Acoustic Change Complex As An Objective Gap Detection Test In Elderly Individuals

Nainitha K.K[1] & Ganapathy M.K[2]

Abstract

A decline in temporal resolution abilities or the ability of the auditory system to track fast changes in incoming sounds is one factor thought to contribute to speech understanding difficulties that accompanies aging process.The present study was carried out to find out the minimum gap duration required to elicit the Acoustic Change Complex (ACC). Also the study was carried out across age groups to find out the effect of age on the behavioral gap duration and gap duration required to elicit the electrophysiological responses. ACC and behavioral Gap Detection Test were administered on sixty participants with normal peripheral hearing, divided into four groups including fifteen young adults in Group I (18-28 years) and older adults in Group II (>50-55 years), Group III (>55-60 years) and Group IV (>60-65 years). The results showed that behavioural gap detection thresholds and gap durations required to elicit ACC increased as age increases and major detrimental effects on gap detection is seen after 60 years of age and above. The results also showed that the behavioral gap detection thresholds were lower than the gaps required to elicit ACC . The results of the current study shows that changes in the aging auditory system older adults required higher gap duration compared to young adults in eliciting the cortical responses and also behavioral responses. These results clearly indicate slow temporal processing thus possibly leading to the difficulties faced by older adults in understanding speech in difficult listening situations. The objective test could also help in testing the difficult to test older adults with associated problems.

Key words: *acoustic change complex, gap detection, elderly.*

Introduction

Structural as well as neural degeneration occurs throughout the auditory system, in the process of ageing. It is often seen that elderly individuals have difficulty in understanding speech particularly in poor listening situations although they have adequate hearing sensitivity (Lee, 2015). Seidman, Ahmad, Joshi, Thawani, & Quirk (2004)reported that due to ageing variety of biochemical and molecular changes occur. These changes in the auditory system have detrimental consequences on the hearing of the elderly individuals.

Older listeners often perform poorly on tasks of speech understanding in noisy and reverberant listening conditions. Roberts & Lister, (2004) suggested that deficits in temporal resolution may be responsible for this condition. Studies reported that age related temporal processing deficits leads to difficulty listening in noise (Robert Frisina & Frisina, 1997; Pichora-Fuller & Souza, 2003). Robert Frisina & Frisina, (1997) implicated that auditory brainstem or auditory cortex temporal resolution dysfunctions could be accounting for the reduced abilities to listen in noise in elderly individuals with adequate cognition and normal hearing sensitivity. Numerous behavioural studies(Pichora-Fuller, Schneider, Benson, Hamstra, & Storzer, 2006; Pichora-Fuller & Souza, 2003) indicated a deficit in auditory temporal processing in elderly individuals. Elderly individuals exhibited more difficulties than younger listeners in detecting short gaps within speech and non-speech stimuli. These behavioral data indicate that cortical processing of rapid changes within an ongoing stimulus could be impaired in healthy adults with normal peripheral hearing. In a magneto encephalography (MEG) by Sörös, Teismann, Manemann, & Lütkenhöner, (2009) reported difference in P1m and N1m amplitude betweenadults and elderly individuals. However they reported of no evidence of N1m being affected by ageing and recommended further studies on cortical temporal processing in elderly individuals. Contradictorily the mismatch negativity was assessed in elderly individuals for temporal resolution (Bertoli, Smurzynski, & Probst, 2002), the results evinced deficient temporal processing.

Due to ageing other physical and physiological changes can occur in elderly individuals (Barbera, 2012). Few of the age related changes which can be seen in elderly individuals are task performance may take longer, difficulty in learning new tasks, motor reaction time decreased, confusion (associated with Alzheimer's), or may fail to recall instructions (W. Barbara, 2012). Ageing also can have psychosocial changes such as decline in intelligence (McArdle, Ferrer-Caja, Hamagami, & Woodcock, 2002), attention deficits (Pichora-Fuller et al., 2006) and memory (Hartke, 1991). These associated problems in elderly individuals warrants for an objective test to assess the temporal processing.

The use of the gap in noise test for measuring behavioural gap detection threshold is based on subjective patient feedback only. The use of an alternative method that provides objective measures is desirable and greatly needed in elderly individuals due to factors like cognitive dysfunctions, linguistic limitations, behavioral problems and others. Carrying out the behavioral tests to assess perceptual deficits in elderly individuals with associated problems may be

1. nainithaaiish93@gmail.com
2. ganapathy.mk8@gmail.com

impractical. The effects of ageing on temporal resolution ability remain unclear as Musiek et al., 2005 argued that "older subjects may present with increased GDTs in comparison to younger control subjects". Cortical evoked potentials to gaps in noise can be recorded to provide an objective measure of temporal resolution (Palmer,& Musiek, 2013). Studies which has used ABR gap threshold (Poth, Boettcher, Mills, & Dubno, 2001; Werner, Folsom, Mancl, & Syapin, 2001) report that ABR gap thresholds tended to be lower than behavioral gap detection thresholds. Hence, there is a clinical need to investigate an objective test that has potential in identifying temporal processing deficit. A gap detection study by Michalewski, Starr, Nguyen, Kong, & Zeng, (2005) on normal hearing and hearing impaired individuals reported ACC along with behavioral scores is a reliable measure. Hence, ACC may serve as a potential tool to assess GDT in elderly individuals.

Study by Gates, Mills, Nam, D'Agostino, & Rubel (2002) reported that cochlear loss due to ageing is subjective. The hair cells are prone to damage not only because of ageing but due to other factors such as noise and trauma. Further any pre-existing peripheral hearing may also lead to alterations in central auditory system. As in the present study older adult with normal hearing are included, the CAEP results may provide details of cortical changes due to ageing.

Aim

To estimate the minimum duration of gap required to elicit ACC in young adults and in older adults. The main objectives of the study were to estimate the minimum duration of gap required to elicit ACC in young adults and olderadults,to compare the minimum duration of gap required to elicit ACC across age groups and to compare the minimum duration of to elicit ACC with the behavioral gap detection scores across different age groups.

Method

The main aim of the study was to find out the minimum duration of gap within an ongoing noise required to elicit Acoustic Change Complex (ACC) in young adults and older adults. To study this, stimuli were synthesized with duration of gap within the ongoing noise systematically increasing. For these stimuli cortical responses were recorded and analyzed across different age groups.

1. Participants

The participants were divided into three groups based on age viz.

Group I: Fifteen ears of young adults in the age range of 18 to 28 years (mean age 21.8 years)

Group II: Fifteen ears of older adults in the age range of >50 to 55 years(mean age 53.9 years)

Group III: Fifteen ears of older adults in the age range of >55 to 60 years(mean age 56.2 years)

Group IV:Fifteen ears of older adults in the age range of >60 to 65 years(mean age 63.8 years)

All the participants had normal hearing in both the ears, i.e., pure tone thresholds (Air Conduction and Bone Conduction thresholds) less than 15 dB HL at octave frequencies from 250 Hz to 4000 Hz. All participants were administered speech audiometry and individuals with scores > 90% were included for the study. Normal middle ear function was ensured in each participant with A type tympanogram with a middle ear pressure between +50 to -50 daPa; middle ear compliance between +0.3 to +1.6 ml (Jerger, 1970) with a probe tone frequency of 226 Hz, and acoustic reflex being present and recorded at <100 dB HL at 1000 Hz in both the ears.A detailed case history was taken to ensure that none of the participants have had history or complaint of any neurological and otological problems. The group II, III and IV individuals was administered Cognitive testing using Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975). Maximum score is 30 and subjects obtaining a score of <24 are interpreted as having cognitive deficits and were not included in the study. Only participants who scored >24 were included in the study.

The following tests were carried out for selection of the participants:

A structured interview was conducted to rule out otological and neurological problems. Following which pure-tone testing was carried out. Air-conduction (AC) thresholds at octaves between 250 Hz to 8000 Hz and bone-conduction (BC) thresholds for octaves between 250 Hz to 4000 Hz were established for each ear. This was done using a calibrated clinical audiometer, TDH-39 head phone encased in MX 41AR ear cushion for AC testing and Radio Ear B-71 bone vibrator for BC testing. The hearing thresholds were estimated using modified Hughson-Westlake procedure (ANSI S3.21-1978, R-1992) with a +5 dB and -10 dB step-size. It was ensured that all participants had hearing thresholds ≤ 25 dBHL.

Tympanometry was carried out, by making the participants sit comfortably on a chair and was instructed to close their eyes and not to move until the test was completed. Immittance testing was administered with a probe tone of 226 Hz. Tympanogram and acoustic reflexthresholds for 1000 Hz were estimated to ensure normal middle ear functioning in each ear.

2. Instrumentation

The following instruments were used for subject selection criteria and for subjective and objective threshold estimation of GDT.

a. GSI 61 a calibrated dual channel audiometer was used to assess hearing ability of the participants

b. Middle ear analyzer GSI tympstar was used to assess middle ear status

c. Evoked potential system (Bio-logic Navigator Pro-ver 7) was used to record CAEPs.

d. CD of Gap Detection Test (GDT).

e. A personal laptop connected to GSI 61 audiometer was used for presenting the stimulus of GDT.

3. Stimuli

A sound treated air-conditioned double room set-up was used to administer all these tests. The noise level in the testing room was maintained within the permissible limits(ANSI, 1999).

For recoding ACC, stimuli were generated using Adobe Audition 1.5. and for these stimuli Cortical Auditory Evoked Potential (CAEP) was recorded. In total eight stimuli were generated. White noises were generated with a total duration of 350 ms. Gaps of duration 0 ms, 3 ms, 4 ms, 5 ms, 6 ms, 7 ms, 8 ms and 10 ms were introduced within the ongoing white noise at 150 ms duration. All stimuli were presented at 70 dBSPL. All the thresholds were obtained for right ear to avoid discrepancy due to ear advantage. To estimate the behavioral gap detection scores Gap Detection Test CD developed by Shivaprakash and Manjula (2003) was used. This test consists of 56 stimuli with 6 catch trials and 4 practice sets. Each set of stimuli consists of three noise bursts in which one of the noise burst has the silent gap, and participant has to identify in which of the noise bursts gap was present.

4. Procedure

The study was carried out in two phases. In phase 1 Acoustic change complex were recorded for different gap durations. In phase 2 subjective gap detection test were administered.

4.1 Objective measure

To record the CAEP the stimuli were presented to the participant's monaurally using ER-3A insert earphone at 70 dBSPL using Bio-logic Navigator EP system. Participants were seated comfortably in a reclining chair. To ensure the client cooperation, the participants were made to watch a muted movie played through a battery operated laptop computer kept at a distance of 2 meters away. Silver chloride disc electrodes were used for recording the CAEP's. Electrode sites were cleaned using a skin abrasive paste and electrodes with conduction paste were placed on the sites and attached using surgical tape. Absolute electrode impedances were maintained within 5 k Ω and relative impedances within 2 k Ω throughout the testing. Sufficient breaks were provided between the testing. Details of the protocol that were used for testing is given in the Table1 below

Table 1:Protocol for recording ACC

Time window	**-50 to 500 ms**
Stimulus	White noise with 0, 3, 4, 5, 6, 7,8 and 10ms gap (Eight stimuli in total)
Stimulus duration	350 ms
Stimulus intensity	70 dB nHL
Repetation rate	0.9/sec
Amplification	10,000 times
Filter	0.1 to 30 Hz band pass 0.2 filter
Artifact rejection	±75 µV
Electrode montage	One channel – Ipsilateral mastoid (A2) - inverting Forehead (Fpz)- Ground Cz - non-inverting
No. of sweeps	150
No. of channels	1

The peaks N11 and P21 were analyzed. The peaks N11 and P21 reflect the response to the onset of the change (encoding of gap) within the ongoing stimulus. The duration of gaps at which N1 and P2 were elicited were analyzed and tabulated. The marking of peaks N11 and P21 were judged by experienced audiologists.

4.2. Behavioral Gap Detection Test

The behavioral gap detection scores Gap Detection Test CD developed by Shivaprakash and Manjula (2003) were used. This test consists of 56 stimuli with 6 catch trials and 4 practice sets. In this study minimum gap detection scores were obtained at 50 dBSL. All the thresholds were obtained for right ear to avoid discrepancy due to ear advantage. The participants were instructed to listen to the set of three noise bursts and indicate verbally which of the three noise bursts in the set had gap. The minimum gap that was detected by the subject was taken as the gap detection threshold.

5. Statistical analysis

The data of behavioural gap detection values and the duration of gaps at which ACC was elicited in four different age groups were tabulated. The data obtained were subjected to statistical analysis using Statistical Package for Social Sciences (SPSS) software (SPSS version 20). Descriptive statistics was applied to estimate the mean and standard deviation for each group. Normality test was carried out for the tabulated data using Shapiro-Wilk test, which revealed normal distribution of behavioral gap detection data and gap detection scores for ACC were not normally distributed. Hence, parametric statistical test ANOVA was administered to compare between age groups for behavioural GDT and a non parametric statistical testKruskal Wallis test was administered to compare between agegroups for gap detection scores of ACC. Mann Whitney U test was carried out to assess the difference between the groups for ACC results. Further, to compare between behaviouralGDT and gap detection scores obtained from ACC,Wilcoxan Signed Rank test was carried out.

Results

The present study aimed to find out the minimum duration of gap within an ongoing noise required to elicit Acoustic Change Complex (ACC) in young adults and older adults.Four groups including fifteen young adults in Group I (18-28 years) and older adults in Group II (>50-55 years), Group III (>55-60 years) and Group IV (>60-65 years) participated in the study.All the subjects were assessed for both behavioral gap detection test and ACC. The results of the older adult participants were compared with that of the younger adult group. It was ensured that all the participants included in the study had normal peripheral hearing sensitivity.

1. Behavioural Gap detection scores between age groups

To obtain the behavioural Gap Detection thresholdthe minimum gap that was detected by the subject in the Gap Detection Test was considered. Descriptive statistics were carried out to obtain mean and standard deviation of behavioural gap detection scores. The mean and standard deviation of the behavioural Gap Detection thresholds in different age groups are as shown in Table 2.

Table 2: The mean and standard deviation of the behavioural Gap Detection thresholds in different age groups

Groups	N	Mean/ Std. Deviation
I	15	2.65/0.74
II	15	4.04/0.35
III	15	4.53/0.49
IV	15	5.40/0.46

ANOVA was carried out to see for statistical significance across groups.Results revealed statistically significant difference between the GDT values across the age groups [F(3,56)=70.135,p=0.000].This results show that the gap detection thresholds were significantly differentbetween age groups.

To assess between age group effect, Bonferroni's adjusted multiple comparisonswas carried out.The results are as shown in table 3. that shows that between all the groups there significant difference except betweenGroups II and Group III.

Table 3: Comparison of behavioural GDT between age groups

Age Groups	Group I	Group II	Group III	Group IV
Group I	-	SD	SD	SD
Group II	SD	-	NSD	SD
Group III	SD	NSD	-	SD
Group IV	SD	SD	SD	-

Note: SD= Significant difference (p >0.05), NSD= No significant difference(p=0.000)

2. Gap detection scores of ACC between age groups

The ACC were recorded for eight stimuli having gaps of duration, 0ms, 3ms, 4ms, 5ms, 6ms, 7ms, 8ms and 10ms for right ear to avoid discrepancy due to ear advantage.The mean and standard deviation of the durations of gaps at which N11 and P21 were elicited are shown in the table 4.

Table 4: Mean and standard deviation of the durations of gaps at which N11 and P21 were elicited.

Groups	N	Mean/ Std. Deviation
Group I	15	4.27/0.45
Group II	15	6.07/0.45
Group III	15	6.13/0.51
Group IV	15	7.13/0.35

Kruskal-Wallis Test was carried out tostudyacross group comparison of the durations of gaps required to elicit ACC. The results shows that there was significant difference across the age groups ($\chi^2(3)$= 49.222, p = 0.000).

As the Kruskal-Wallis test results showed significant difference, Mann Whitney U test was carried out to study between which groups there was statistically significantdifference.The results are as shown in the Table 5.The results reveal that except for the groups II and III (i.e. between the age range 51-55 years and 55-56 years),all other groups indicated statistically significant difference. These results indicate that in older adults the gap required to elicit is longer.

Table 5: Comparison of duration of gaps required to elicit ACC between groups.

Groups	Z value
Group I & II	-4.878*
Group I & III	-4.840*
Group I & IV	-5.010*
Group II & III	-0.393
Group II & IV	-4.581*
Group III & IV	-4.314*

* =significant difference (p=0.000)

3. Comparison between Electrophysiological and behavioral measures

The results of behavioral gap detection scores and gap duration for which ACC were elicited were compared. The mean scores of the responses obtained are shown in

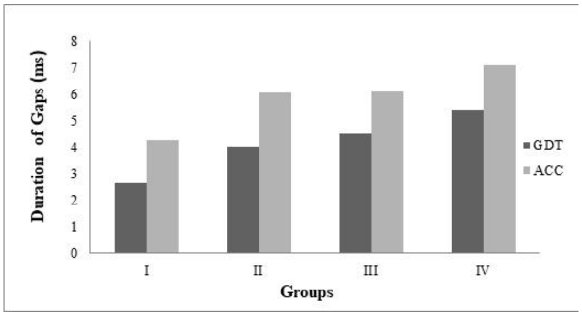

Figure 1: The mean scores of gap detection scores and mean gap duration required to elicit ACC across age groups. Note:GDT= Gap Detection Threshold,ACC= Acoustic Change Complex.

To compare between behavioral gap detection thresholds and gap detection required to elicited ACCWilcoxon Signed Rank test was carried out. The results are as shown in table 4.5. The results indicated statistically significant difference between values of both behavioural and objective tests. The above figure of mean scores also indicates that the behavioural gap detection scores are lesser than the gap detection scores elicited through ACC.

Table 6: The Wilcoxon Signed Rank test results of comparison between GDT and ACC across the age groups

GROUPS	Z value
Group I	-3.352*
Group II	-3.416*
Group III	-3.411*
Group IV	-3.409*

* = Significant Difference (p=0.000)

Discussion

The aim of the present study was to estimate the minimum duration of gap required to elicit ACC in young adults and in older adults. To study this, the following objectives were taken (1)To estimate the minimum duration of gap required to elicit ACC in young adults.(2) To estimate the minimum duration of gap required to elicit ACC in older adults.(3) To compare the minimum duration of gap required to elicit ACC across age groups.(4)To compare the minimum duration of to elicit ACC with the behavioral gap detection scores across different age groups.

1. Behavioural Gap detection scores between age groups

The results of the present study show that the minimum gap detection scores increases with the age. This indicates that gap detection seems to be affected by increasing age, the mean gap detection thresholds obtained in the study was smaller for the younger adults as compared to older subjects. These findings are in congruence with those reported in theprevious studies done by Snell (1997), Snell, Frisna(2000), which shows that there is significant age-related changes in auditory processing that occur throughout adulthood. Price and Simon (1984), reported that there are detrimental effects on temporal resolution abilities as age increases. Strouse, Ashmeadohde,Grantham (1998) measured gap detection scores in 12 young (mean age = 26.1 years) and 12 elderly (mean age = 70.9 years) adults with clinically normal hearing and the results revealed that elderly listeners displayed higher gap detection thresholds. Their findings suggest that age-related factors other than peripheral hearing loss contribute to temporal processing deficits of elderly listeners. Moore, Peters, Glasberg (1992) found that elderly listeners have more difficulties than younger adultlisteners in detecting short gaps within noise, reportinglargergap detection thresholdsfor elderly listeners than young listeners. Furthermore, they reported that age-related difference in gap detection appears to be independent ofperipheral hearing loss because performance in gap detection is not correlated with pure tone hearing thresholds, this supports the present study as participants in all groups had normal hearing sensitivity yet showed greater gap detection scores.

The results also show that the age Groups II and III had reduced scores in comparison with young adults they did not show significant difference. This indicates that ageing effects are uniform between these age groups. The results of Group IV i.e.,>60 years of age the minimum gap detection are higher, which indicates influence ofage, which may be due to age related decline in physiology of auditory system.

These results show that the temporal resolution may be affected in older adults. This indicates that the ability of the aging auditory system even normal hearing sensitivity may have problems in detecting rapid and abrupt changes in the sound stimuli thus have difficulty in discriminating the shortest time interval between two acoustic cues (Zidan, Garcia, Tedesco, &Baran, 2008). This could also point out to the reduced speech understand scores in older adults even with normal hearing sensitivity (Diveny, Stark, &Haupt, 2005).

2. Gap detection scores of ACC between age groups

The results of the study revealed that the mean gap required to elicit ACC in young adults was 4 ms and greater. Palmer and Musiek (2013) also studied gap detection using N1-P2 complex. They report that young adults had N1-P2 complex for gaps >2ms. In older adults the gap duration required to elicit ACC was >6 ms. Older adults required wider gaps to elicit the responses. These results corroborate the study done by Harris, Wilson, Eckert and Dubno(2012).

They reported that older adults required longer duration of gaps. They found that clear N1-P2-N2 components were obtained inresponse to gaps of 6 ms or shorter in younger adults where as in older adults, N1-P2-N2 components was present in response to gaps of 9 ms,although in some subjects the ERP was not present until gap duration increased to 12 or 15ms. In the above-mentioned study the mean age of older adults was 69 years. Study byMichalewski and Pratt (2005) used N1-P2 measure to evaluate temporal processing abilities and found that older subjects require more gap duration to elicit N1-P2.

The findings of the present study indicate that the increase in gap duration indicate age related slowing in processing. These may be due to changes in auditory cortex as a result of ageing (Canlon, Illing, & Walton, 2010). FrisinaandFrisina (1997) reported that temporal resolution deficits are seen in the auditory brainstem or auditory cortex as age increases. Further, there was no significant differences seen between Group II and III suggesting that major changes in auditory systems happens after 60years of age.Konigsmark and Murphy (1972) reported that around the beginning of 60 years of age, there is decline in the volume of neurons in ventral cochlear nucleus along with decrease in number of myelinated fibers, reduced vessels and capillaries. Further Ling, Hughes, and Caspary (2005) reported in their study that there was a significant decrease in GABA in primary auditory cortex in aged rats. According to these observations they concluded that temporal coding of older adults is likely to get altered due to the loss of GABA neurotransmission in primary auditory cortex.

These results in older adults with normal hearing sensitivity the cortical auditory responses indicate possible age related deterioration of central auditory processes. Studies have reported reduced temporal resolution in hearing impaired listeners (Moore, &Glasberg, 1988; Long, & Cullen, 1988), however the current findings point out to reduced temporal resolution due to ageing alone.

3. Comparison between Electrophysiological and behavioral measures

The comparison of behavioural gap detection test and ACC did not correlate. The results showed that the duration of gap required to elicit ACC was more than the behavioural gap detection scores across all age groups. Shuman, Grose, &Buchman (2012) reported that the gap detection and frequency discrimination thresholds determined by the electrophysiological measure were signi?cantly larger than the behavioral threshold. Their thresholds for gap detection ranged from 5.0 to 8.0ms and behavioral gap detection thresholds ranged from 4.1 to 6.6 ms in older adults group. Palmer and Musiek (2013) showed that most of the young adults included in their study had responses at gaps > 2 ms, but all subjects had presentclear evoked potential responses to 20 msec.Palmer (2014) also reported that older adults demonstrated significantly larger gap detection thresholds than the younger adults. The higher gap duration required to elicit electrophysiological responses could also be due to the number of neurons responding to the gap may decrease with shorter gaps than the number of neurons responding to longer gaps (Walton, Frisina, Ison, & Neill, 1997; Palmer, Musiek, 2013).

The results of the current study show that cortical auditory evoked potentials can be recorded for gaps in young and older adults. However the older adults require higher gap durations to elicit the cortical responses. These could be due to the temporal changes in the ageing auditory system. These clearly point out the older adult problem in understand speech in difficult listening situations. Further, by establishing norms these objective tests could be used to study the temporal resolution in older adults thus helping them in theaudiological rehabilitation. The objective test could also help in testing the difficult to test older adults with associated problems.

Summary and conclusion

The present study aimed to find out the minimum duration of gap within an ongoing noise required to elicit Acoustic Change Complex (ACC) in young adults and older adults. The study consisted of four groups of participants including fifteen young adults in Group I (18-28 years) and older adults in Group II (>50-55 years), Group III (>55-60 years) and Group IV (> 60-65 years). Normal peripheral hearing sensitivity was ensured for all the participants in the study through detailed audiological evaluations. The participants were assessed for both behavioural gap detection and electrophysiological using ACC.

The results of the study showed that the behavioral gap detection scores were different across age groups. The older adults require higher gap duration to detect the gaps. The behavioral data also showed that the gap duration required for Group IV was higher indicating slower temporal processing with increase in age. The results for gap detection using ACC also showed that gaps required to elicit the responses were different between age groups. The older adults required higher gap duration to elicit ACC than the younger individuals. As seen in the behavioral responses the Group IV individuals required higher gaps to elicit responses. This also indicates that the ability of the aging auditory system even normal hearing sensitivity may have problems in detecting rapid and abrupt changes in the sound stimuli thus have difficulty in discriminating the shortest time interval between two acoustic cues.

It is usually seen that older adults complaining of speech understanding problems especially in adverse listening conditions and studies have also reported it (Dubno, Lee, Matthews, & Mills, 1997; Gelfand, Piper, &Silman, 1986). The current study was carried out on normal hearing older adults and both the behavioral and ACC data shows that with increase in age the gap required for behavioral response and cortical encoding were higher. This indicates slower temporal processing in older adults. The affected temporal processing in older adults could be a factor for speech understanding problems seen in normal hearing older adults.

Further, the comparison of behavioural gap detection test and ACC did not correlate. That is, the gap required to elicit cortical responses were higher than the gaps required to elicit behavioral responses. Even though the behavioural gap detection thresholds were significantly lower than the gap detection scores obtained for ACC but scores were still within the same range of performance in each tests carried out. Overall these results suggest that the ACC response can be used as an objective indicator of behavioral sensitivity to changes in an ongoing acoustic signal

The results of the current study shows that changes in the aging auditory system older adults required higher gap duration compared to young adults in eliciting the cortical responses and also the behavioural responses. These results clearly indicate slow temporal processing thus possibly leading to the difficulties faced by older adults in understanding speech in difficult listening situations. The objective test could also help in testing the difficult to test older adults with associated problems.

References

Anderson, S., Chandrasekaran, B., Yi, H. G., & Kraus, N. (2010). Cortical-evoked potentials reflect speech?in?noise perception in children. European Journal of Neuroscience, 32(8), 1407-1413.

Anderson, S., Parbery-Clark, A., White-Schwoch, T., & Kraus, N. (2012). Aging affects neural precision of speech encoding. Journal of Neuroscience, 32(41), 14156-14164.

Barbara, W. (2012).The Biology of Ageing. In Barbara (Ed.), Geriatric Audiology (2nd ed., pp. 15-47). New York: Thieme.

Barbera, W. E. (2012). Geriatric Audiology. (W. E. Barbara, Ed.) (2nd ed.). New York: Thieme.

Bertoli, S., Smurzynski, J., & Probst, R. (2002). Temporal resolution in young and elderly subjects as measured by mismatch negativity and a psychoacoustic gap detection task. Clinical Neurophysiology, 113(3), 396-406.

Billings, C. J., Tremblay, K. L., Stecker, G. C., &Tolin, W. M. (2009). Human evoked cortical activity to signal-to-noise ratio and absolute signal level. Hearing research, 254(1), 15-24.

Brant, L. J., &Fozard, J. L. (1990). Age changes in pure?tone hearing thresholds in a longitudinal study of normal human aging. The Journal of the Acoustical Society of America, 88(2), 813-820.

Canlon, B., Illing, R. B., & Walton, J. (2010).Cell biology and physiology of the aging central auditory pathway.In The aging auditory system (pp. 39-74).Springer New York.

Chance, S. A., Casanova, M. F., Switala, A. E., Crow, T. J., &Esiri, M. M. (2006).Minicolumn thinning in temporal lobe association cortex but not primary auditory cortex in normal human ageing. Acta neuropathologica,111(5), 459-464.

Cruickshanks, K. J., Wiley, T. L., Tweed, T. S., Klein, B. E., Klein, R., Mares-Perlman, J. A., &Nondahl, D. M. (1998). Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin the epidemiology of hearing loss study. American journal of epidemiology, 148(9), 879-886.

Divenyi, P. L., Stark, P. B., &Haupt, K. M. (2005).Decline of speech understanding and auditory thresholds in the elderly . The Journal of the Acoustical Society of America, 118(2), 1089-1100.

Dubno, J. R., Dirks, D. D., & Morgan, D. E. (1984).Effects of age and mild hearing loss on speech recognition in noise. The Journal of the Acoustical Society of America, 76(1), 87-96.

Friesen, L. M., & Tremblay, K. L. (2006). Acoustic change complexes recorded in adult cochlear implant listeners. Ear and hearing, 27(6), 678-685.

Frisina, D. R., &Frisina, R. D. (1997). Speech recognition in noise and presbycusis: relations to possible neural mechanisms. Hearing research,106(1), 95-104.

Frisina, R. D., & Walton, J. P. (2006).Age-related structural and functional changes in the cochlear nucleus. Hearing Research, 216, 216-223.

Gates, G. A., & Mills, J. H. (2005).Presbycusis. The Lancet, 366(9491), 1111-1120.

Gates, G. A., Cooper Jr, J. C., Kannel, W. B., & Miller, N. J. (1990). Hearing in the Elderly: The Framingham Cohort, 1983-1985: Part 1. Basic Audiometric Test Results. Ear and hearing, 11(4), 247-256.

Gates, G. A., Mills, D., Nam, B., D'Agostino, R., & Rubel, E. W. (2002). Effects of age on the distortion product otoacoustic emission growth functions. Hearing Research, 163(1-2), 53-60.

Gelfand, S. A., Piper, N., &Silman, S. (1986). Consonant recognition in quiet and in noise with aging among normal hearing listeners. The Journal of the Acoustical Society of America, 80(6), 1589-1598.

Goodin, D. S., Squires, K. C., Henderson, B. H., & Starr, A. (1978).Age-related variations in evoked potentials to auditory stimuli in normal human subjects. Electroencephalography and clinical neurophysiology, 44(4), 447-458.

Gordon-Salant, S. (2005).Hearing loss and aging: new research findings and clinical implications. Journal of rehabilitation research and development,42(4), 9.

Gordon-Salant, S., & Fitzgibbons, P. J. (1993).Temporal factors and speech recognition performance in young and elderly listeners. Journal of Speech, Language, and Hearing Research, 36(6), 1276-1285.

Harris, K. C., Mills, J. H., &Dubno, J. R. (2007).Electrophysiologic correlates of intensity discrimination in cortical evoked potentials of younger and older adults. Hearing research, 228(1), 58-68.

Harris, K. C., Wilson, S., Eckert, M. A., &Dubno, J. R. (2012). Human evoked cortical activity to silent gaps in noise: effects of age, attention, and cortical processing speed. Ear and hearing, 33(3), 330.

Hartke, R. (1991). The aging process: Cognition, personality and coping. In R. Hartke (Ed.), Psychological aspects of geriatric rehabilitation. Gaithers-burg: Aspen Publishers.

He, S., Grose, J. H., & Buchman, C. A. (2012). Auditory discrimination: the relationship between psychophysical and electrophysiological measures.International journal of audiology, 51(10), 771-782.

Humes, L. E. (1996). Speech understanding in the elderly. Journal-American Academy of Audiology, 7, 161-167.

Iragui, V. J., Kutas, M., Mitchiner, M. R., &Hillyard, S. A. (1993). Effects of aging on event?related brain potentials and reaction times in an auditory oddball task. Psychophysiology, 30(1), 10-22.

Konigsmark, B. W., & Murphy, E. A. (1972). Volume of the ventral cochlear nucleus in man: its relationship to neuronal population and age. Journal of Neuropathology & Experimental Neurology, 31(2), 304-316.

Laffont, F., Bruneau, N., Roux, S., Agar, N., Minz, M., &Cathala, H. P. (1989). Effect of age on auditory evoked responses (AER) and augmenting-reducing. Neurophysiologie Clinique/Clinical Neurophysiology, 19(1), 15-23.

Lee, J. Y. (2015). Aging and Speech Understanding. Journal of Audiology & Otology, 19(1), 7-13.

Letowski, T., &Poch, N. (1995). Understanding of time-compressed speech by older adults: effect of discard interval. Journal-American Academy Of Audiology, 6, 433-439.

Ling, L. L., Hughes, L. F., &Caspary, D. M. (2005).Age-related loss of the GABA synthetic enzyme glutamic acid decarboxylase in rat primary auditory cortex. Neuroscience, 132(4), 1103-1113.

Lister, J. J., Roberts, R. A., Shackelford, J., & Rogers, C. L. (2006).An adaptive clinical test of temporal resolution. American journal of audiology,15(2), 133-140.

Martin, B. A., &Boothroyd, A. (1999).Cortical, auditory, event-related potentials in response to periodic and aperiodic stimuli with the same spectral envelope. Ear and Hearing, 20(1), 33-44.

Martin, B. A., &Boothroyd, A. (2000). Cortical, auditory, evoked potentials in response to changes of spectrum and amplitude. The Journal of the Acoustical Society of America, 107(4), 2155-2161.

McArdle, J. J., Ferrer-Caja, E., Hamagami, F., & Woodcock, R. W. (2002). Comparative longitudinal structural analyses of the growth and decline of multiple intellectual abilities over the life span. Developmental Psychology, 38(1), 115-42.

Michalewski, H. J., Starr, A., Nguyen, T. T., Kong, Y. Y., & Zeng, F. G. (2005). Auditory temporal processes in normal-hearing individuals and in patients with auditory neuropathy. Clinical Neurophysiology, 116(3), 669-680.

Mukari, S. Z. M. S., Wahat, N. H. A., &Mazlan, R. (2014). Effects of ageing and hearing thresholds on speech perception in quiet and in noise perceived in different locations. Korean journal of audiology, 18(3), 112-118.

Musiek, F. E., Shinn, J. B., Jirsa, R., Bamiou, D.-E., Baran, J. A., & Zaida, E. (2005). GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. Ear and Hearing, 26(6), 608-18.

Näätänen, R., &Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: a review and an analysis of the component structure. Psychophysiology, 24(4), 375-425.

Neupane, A. K., Gururaj, K., Mehta, G., &Sinha, S. K. (2014). Effect of repetition rate on speech evoked auditory brainstem response in younger and middle aged individuals. Audiology research, 4(1).

Ostroff, J. M., Martin, B. A., &Boothroyd, A. (1998). Cortical evoked response to acoustic change within a syllable. Ear and hearing, 19(4), 290-297.

Ostroff, J. M., Martin, B. A., &Boothroyd, A. (1998). Cortical evoked response to acoustic change within a syllable. Ear and hearing, 19(4), 290-297.

Palmer, S. B., & Musiek, F. E. (2013). N1-p2 recordings to gaps in broadband noise. Journal of the American Academy of Audiology, 24(1), 37-45.

Palmer, S. B., &Musiek, F. E. (2013).N1-p2 recordings to gaps in broadband noise. Journal of the American Academy of Audiology, 24(1), 37-45.

Palmer, Shannon B., and Frank E. Musiek. "Electrophysiological gap detection thresholds: effects of age and comparison with a behavioral measure." Journal of the American Academy of Audiology 25.10 (2014): 999-1007.

Pichora-Fuller, M. K. (2003). Processing speed and timing in aging adults: psychoacoustics, speech perception, and comprehension. International Journal of Audiology, 42, S59-S67.

Pichora-Fuller, M. K., & Souza, P. E. (2003). Effects of aging on auditory processing of speech. Int J Audiol, 42(Suppl 2), S11-S16. Poth, E. A., Boettcher, F. A., Mills, J. H., & Dubno, J. R. (2001). Auditory brainstem responses in younger and older adults for broadband noises separated by a silent gap. Hearing Research, 161(1-2), 81-86.

Pichora?Fuller, M. K., Schneider, B. A., &Daneman, M. (1995). How young and old adults listen to and remember speech in noise. The Journal of the Acoustical Society of America, 97(1), 593-608.

Price, P. J., & Simon, H. J. (1984). Perception of temporal differences in speech by "normal-hearing"adults: Effects of age and intensity. The Journal of the Acoustical Society of America, 76(2), 405-410.

Raza, A., Milbrandt, J. C., Arneric, S. P., &Caspary, D. M. (1994). Age-related changes in brainstem auditory neurotransmitters: measures of GABA and acetylcholine function. Hearing research, 77(1), 221-230.

Rose, M., Flatt, T., Graves Jr, J. L., Greer, L. F., Martinez, D. E., Matos, M.,&Shahrestani, P. (2012). What is aging?. Frontiers in genetics, 3, 134.

Schneider, B. A., &Hamstra, S. J. (1999).Gap detection thresholds as a function of tonal duration for younger and older listeners.The Journal of the Acoustical Society of America, 106(1), 371-380.

Schneider, B. A., Pichora-Fuller, M. K., &Daneman, M. (2010).The Aging Auditory System.

Seidman, M. D., Ahmad, N., Joshi, D., Seidman, J., Thawani, S., & Quirk, W. S. (2004).Age-related hearing loss and its association with reactive oxygen species and mitochondrial DNA damage. Acta Oto-Laryngologica,124(0), 16-24.

Shankar, S. K. (2010). Biology of aging brain. Indian Journal of pathology and microbiology, 53(4), 595.

Sharashenidze, N., Schacht, J., &Kevanishvili, Z. (2007). Age-related hearing loss: gender differences. Georgian Med News, 144, 14-18.

Sharma, M., Purdy, S. C., & Kelly, A. S. (2014, February).The contribution of speech-evoked cortical auditory evoked potentials to the diagnosis and measurement of intervention outcomes in children with auditory processing disorder.In Seminars in Hearing (Vol. 35, No. 01, pp. 051-064).Thieme Medical Publishers.

Shinn, J. B., Chermak, G. D., &Musiek, F. E. (2009). GIN (Gaps-In-Noise) performance in the pediatric population. Journal of the American Academy of Audiology, 20(4), 229-238.

Shivaprakash, S., & Manjula, P. (2003). Gap detection test-Development of norms. An Unpublished Independent Project. Mysore: University of Mysore

Snell, K. B. (1997). Age-related changes in temporal gap detection. The Journal of the Acoustical Society of America, 101(4), 2214-2220.

Sörös, P., Teismann, I. K., Manemann, E., & Lütkenhöner, B. (2009). Auditory temporal processing in healthy aging: a magnetoencephalographic study. BMC Neuroscience, 10,34.

Tremblay, K. L., Billings, C. J., Friesen, L. M., & Souza, P. E. (2006). Neural representation of amplified speech sounds. Ear and Hearing, 27(2), 93-103.

Tun, P. A. (1998). Fast noisy speech: age differences in processing rapid speech with background noise. Psychology and aging, 13(3), 424.

Vander Werff, K. R., & Burns, K. S. (2011).Brain stem responses to speech in younger and older adults.Ear and hearing, 32(2), 168-180.

Walton, J. P., Frisina, R. D., Ison, J. R., & O'Neill, W. E. (1997). Neural correlates of behavioral gap detection in the inferior colliculus of the young CBA mouse. Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology, 181(2), 161-176.

Werner, L. A., Folsom, R. C., Mancl, L. R., & Syapin, C. L. (2001). Human Auditory Brainstem Response to Temporal Gaps in Noise.Journal of Speech Language and Hearing Research, 44(4), 737.

Wiley, T. L., Chappell, R., Carmichael, L., Nondahl, D. M., &Cruickshanks, K. J. (2008).Changes in hearing thresholds over 10 years in older adults.Journal of the American Academy of Audiology, 19(4), 281-292.

Willott, J. F. (1991). Aging and the auditory system: Anatomy, physiology and psychophysics. Whurr Pub Ltd.

Zaidan, E., Garcia, A. P., Tedesco, M. L. F., &Baran, J. A. (2008). Desempenho de adultosjovensnormaisemdois testes de resolução temporal. Pró-FonoRevista de AtualizaçãoCientífica.

.