wave V was noted for all the repetition rates (*i.e*. 6.9/s, 10.9/s and 15.4/s). The delay in latency even at lower repetition rate suggests an age related decline in neural processing of speech signal in middle-aged individuals.

Wave V of speech evoked ABR reflects a synchronized response to the onset of the stimulus and is similar to the wave V elicited by click stimulus.[26,31] Previous studies utilizing click stimulus have reported an increase in latency with advancing age.[48-50] The increase in latency of wave V elicited by click stimulus with advancing age has been reported in individuals with essentially normal hearing sensitivity. Literature in speech evoked ABR in aging population have just started to appear and these studies also indicate an increase in wave V latency elicited by speech stimulus in elderly population.[51-54]

The delay in latency of wave V obtained for /da/ syllable for elderly population could be due to the reduced synchronous firing of the auditory neurons; as such changes are reported by Vander-Werff and Burns.[52] It might also be possible that the latency delay obtained for the speech stimulus in elderly population could be due to a slower conduction of the nerve fibers, as it has been reported that there is a degeneration of the myelin sheath of the neurons in middle aged individuals[55] and degeneration of myelin sheath reduces conduction velocity resulting in increased latency.

Secondly, It has been shown that the onset responses (wave V) of speech evoked ABR reflects the responses from the different types of cells in the brainstem, particularly at the level of cochlea nucleus and inferior colliculus.[56] It has been reported that aging results in reduction in the number of cochlear nucleus cells,[57,58] reduction in inferior colliculus neurons.[59-61] Apart from the structural changes, a decline in efficiency of synaptic transmission between the auditory nerve and the bushy cells is seen with age.[62] Reduction in the width of the response area of the various neurons,[63] and decline in the inhibitory effects in shaping the neurophysiologic responses[64] is also noticed with age. All these changes might have also resulted in wave V latency shifts in the elderly.

It has also been reported that there is a reduction in the inhibitory GABA neurotransmitter with advancing age,[65,61] leading to increased spontaneous activity of the neurons, which might act as neural noise in the aging auditory system.[65] The reduction in GABA occurs in middle aged.[66,67] Thus, it can be hypothesized that the neuronal noise because of the reduced GABA might also be one of the components responsible for delay in latency of wave V.

Amplitude of F0, F1 and F2

The results of the present study revealed that there was no difference in encoding of F0 between middle aged and younger individuals at any of the repetition rates. However, increase in repetition rate did affect the encoding of the F0 in middle-aged individuals. The above results suggest a differential effect of repetition rate on wave V latency and encoding of F0. Further, it was noticed that repetition rate did not affect the amplitude of F1 or F2 in middle aged participants compared to the younger participants.

It has been suggested that the transient response and frequency following responses elicited by speech stimuli reflect two different neural mechanisms within the brainstem.[56] Probable neural mechanism which is responsible for generations of transient response are lesser in number or affected more with age compared to the mechanism responsible for generation of sustained responses. This might have resulted in differential affect on both the transient and sustained response.

The evidence for a different site of generation of the transient *versus* sustained responses also comes from the effect of noise or higher repetition rate on speech evoked ABR. Cunningham *et al.*[44] and Russo *et al*.[26] reported that the background noise affects the latency of the onset responses more than the latency of the frequency following responses. Furthermore, increasing the repetition rate of the stimuli selectively affects the latency of the onset responses and does not affect the latency of the sustained responses.[24] In the present study also, the transient responses were affected more in middle aged individuals whereas no difference could be obtained between the younger and middle aged individuals for encoding of F0, F1 and F2 even at higher repetition rate.

However, increasing the repetition rate affected the encoding of F0 within the middle-aged group. The reduction in encoding of F0 with age generally has been attributed to the changes in neural synchrony of the peripheral auditory nerves.[68] This disrupted neural synchrony may arise due to reduction in the auditory nuclei[69] or due to age related changes in the metabolic activity of the cochlea[70] or the reduction in the amplitude of F0 might also arise from age related decrease in GABA inhibition. The reduction in inhibitory function of GABA may lead to reduction in temporal processing at the brainstem level,[64] which might lead to degradation of coding of main acoustic features of the stimulus.[70] The GABA inhibition is very important for stronger encoding of the F0[51] and hence a reduction in GABA inhibition will lead to a deficit in encoding of F0. There was a reduction in encoding of F0 with increase in repetition rate, which could be due to adaptation or saturation of the any of the above mentioned mechanism due to increase in repetition rate. However, the change in the above mentioned activities may not be significant enough so that a difference could be obtained between the younger and the middle aged population.

Summary and Conclusions

The findings of this study indicate that the transient responses (*i.e* wave V) latency is increased at all the three repetition rates in middle-aged individuals compared to the younger individuals. The increase in repetition rate also affected the encoding of fundamental frequency in middle-aged participants however; a significant difference could not be obtained between younger and middle aged individuals. This suggests that the transient responses in middle-aged individuals gets affected faster compared to sustained responses. The study also suggests that the age related increase in latency of transient portion of speech ABR might start in the middle aged individuals itself. One of the limitations of the study was that a comparison between click and speech stimulus was not made. The comparison between click and speech stimulus would have given more information on how speech and non-speech stimulus are processed in middle-aged individuals. However, the objective of the present study was to compare only the encoding of speech in the auditory brainstem, between younger population and middle-aged individuals. Several other studies have also utilized only speech evoked ABR and not compared a click and a speech stimulus in various populations such as Geriatrics[71,72] and learning disability.[73,74]

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