Stimulus Rate and Subcortical Auditory Processing of Speech: Comparison between Younger and Older Adults

[1]Garvita & [2]Sinha S. K.

Abstract

Perception of acoustic signal depends on accurate encoding of temporal events of auditory signals. The auditory brainstem reflects processing of temporal events those are diagnostically significant in the assessment of hearing loss and neurological function (Hall, 1992). Degenerative changes occur with advancing age in the central auditory pathway, including both sub cortical and cortical structures. 17 young aged individuals (30 ears- 18 to 30 years) and 15 older adults (30 ears- 40 to 55 years) with normal hearing sensitivity participated in the study. The brainstem responses to click stimulus was recorded presented at 80 dB SPL across three repetition rates) and was analyzed for wave V latency. The brainstem response to speech evoked ABR was also recorded by using syllable /da/ presented at 80 dB SPL across the three repetition rates (6.9, 10.9 & 15.4). The speech ABR waveforms were analyzed for both the onset (latency of wave V and A) and the sustained (latencies of wave - D, E and F) responses. FFT was done to find the raw amplitude of F0, F1 and higher harmonics (F2) frequency components. The increase in latency of speech evoked ABR (transient and sustained response) and click evoked ABR for the older adults suggest that the brainstem timing might be affected for the older adults. A reduction in amplitude for the coding of F0, F1 and F2 for the older adult group was seen. Reduction in coding of F0, F1 and F2 might be leading to the speech perception problems in older individuals.

Keywords: *Speech ABR, older adults,, repetition rate*

Introduction

Older aged individuals have been shown to have greater difficulty with speech understanding than younger listeners (CHABA, 1988). However, there are studies which demonstrate that in adverse listening conditions, older individuals with essentially normal peripheral hearing sensitivity, have difficulty in understanding speech (Ewertsen & Birk-Nielsen, 1971; Plomp & Mimpen, 1979; Nabelek & Robinson, 1982; Era, Jokela, Qvarnberg & Heikkinen, 1986; Gelfand, Piper & Silman,1986; Dubno, Horwitz & Ahlstrom, 2002; Kim, Frisina, Mapes, Hickman & Frisina, 2006; Wingfield, McCoy, Peelle, Tun & Cox, 2006). This may lead one to conclude that age-related changes occur beyond the peripheral auditory system, i.e., the central auditory nervous system might play a role in this difficulty (Gordon-Salant, 1987; Humes, 1996; Frisina & Frisina, 1997; Mazelova, Popelar & Syka, 2003). These studies have a group of subjects in the middle age range i.e. in the age range of 40-60 years.

Studies suggest that certain auditory abilities begin to decline in older adult population. For example, Barr and Giambra (1990) reported that middle-aged subjects perform more poorly than younger listeners (but better than older individuals) on tasks such as perception of dichotically presented speech. Bergman (1971) reported a significant decline in perception of interrupted speech in middle aged individuals. As the difficulty in speech understanding in elderly individuals arises from the central auditory nervous system, the decline of speech understanding in older adults 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 elderly individuals is the temporal processing (Fitzgibbon & Gordon-Salant, 1996).

Temporal processing is one of the functions necessary for the discrimination of subtle cues such as voicing and discrimination of similar words. Deficits of temporal processing have been found in a group of 40to55 year-old individuals (Grose, Hall & Buss, 2006), reduced gap detection ability in middle-aged women (Helfer & Vargo, 2006), subtle differences in auditory perception between younger and older adults in auditory event-related potential (Alain, McDonald, Ostroff & Schneider, 2004; Geal-Dor, Goldstein, Kamenir & Babkoff, 2006) processing of interaural phase differences both in behavioral and physiological tasks (Ross, Fujioka, Tremblay & Picton, 2007) demonstrating that age-dependent subtle auditory changes may begin in older adults. One way to assess the temporal processing electrophysiologically is to study the stimulus complexity by examining the effects of stimulus rate on speech evoked auditory brainstem responses (Krizman, Skoe & Kraus, 2010; Basu, Krishnan & Weber-Fox, 2010). Click-evoked ABR is a gross measure of time-locked neural activity in response to stimulus onset. In contrast, the frequency-following response (FFR) is a steady state AEP that is sensitive to sustained features within a stimulus and is dependent on the integrity of phase-locked neural activity in the auditory brainstem (Worden & Marsh, 1968).

By increasing the repetition rate of the stimuli, the au-

[1]Email: garvita28mehta@gmail.com,
[2]Lecturer in Audiology, Email: sujitks5@gmail.com

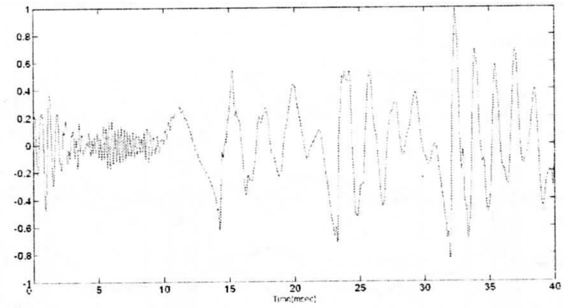

Figure 1: Time domain waveform the Speech stimulus /da/ used in the present study. The top one represents the temporal details of the waveform whereas the bottom one depicts the spectral details.

ditory temporal processing can be checked. By utilizing speech stimulus for assessing the temporal processing will give additional information about temporal coding of speech at the brainstem. Present study was taken up with an aim of investigating the interactions between auditory temporal processing and stimulus complexity by examining the effects of stimulus rate on speech evoked and click evoked ABR in normal hearing younger adults and older adults and to check whether the stimulus rate affects the encoding of the onset of the response or the sustained portion of the response in older adults.

Method

Participants

Younger adults- 17 participants (30 ears) in the age range of 18 to 30 years (Mean age= 21.8 years) and older adults - 15 participants (30 ears) with normal hearing sensitivity in the age range of 40 to 55 years (Mean age= 47.3 years) participated in the study.

Instrumentation and Test Environment

Pure Tone Audiometry was done to confirm bilateral normal hearing sensitivity. Immittance audiometry was done to rule out middle ear abnormalities. Biologic Navigator Pro EP was used to record both click evoked and speech evoked ABR. All the audiological evaluation and recording were carried out in a sound treated room. The ambient noise was within the permissible limits as recommended by ANSI (S3.1; 1991).

Test Stimulus for Speech ABR

Figure 1 shows both the time and spectral domain of the stimulus used in the present study. The stimulus is available in evoked potential system with the BioMARK protocol. The /da/ stimulus is a 40 ms synthesized speech syllable produced using KLATT synthesizer (Klatt, 1980). This stimulus simultaneously contains

Table 1: Recording protocol of the click and speech evoked ABR

Parameters	Click evoked ABR	Speech evoked ABR
Stimulus, duration	Click, 100 μs	CV syllable /da/, 40 ms
Level	80 dB SPL	80 dB SPL
Filter band	100 to 3000 Hz	100 to 3000 Hz
Rate	9.1/s, 19.1/s & 40.1/s	6.9/s, 10.9/s & 15.4/s
No of sweeps	2000	2000
Transducer	BioLogic Insert ear phone	BioLogic Insert ear phone
Polarity	Alternating	Alternating
Time window	12 ms	64 msec which included a prestimulus time of 10 ms (default setting in Biologic system)
Electrode montage	Non-inverting electrode:ForeheadInverting electrode: Test ear MastoidGround electrode: Non test ear mastoid.	Non-inverting electrode:ForeheadInverting electrode: Test ear Mastoid.Ground electrode: Non test ear mastoid.

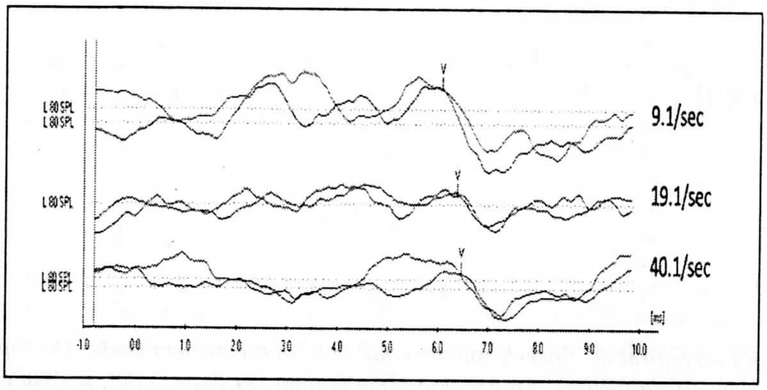

Figure 2: A sample waveform of click evoked ABR recorded at three different repetition rates in a young adult.

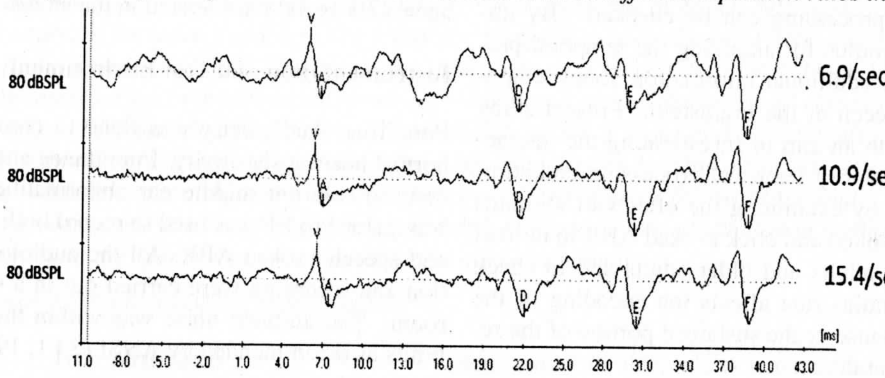

Figure 3: A sample waveform of Speech evoked ABR- transient and FFR waveform at three repetition rates obtained from one young group individual.

broad spectral and fast temporal information characteristics of stop consonants, and spectrally rich formant transitions between the consonant and the steady-state vowel. The fundamental frequency (F0) linearly rises from 103 to 125 Hz with voicing beginning at 5 ms and an onset noise burst during the first 10 msec. The first formant (F1) rises from 220 to 720 Hz, while the second formant (F2) decreases from 1700 to 1240 Hz over the duration of the stimulus. The The third formant (F3) falls slightly from 2580 to 2500 Hz, while the fourth (F4) and fifth formants (F5) remain constant at 3600 and 4500 Hz, respectively.

Procedure

Click ABR and Speech ABR was recorded using the protocol shown in Table 1.

Results

Effect of Repetition Rate and Age (young and older adult group) on the Latency of Click Evoked ABR

The latency of wave V was analyzed for the click evoked ABR across the three different repetition rates (9.1, 19.1 & 40.1/sec). Figure 2 shows an ABR waveform elicited by click at three repetition rates in normal hearing young adult.

It can be seen in the figure 2 that there is an increase in latency of the click evoked wave V as the repetition rate increased. To see the effects of repetition rate on latency of click evoked ABR wave V, Mixed ANOVA was done. Mixed ANOVA revealed a significant main effect for three repetition rates [F (2,116) = 126.11, p<0.05], but Mixed ANOVA failed to show any significant interaction between the repetition rates and the two groups [F (2,116) = 1.94, p>0.05]. Mixed ANOVA also showed a significant difference for the two groups [F (1, 58) = 40.77, p<0.05]. Bonferroni pairwise comparison test was done to see the groupwise differences for the three repetition rates. Pairwise comparison test showed a significant difference between the repetition rate 9.1- 19.1,

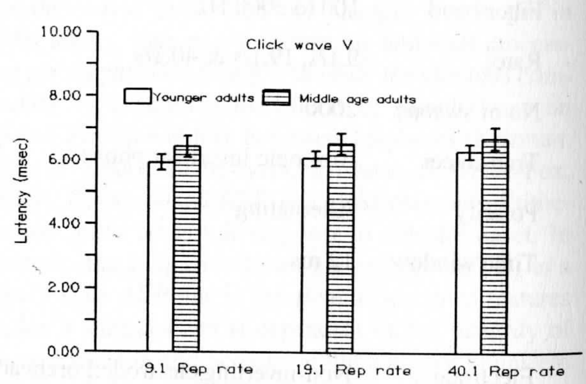

Figure 4: Mean latency of wave V peak latency of click ABR for three repetition rates across the two groups.

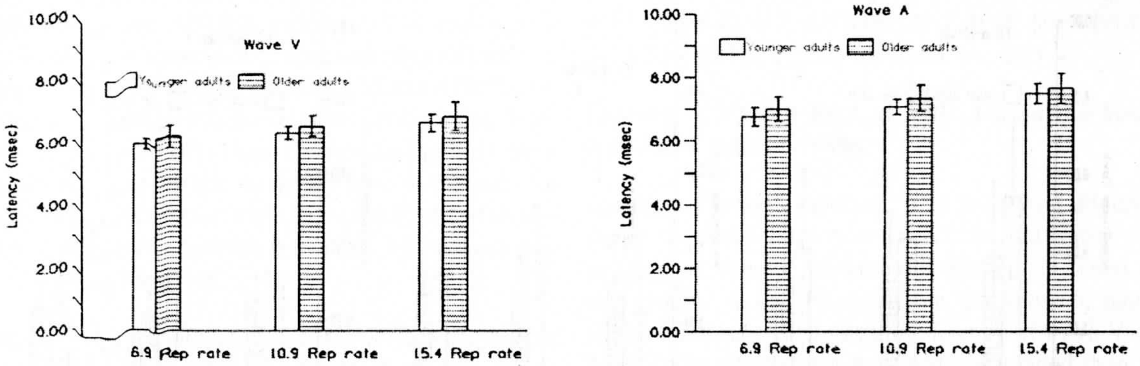

Figure 5: Latency of speech evoked transient V and A peak latency for three repetition rates across the two groups.

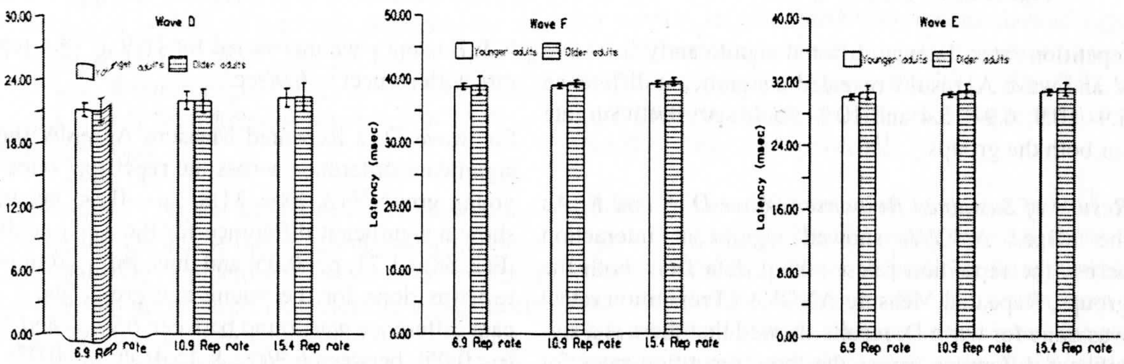

Figure 6: Latency of speech evoked D, E and F peak latency for three repetition rates across the two groups.

9.1- 40.1 and 19.1- 40.1/sec.

As the Mixed ANOVA showed significant interaction across the repetition rates, taking data from both the groups, Repeated measure ANOVA test was done which showed that there was significant difference across the three repetition rates for the young group [F (2, 58) = 66.71, p<0.05] and for the older adult group [F (2, 58) = 60.18, p<0.05]. Thus, Bonferroni post hoc test was done which revealed a significant difference between the repetition rate 9.1- 19.1, 9.1- 40.1 and 19.1- 40.1/sec for young and older adult group.

Effect of Repetition Rate and Age (young and older adult group) on the Latency of Speech Evoked ABR

The latency of wave V, A, D, E, F was analyzed for the speech evoked ABR for three different repetition rates (6.9, 10.9, and 15.4). Figure 3 shows syllable /da/ evoked ABR and FFR waveform at three repetition rates obtained from one of the young group individual.

As it can be seen in the Figure 3, that there is an increase in latency of all the peaks of speech evoked transient response (wave V and wave A) and FFR (wave D, E and F) with the increase in repetition rate. The mean and standard deviations for the latency of different peaks of speech evoked auditory brainstem responses were calculated.

Mixed ANOVA revealed a significant main effect for repetition rates for the latency of wave V, A D, E and F of speech evoked ABR [F (2, 116) = 155.34, p< 0.05], but Mixed ANOVA failed to show any significant interaction between repetition rates and groups [F (2, 116) = 0.17 p> 0.05]. Mixed ANOVA revealed a significant difference between the two groups [F (1, 58) = 4.78, p< 0.05]. Bonferroni pairwise comparison was done to see the group wise differences for the three repetition rate which revealed significant difference between 6.9-10.9, 6.9- 15.4 and 10.9- 15.4/ sec repetition rate.

Results of Onset responses (Wave V and Wave A): As the Mixed ANOVA showed significant interaction across the repetition rates, taking data from both the groups, Repeated Measure ANOVA (3 repetition rates) was done within the group, results showed that for wave V latency, there was a significant difference across the three repetition rates for younger group [F(2, 58)= 292.93, p< 0.05] and the older adult group [F(2, 58)= 169.50, p< 0.05] and for wave A latency also, there was a significant difference across the three repetition rates for younger group [F(2, 58)= 115.05, p< 0.05] and the older adult group [F(2, 58)= 107.85, p< 0.05]. Thus, Bonferroni post hoc test was done to see, at which two

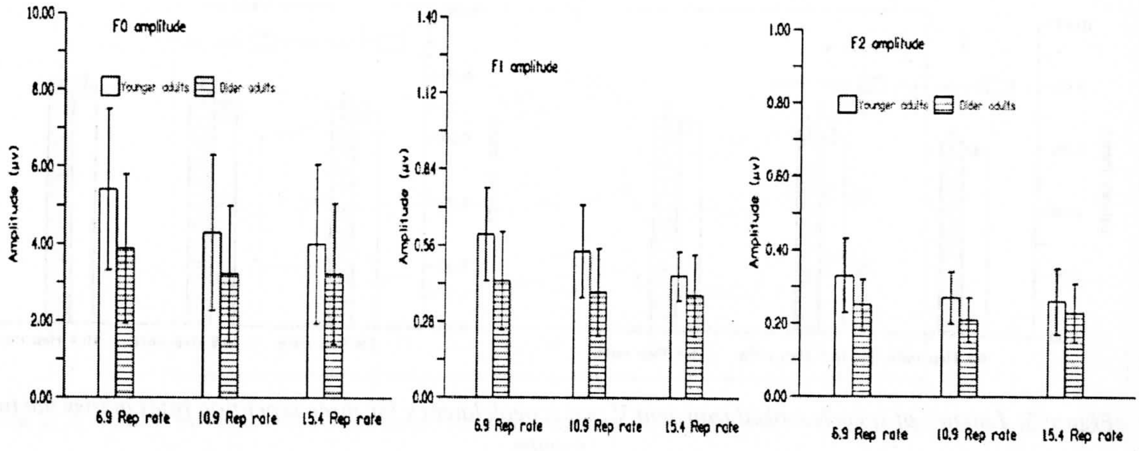

Figure 7: Amplitude of F0, F1 and F2 at 6.9, 10.9 and 15.4 repetition rates across the two groups.

repetition rates, latency differed significantly for wave V and wave A, results revealed a significant difference 6.9- 10.9, 6.9- 15.4 and 10.9- 15.4/ sec repetition rate for both the groups.

*Results of Sustained Responses (Wave D, E and F):*As the Mixed ANOVA showed significant interaction across the repetition rates, taking data from both the groups, Repeated Measure ANOVA (3 repetition rates) was done for wave D, results showed that there is a significant difference across the three repetition rates for younger group [$F(2, 58) = 18.39$, $p< 0.05$] and the older adult group [$F(2, 58) = 9.22$, $p< 0.05$]. Thus, Bonferroni post hoc test was done for wave D, results obtained showed a significant difference between 10.9- 15.4 and 6.9- 15.4/sec repetition rate for both the groups.

Similarly Repeated Measure ANOVA (3 repetition rates) was done for wave E. Test results showed that there is a significant difference across the three repetition rates for younger group [$F(2, 58)= 40.14$, $p< 0.05$] and the older adult group [$F(2, 58)= 10.62$, $p< 0.05$]. Thus, Bonferroni post hoc test was done for wave E and the results obtained showed a significant difference between all the repetition rates except between 6.9- 10.9 for the older age group.

Similarly Repeated Measure ANOVA (3 repetition rates) was done for wave F. Test results showed that there is a significant difference across the three repetition rates for the younger group [$F(2,58)=44.33$, $P<0.05$] and the older group [$F(2,58)=3.39$, $P<0.05$]. Boneferroni post hoc test showed a significant difference between 6.9-15.4 and 10.9-15.4 for the young group only.

Since, the wave V latency increased with increase in repetition rate, the delay in sustained response (wave D, E & F) might be due to delay in wave V. To understand whether the delay in the sustained response was because of increase in latency of wave V or repetition rate affected the sustained reponse latency, the wave D, E & F latency were covaried for 10.9 & 15.4 repetition rate with respect to 6.9/sec.

For wave D, a Repeated Measure ANOVA showed a significant difference across the repetition rates for the young group [$F(2, 58)= 11.87$, $p< 0.05$] but failed to show a significant difference for the older adult group [$F(2, 58)= 1.71$, $p> 0.05$] and thus, Bonferroni post hoc test was done for the young age group and a significant difference was found between 6.9/sec and 10.9/sec ($p<0.05$), between 6.9/sec & 15.4/sec ($p<0.05$) but not between 10.9/sec & 15.4/sec ($p>0.05$).

For wave E, a Repeated Measure ANOVA failed to show any significant difference across the repetition rates for the young group [$F(2, 58)= 1.97$, $p> 0.05$] and for the older adult group [$F(2, 58)= 2.41$, $p> 0.05$].

For wave F, a Repeated Measure ANOVA showed a significant difference across the repetition rates for the young group [$F(2, 58)= 26.62$, $p< 0.05$] but failed to show any significant difference for the older adult group [$F(2, 58)= 0.43$, $p> 0.05$]. Thus, Bonferroni post hoc test was done for the young age group and a significant difference was found between 6.9/sec and 10.9/sec ($p<0.05$), between 6.9/sec & 15.4/sec ($p<0.05$) and between 10.9/sec & 15.4/sec (<0.05).

Effect of Repetition Rate and Age (Young and Older Adult Group) on the Amplitude of Pitch and Harmonics of Speech Evoked ABR

The amplitude of F0 (103 to 125 Hz), F1 (220 to 720 Hz) and higher harmonics (F2- 1700 to 1240 Hz) was analyzed for the speech evoked ABR for three different repetition rates (6.9, 10.9, 15.4/s). The mean and the SD of the amplitude of F0, F1 and F2 were calculated for the speech evoked FFR recorded at three repetition rates. To see the significant difference across three repetition rates on F0, F1 and F2 mean amplitude, Mixed ANOVA (3 repetition rates and 2 groups) was done. Mixed ANOVA revealed a significant main effect across the repetition rates [F (2, 116) = 7.58, p< 0.05], but Mixed ANOVA failed to show any significant interaction between the repetition rates and the two groups [F (2, 116) = 1.01, p> 0.05]. Mixed ANOVA revealed a significant difference across two groups [F (1, 58) = 13.66, p< 0.05]. Thus, Bonferroni pairwise comparison was done to see the group wise differences for the three repetition rates and the results revealed as significant difference between 6.9- 10.9 and between 6.9- 15.4/sec repetition rate.

Results of Amplitude of F0- Pitch measure: As the Mixed ANOVA showed significant interaction across the repetition rates, Repeated Measure ANOVA (3 repetition rates) was done within the groups, results showed that there is a significant difference across the three repetition rate for younger group [F(2, 58)= 4.93, p< 0.05], but failed to show a significant difference for the older adult group [F(2, 58)= 1.40, p> 0.05]. Thus, the young group, Bonferroni post hoc test was done which revealed a significant difference between 6.9- 15.4/ sec repetition rate only.

Amplitude of F1: As the Mixed ANOVA showed significant interaction across the repetition rates, Repeated Measure ANOVA (3 repetition rates) was done within the groups, results showed that there is a significant difference across the three repetition rates for younger group [F(2, 58)= 20.41, p< 0.05] but not in the older adult group [F(2, 58)= 1.88, p> 0.05]. Thus, the young group, Bonferroni post hoc test was done which revealed a significant difference between 6.9- 10.9, 6.9- 15.4 and 10.9- 15.4/sec repetition rate.

Amplitude of F2: As the Mixed ANOVA showed significant interaction across the repetition rates, Repeated Measure ANOVA (3 repetition rates) was done within the groups, results showed that there is a significant difference across the three repetition rates for younger group [F(2, 58)= 14.15, p< 0.05] and in the older adult group [F(2, 58)= 4.87, p<0.05]. Thus, Bonferroni post hoc test was done which revealed a significant difference between 6.9- 10.9, 6.9- 15.4/sec for young group and for 6.9- 10.9/sec repetition rate for the older adult age group.

Latency of Click ABR across the Young and Older Adults

Figure 4 shows the mean latency of wave V peak latency of click ABR for three repetition rates across the two groups.It can be seen from the Figure 4 that at all the three repetition rates, the mean latency of wave V of click ABR for older adult group was more prolonged than the young age group. Multiple analysis of variance (MANOVA) was done to understand the significant difference in latency of wave V of click ABR for the two groups across the three repetition rates. MANOVA results showed significant difference in wave V latency of click ABR across the two groups for repetition rate 9.1 [F (1, 58) = 44.013, p< 0.05], 19.1 [F (1, 58) = 36.718, p< 0.05], 40.1 [F (1, 58) = 30.169, p< 0.05].

Latency of Speech Evoked ABR Across the Young and Older Adult Groups

Latency of onset response: The following Figure 5 shows the mean latency of speech evoked transient V and A peak latency for three repetition rates across the two groups. It can be seen from the figure 5, that at all the three repetition rates, the latency of wave V and A for older adult group was more prolonged than the young age group. For wave V latency, MANOVA results showed significant difference across the groups for repetition rate 6.9 [F (1, 58) = 13.70, p< 0.05], 10.9 [F (1, 58) = 9.96, p< 0.05], 15.4 [F(1, 58) = 4.83, p< 0.05]. For wave A latency, MANOVA results showed significant difference across the groups for repetition rate 6.9 [F(1, 58)= 7.40, p< 0.05], 10.9 [F(1, 58)= 8.92, p< 0.05] , but no significant difference for repetition rate 15.4 [F(1, 58)= 2.14, p> 0.05].

Latency of sustained response of speech evoked ABR across the groups: The following figure 6 shows the mean latency of D, E and F peak for three repetition rates across the two groups. It can be seen from the Figure 6, that at all the three repetition rates, the mean latency of wave D for older adult group is almost similar to the young age group and the mean latency of wave E and F for older adult group was more prolonged than the young age group.

Multiple analysis of variance was done to see the significant difference in latency of wave D, E and F across the young and the older adult groups. MANOVA results showed no significant difference in wave D latency across the groups for repetition rate 6.9 [F (1, 58)= 0.005, p> 0.05], 10.9 [F(1, 58)= 0.001, p> 0.05] and 15.4 [F(1, 58)= 0.097, p> 0.05]. MANOVA results showed significant difference in wave E latency across the groups for repetition rate 6.9 [F (1, 58) = 9.89, p< 0.05], 10.9 [F (1, 58) = 7.23, p<0.05] and 15.4 [F(1, 58)= 5.98, p< 0.05]. MANOVA results showed no significant difference in wave F latency across the groups for repetition rate 6.9 [F (1, 58) = 0.18, p> 0.05], but showed significant for 10.9 [F (1, 58) = 9.197, p<0.05] and 15.4 [F (1, 58) = 5.250, p< 0.05].

Latency of wave D, E and F were covaried for 10.9 & 15.4 repetition rates with respect to 6.9/sec repetition rate in order to understand the significant difference in wave D, E and F was due to wave V prolongation or there was an actual delay in wave D, E and F at higher repetition rate. Multiple analysis of variance was done with the covaried values of 10.9 and 15.4 repetition rates with respect to the latency of wave V of 6.9 repetition rate. MANOVA results showed no significant difference in wave D latency for the 10.9/sec [F (1, 58) = 0.02, p>

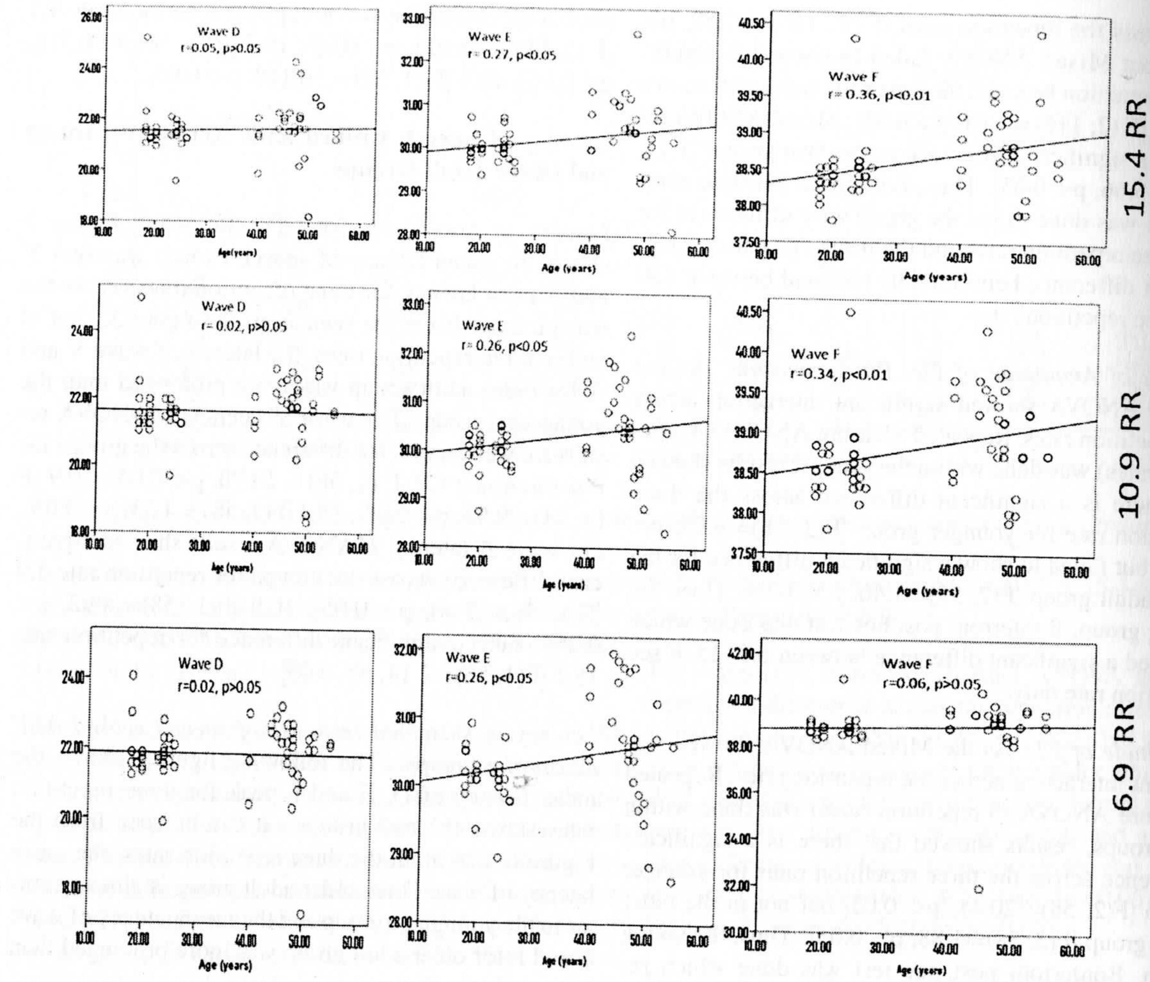

Figure 8: Correlation analysis between the age and the latency of the frequency following responses (sustained responses).

0.05] and for 15.4/sec [F (1, 58) = 0.27, p> 0.05] between the young and older adult groups for the covaried values. MANOVA results showed a significant difference in wave E latency for the 10.9/sec [F (1, 58) = 7.78, p< 0.05] and for 15.4/sec [F (1, 58) = 7.89, p< 0.05]. MANOVA results also showed significant difference in wave F latency for the 10.9/sec [F(1, 58)= 10.36, p< 0.05] and for 15.4/sec [F(1, 58)= 8.84, p<0.05].

Amplitude of the F0, F1 and Higher Harmonics (F2) across the Young and Older Adult Groups

The mean amplitude of F0, F1 and F2 comparing between young and older adult group is shown in the Figure 7.It can be seen from the Figure 7, that at all the three repetition rates, the F0, F and F2 amplitude of older adult group was lesser than young age group. Multiple analysis of variance was done to understand the significant difference for the amplitude of F0 between the young and the older adult group. MANOVA results showed significant difference in F0 amplitude across the groups for repetition rate 6.9 [F(1, 58)= 8.902, p<0.05], 10.9 [F(1, 58)= 4.799, p<0.05] , but showed no significant difference for repetition rate 15.4 [F(1, 58)= 2.402, p> 0.05]. MANOVA results showed significant difference in F1 amplitude across the groups for repetition rate 6.9 [F(1, 58)= 13.665, p<0.05], 10.9 [F(1, 58)= 11.048, p<0.05] , 15.4 [F(1, 58)= 5.069, p< 0.05]. MANOVA results showed significant difference in F2 amplitude across the groups for repetition rate 6.9 [F(1, 58)= 12.999, p<0.05], 10.9 [F(1, 58)= 10.323, p<0.05] , but no significant difference for 15.4 [F(1, 58)= 2.023, p> 0.05].

Pearson Correlation between Age and Sustained Components:

In MANOVA, after covarying it with respect to wave V, it was found that for wave D, there was no significant difference across the groups, whereas a significant difference was found for peak E & F. So, to understand the significant difference, a correlational analysis was done where age was the independent variable and wave D, E & F were the dependent variables. Correlation analysis reveals the following results in figure 8 in terms of scatter plot.

Discussion

The present study was conducted with an aim of studying the brainstem correlates of the auditory temporal processing in the young age and older adult adults with normal hearing sensitivity. This was done by recording speech and click evoked ABR at different repetition rates. The two stimuli were chosen as they differ significantly in their acoustic properties.

Effect of Repetition Rate on Latency of Onset Response of Click ABR and Speech Evoked ABR

Present study supports the earlier studies which report a prolongation in latency with increase in repetition rate (Thornton & Coleman 1975; Don, Allen & Starr, 1977; Yagi & Kaga 1979; Lasky, 1984, 1997; Burkard & Hecox 1983, 1987a, 1987b). Burkard and Sims (2001) reported that with increasing click rate, peak latencies increased, the I-V interval increased and peak amplitudes decreased in both young and older normal individuals. Mamatha and Barman (2008) reported that the latencies of wave I, III and V increased with increase in repetition rate within the age groups from 30 to 65 years.

However, there are studies which report that there is no change in latency of click evoked ABR with increase in repetition rate up to 20/sec (Jewett, Romano & Williston, 1970; Krizman, Skoe & Kraus, 2010). Fowler and Noffsinger (1983) also reported no change in latency of click evoked ABR waves with increase in repetition rate between 2- 20 Hz. However, in present study a significant difference was obtained between 9.1/sec and 19.1/sec repetition rates. The difference reported in the present study might be due to the methodological differences between the present and the earlier studies. Earlier studies have been utilized either 80 dB nHL or 90 dB nHL intensity to record auditory brainstem responses whereas, the present study has been done at 80 dB SPL intensity.

With respect to the onset response of the speech evoked ABR, several authors have reported an increase in the onset response with the increase in repetition rate of the stimuli in adults (Krizman, Skoe & Kraus, 2010) and in children (Ranjan, 2011, Mehta & Singh, 2012). The increase in latency of wave V of click ABR and wave V and A of speech evoked ABR due to increase in the repetition rate might be due to cumulative neural fatigue and adaptation, and incomplete recovery involving hair-cell-cochlear nerve junction and also subsequent synaptic transmission. Latency shifts seen with increase in rate in normals may also be due to a change in cochlear receptor functions (Don et al., 1977), the refractory period of individual nerve fibers resulting in a desynchronization of the response that most affects the encoding of the faster elements of the stimulus (Hall, 1992; Jacobson, Murray & Deppe, 1987), decrease in synaptic efficiency (Pratt & Sohmer, 1976) due to which conduction rate decreases and there is an increase in latency. The effect of rate would be additive as the synapses increases from wave I to wave V (Hall, 1992).

The present study also revealed that the latency of the onset responses was more for 40-55 years age group compared to the 18 to 30 years age group for a higher repetition rate and even at lower repetition rates also. Mamatha & Barman (2008) reported that the latencies of wave I, III and V increased with increase in repetition rate across the age groups from 30 to 65 years and there was a greater increase in the latency for wave III and wave V in older individuals. Patterson, Michalewski, Thompson, Bowmanm and Litzelman (1981) reported that older elderly individuals (60 to 79 years) had longer latencies at wave III and wave V compared to the middle aged individuals (40 to 59 years) and middle aged individuals had longer latencies compared to the young adults (20 to 39 years).

These delayed latencies in the onset of the click and speech evoked ABR with increasing age could be consistent with a reduction in synchronous neural firing to transient changes in stimulus and impaired neural encoding of the onset of a stimulus in the older adult individuals. Akhoun et al. (2008) suggested that the onset response of the ABR particularly reflects the synchronous response of many types of brain stem cells at the levels of the cochlear nucleus and inferior colliculus. Therefore, this portion of the response is likely to be affected by age-related loss in neural synchrony in the central auditory system, which may be independent of changes at the periphery (Boettcher, Mills, Swerdloff & Holley, 1996; Gates, Feeney & Higdon, 2003; Mills, Schmeidt, Schulte & Dubno, 2006; Pichora-Fuller, Schneider & McDonald, 2007). This provides an index for examining the role of subcortical timing and its relationship to normal, impaired and the expert auditory perception.

Further, as the repetition rate increased, the difference was maintained between the two groups i.e. the latency was consistently more for the older adult group compared to the younger adults even at higher repetition rate. The neurophysiological mechanisms responsible for observed latency shifts at higher repetition rates in the older adults might be due to taxing the auditory system at higher repetition rates resulting in cumulative neural fatigue and adaptation, and incomplete recovery involving hair-cell-cochlear nerve junction and also subsequent synaptic transmission. This phenomenon might be affected more in older adult individuals compared to the young adults probably because of reduced neural synchrony in older adult individuals. The findings observed at higher repetition rates also suggest an impaired temporal processing in older adults. Behavioral studies have also reported that temporal processing is affected in older adult individuals (Babkoff, Ben-

Artzi & Fostick, 2011; Abel, Krever & Alberti, 1990; Grose, Hall & Buss, 2006). Impaired temporal processing in older adults might be due to reduced neural synchrony, slowed neural conduction time, and reduced phase-locking abilities, which might affect the neurons in the central auditory system to accurately encode important temporal features of signal.

These findings suggest that older adults had a general reduction in synchronous neural firing in response to transient information at the onset of a speech and a click stimulus. Thus, one can hypothesize that the degradation in the onset response of the auditory brainstem responses might start in the older adults itself.

Effect of Repetition Rate on Latency of Speech evoked FFR-Sustained Measure

As the repetition rate increased, a significant prolongation in the latency of few peaks of sustained responses was obtained for both the young adults as well as the older adult group. Looking at the prolongation of the wave V latency of speech evoked ABR, it was suspected that the latency prolongation of the sustained responses might be due to the prolongation of wave V with increase in repetition rate. Hence, the peaks of sustained response were covaried with the wave V latency and after covarying, the rate effect disappeared for all the peaks of older adult group suggesting that the shift seen at sustained responses were a carryover of the large effect of rate on wave V latency for the older adult group. However, after covarying the latencies for the young group, there was a significant difference for wave D and wave F but not for wave E. Krizman et al. (2010) have reported no effect of repetition rate on the sustained responses of the speech evoked ABR in younger adults. The present study followed the recording protocol of Krizman et al. (2010). Although the recording protocol was same, the results obtained were different for the two studies. At this point of time it is difficult to define why repetition rate selectively affected the latencies of two peaks of the sustained responses for the young group.

After covarying the peaks of sustained responses, a significant difference was obtained for E peak between the two groups at all the repetition rates whereas, a significant difference was obtained for the F peak at 10.9 repetition rate and 15.4 repetition rate but not the 6.9 repetition rate and for peak D, there was no difference obtained between the two groups for any of the repetition rate. To understand this, a correlation analysis was done which revealed that there was no correlation between age and wave D latency (i.e. as the age increased, there was no prolongation in the D peak latency), whereas it revealed a significant correlation for wave E for all the repetition rates and for wave F for 10.9 and 15.4 repetition rate. The differences between the two groups for these peaks suggest a selective prolongation of the wave E and F component of the sustained responses for the older adults.

Clinard, Tremblay and Krishnan (2010) also found some significant age effects for the sustained portion of the S-ABR. Significant correlations with advancing age were reported for latencies of the sustained responses for older adults in the age range of 22- 77 years old. Vander, Kathy, Burns and Kristen (2011) also reported a similar finding for individuals in the age range of 61-78 years. The results of the Clinard et al. (2010) and Vander et al. (2011) are in good general agreement with those of this study.

The neurophysiological mechanism behind the encoding of sustained FFR response is dependent on the integrity of phase locked neural activity in the auditory brainstem (Worden & Marsh, 1968). For the encoding of sustained components (wave E and F), there is a significant difference between the young and older adult group, which suggests a delay in encoding of these components at lower repetition rate for the older adults compared to the young adults at the upper brainstem. The effect continues even at higher repetition rates which suggest a possible reduction in temporal processing in the older adults at the upper brainstem level. Temporal processing is dependent on the neural detection of time-varying acoustic cues which might be affected in older adults as a result of poor neural synchrony (Frisina & Frisina, 1997; Schneider & Pichora-Fuller, 2001).

This effect could result from a reduced neural synchrony in peripheral and/or central auditory changes with age. This delay in latencies reflects disrupted neural synchrony, which may also be related to age-related changes in physiology such as metabolic activity in the cochlea (Mills et al., 2006), levels of inhibitory neurotransmitters (Caspary, Schatteman & Hughes, 2005), or decreased cell counts in auditory nuclei (Frisina & Walton, 2006). Age-related related changes to the capacitance and input resistance of inner hair cells (IHCs) or changes in synapses between IHCs and auditory nerve fibers could also influence the coding of the sustained responses (Moser, Neef & Khimich, 2006). For example, deficits of temporal processing have been found in a group of 40-55 year-old individuals (Grose et al., 2006), reduced gap detection ability in middle-aged women (Helfer & Vargo, 2006), reduced DPOAE amplitudes in normal-hearing middle-aged adults (Dorn et al., 1998), subtle differences in auditory perception between younger and older adult subjects in auditory event-related potential (Alain, McDonald, Ostroff & Schneider, 2004; Geal-Dor, Goldstein, Kamenir & Babkoff, 2006), processing of inter aural phase differences both in behavioral and physiological tasks (Ross, Fujioka, Tremblay & Picton, 2007) demonstrating that age-dependent subtle auditory changes may begin in older adult individuals. Thus the poorer encoding of periodicity at the brainstem level in terms of FFR suggests that age-related decline tends to start in the mid age itself.

Effect of Repetition Rate on Representation of F0, F1 & F2-Pitch and Harmonic Measure

Krizman et al. (2010) reported a significant rate effect on the higher harmonics and not on the coding of F0 and F1. However, in the present study there was a significant effect of repetition rate on encoding of F0, F1 and F2 for younger adults and encoding of F2 in older adults. The results obtained in the present study for the older adult group is similar to Krizman et al. (2010). One thing to be noticed here is that even the repetition rate had greater effect on the latencies of sustained responses for the young group compared to the older adult group. After covarying, in the older adult group, there was no effect of repetition rate on latencies of the sustained responses (wave D, E and F). Since the encoding of the F0, F1 and F2 is dependent upon the sustained responses, the responses obtained here for F0, F1 and F2 might be somehow correlated with the latency of the sustained responses in the young group and older adult group. But this mechanism needs to be further checked with more investigations.

A significant difference was seen in the amplitude of F0 and F2 across the groups for 6.9/sec & 10.9/sec and for all repetition rates in the amplitude of F1. These findings suggest that in the older adult individuals there might be a problem in encoding of these key elements of speech. Vander et al. (2011) also reported reduced phase-locking to the fundamental and harmonic frequency components of speech, as measured by the reduced spectral amplitude for F0, F1, and F2 for individuals in the age range of 22-77 years old. Clinard et al. (2010) also reported a reduction in amplitude of F0 in older individuals.

Reduced encoding of F0, F1 and F2 in older adults is consistent with the interpretation of an age-related decline in phase-locking ability involving the brainstem. However, for the F0 and F1 at 15.4 repetitions rate there was no significant difference obtained between the two groups. This might be due to higher standard deviations recorded for these two components at higher repetition rates. Speech recognition abilities were not assessed in this study; therefore, it is not known whether the age-related differences in coding of F0, F1 and F2 directly relate to difficulty in understanding speech in older adults. It will be of interest to see whether the encoding of F0, F1 and F2 such as those observed in the older adult subjects in this study are correlated with reduced speech perception with and without noise condition. However, in the present study, a relation between the temporal processing abilities in this population and encoding of F0, F1 and F2 was obtained, which suggests that the temporal processing might be affected in the older adult individuals itself.

Conclusions

The increase in latency of speech evoked ABR and click evoked ABR for the older adults suggest that the brainstem timing might be affected for the older adults. Both transient and sustained responses of speech evoked ABR shows a significant difference between the young and the older adults suggesting that both the transient and sustained responses are important while doing speech evoked ABR. The peripheral hearing sensitivity was intact in both the groups considered for the study, but there was a reduction in amplitude for the coding of F0, F1 and F2 for the older adult group. Reduction in coding of F0, F1 and F2 might be leading to the speech perception problems in older individuals. Although the perception of speech requires lot more component, brainstem coding of speech sounds might be one of the neural code which might be leading to the speech perception problems in older adults. The study can be utilized to study the subcortical coding of speech at the brainstem level in younger and the older adults. This knowledge could lead to objective diagnostic tests as well as techniques to determine appropriate intervention strategies and ways to monitor the effectiveness of intervention in the elderly population. The data obtained helps us to understand how the temporal aspect of speech and non speech sound is coded at the brainstem level. It highlights the necessity of further studies in different clinical population.

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