TITLE OF THE PROJECT

Relationship between Electrophysiological Sub-Cortical Processing of Speech and Behavioral Tests of Central Auditory Function in Children with (Central) Auditory Processing Disorder

Principal Investigator

Dr. Prawin Kumar
Lecturer in Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysore-06
E Mail: prawin_audio@rediffmail.com

Co Investigator
Mr. Niraj Kumar Singh
Lecturer in Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysore-06
E Mail:niraj6@gmail.com

Research Officer
Mr. Vipin Ghosh P G

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All India Institute of Speech and Hearing
Manasagangothri, Mysore-06

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LIST OF ABBREVIATIONS

ABR	Auditory Brainstem Responses
AEPs	Auditory Evoked Potentials
APD	Auditory Processing Disorders
BioMARK	Biological Marker
CANS	Central Auditory Nervous System
CAPD	Central Auditory Processing Disorder
CNS	Central Nervous System
DCV	Dichotic Consonant Vowel
DPT	Duration Pattern Test
FFT	Fast Fourier Transform
FPT	Frequency Pattern Test
GDT	Gap Detection Test
Hz	Hertz
LE	Left ear
MLD	Masking Level Difference
PC	Personal Computer
PPT	Pitch Pattern Test
RE	Right Ear
SCAP	Screening Checklist for Auditory Processing
SD	Standard Deviation
SPIN	Speech Perception in Noise

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ABSTRACT

(Central) auditory processing refers to the perceptual processing of auditory information in the central nervous system and the neurobiological activity that underlies the processing, which gives rise to electrophysiological auditory evoked potentials. The underlying mechanism of the auditory processing may be assessed using electrophysiological and behavioral measures. With this focus the present study aimed at checking the relationship between speech evoked ABR and a set of behavioral tests of central auditory function in children at the risk for (central) auditory processing disorder [(C)APD].

The study included 336 school going children in the age range of 8 to 14 years as participants. Initial screening for (C)APD was carried out for all the participants using screening checklist for auditory processing (SCAP). Out of 336 children, 30 children who were found to be at risk for (C)APD based on SCAP and they formed the experimental group. Further, the control group was constituted by 30 age matched typically developing children. The participants of both the groups underwent a series of behavioral tests for central auditory function which included gap detection test (GDT), pitch pattern test (PPT), dichotic CV test (DCV), speech perception in noise (SPIN) test and masking level difference (MLD) test. They also underwent speech evoked auditory brainstem response (ABR) testing using /da/ stimuli. The parameters assessed were wave V and A latencies, V/A slope, first and higher formant frequency and sustained responses.

On the behavioral central auditory function tests, children at risk for (C)APD showed significantly poorer performance than the typically developing children ($p<0.05$), except MLD at 500 Hz. Similarly for different components of speech evoked ABR, the results revealed significantly delayed response latencies of waves V, A and the sustained responses. Further, the amplitude of first formant frequency was significantly smaller in this group ($p<0.05$). However, there was no significant group difference for V/A slope and amplitude of higher formant frequencies. In addition, the correlation between different behavioral tests and different components of speech evoked ABR tests was done. The results revealed a significant negative correlation of GDT and SPIN with amplitude and latency measures of speech evoked ABR, respectively. However, PPT and MLD at 500 Hz and 1000 Hz showed positive correlation with latency measure of speech evoked ABR. From the results it can be concluded that the various behavioral tests along with different components of speech evoked ABR are capable of tapping subtle auditory processing deficits in children at the risk for (C)APD.

CHAPTER 1: INTRODUCTION

(Central) auditory processing refers to the perceptual processing of auditory information in the central nervous system (CNS) and the neurobiological activity that underlies processing and gives rise to electrophysiologic auditory potentials. It includes the auditory mechanisms that underlie the following abilities or skills: sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition including temporal integration, temporal discrimination (e.g. temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals (ASHA, 1996; Bellis, 2003; Chermak & Musiek, 1997).

(Central) Auditory Processing Disorder [(C)APD] refers to difficulties in the perceptual processing of auditory information in the CNS as demonstrated by poor performance in one or more of the above skills. According to the present consensus statements and guidelines (American Academy of Audiology, 2010; ASHA, 2005), the diagnosis of (C)APD should be made via test battery approach using psychophysical (behavioral) and/or electrophysiological measures that have been shown to be sensitive, specific, and efficient for identification of disorders of central auditory nervous system (CANS). Auditory processing deficits have also been associated with learning disability. It has been reported that impaired auditory processing disrupts the normal development and efficiency of phonological system which may result in language disorders, speech processing disorders and reading disorders (Merzenich et al., 1996; Tallal, Miller & Fitch, 1993). The prevalence of (C)APD in school going children are estimated to be 2 to 3 % in western population (Chermak & Musiek, 1997). Similarly, in school going children of India the prevalence of suspected (C)APD is estimated to be 3.2% (Muthuselvi & Yathiraj, 2009).

The underlying mechanism of the auditory processing may be assessed using electrophysiological and behavioral measures. Auditory evoked potentials (AEPs) have long been recognized as a reliable tool for providing objective information about the structural and functional integrity of the central auditory system (Hall, 1992; Kraus & McGee, 1992). Brainstem electrophysiological response elicited by speech stimuli may provide additional insight into the auditory processing abilities of children at risk for (C)APD.

Speech evoked Auditory Brainstem Responses (ABR) are electrophysiological potentials in response to a speech stimulus that reflects the onset, offset and periodicity of the stimulus (Banai et al., 2009). Speech evoked ABR has been used in various studies in order to explore the brainstem encoding of complex signals in individuals with dyslexia and learning disorders (Banai et al, 2009; Billet & Bellis, 2011; Singh & Kumar, 2012; Song, Banai & Kraus, 2008). Biological marker of auditory processing (BioMARK) is a testing protocol developed based on the speech-evoked ABR. It is a brainstem electrophysiological response recorded to multiple presentations of a 40 ms synthetic /da/ syllable (Johnson, Nicol & Kraus, 2005). The complex /da/ stimulus consists of both transient and sustained features which are capable of eliciting an onset response consisting of waves V, A, and C as well as frequency following response (FFR) consisting of waves D, E, and F in addition to the offset response O (Skoe & Kraus, 2010).

Various studies have reported abnormal encoding of speech signals despite of normal click-evoked auditory brainstem responses among children with auditory based learning problems like reading disorders, dyslexia and learning disorders (Banai et al, 2009; Billet & Bellis, 2011; Singh & Kumar, 2012; Song, Banai & Kraus, 2008). Banai et al (2009) studied the relationship between reading and sub-cortical processing of auditory signals in 63 children with normal hearing and normal click-evoked ABR. Psychoeducational assessments were carried out using battery of tests and the findings were correlated with speech evoked ABR. They found prolonged latencies and reduced amplitudes of the peaks among poor readers compared to the good readers. They further obtained a significant correlation between sub-cortical auditory function and reading abilities.

Billet and Bellis (2011) explored the relationship between brainstem temporal processing and performance on tests of central auditory function in children with reading disorders. Thirty two children in the age range of 8 to 12 years who were diagnosed as having dyslexia, participated in the study. When tested using the BioMARK protocol, 37.5% of children exhibited abnormal absolute latencies of V, A, C, D, E, F and O as well as a shallow slope of V/A complex. These abnormalities in latency measures indicate towards abnormal encoding of the cues for vowel and consonant identification in children with Dyslexia.

Singh and Kumar (2012) investigated speech evoked ABR in 15 children with dyslexia and compared their findings with 10 typically developing children. They found poorer waveform morphology and prolonged latencies among children with dyslexia compared to the typically developing children. They further reported reduction in the amplitude of first formant (F1) and second formant (F2) in children with dyslexia in contrast to the typically developing children. Nonetheless, the groups fared alike in terms of fundamental frequency and wave V/A slope. Based on the above findings the study concluded that children with dyslexia show abnormal brainstem timing and speech signal encoding and thereby reflect temporal processing deficits.

Brainstem timing deficits in children with learning impairment was studied by Song, Banai and Kraus (2008). They carried out speech evoked ABR in 8-12 year old typically developing children and in children with learning disability. They observed that the early peaks were similar in appearance in both typically developing children and in children with learning disability, however the later peaks (V and A) were abnormal in children with learning disability. Banai, Abrams and Kraus (2007) reviewed studies on speech ABR in children with learning disability and in typically developing children. They reported that as many as 40% of children with learning disability shows abnormality in speech evoked ABR. Wible, Nicol and Kraus (2004) also reported shallow Vï Va slopes of speech evoked ABR in children with language based learning problems.

A group of 54 children with learning problems in the age range of 8 to 12 years were compared against 33 typically developing children. Results reflected a lack of difference between the groups on click evoked ABR. However, speech-evoked ABR demonstrated significantly longer latencies among children with learning problems compared to their typically developing counterparts (King et al, 2002).

Muniz, Lopes and Schochat (2012) also studied speech evoked ABR in 18 children with auditory processing disorder within the age range of 6 to 12 years. They reported that the children with (C)APD might have a greater difficulty in distinguishing stimuli based on timing cues which is important for the identification of speech sounds.

Various behavioral tests are also been used to assess the integrity of the auditory processing. These include, Speech perception in Noise test (SPIN) to evaluate auditory closure, Masking level difference (MLD) test to assess auditory interaction, Dichotic speech test (dichotic CV) to assess auditory integration, Pitch pattern tests (PPT) to evaluate temporal ordering/patterning and Gap detection test (GDT) to evaluate temporal resolution.

The efficacy of behavioral tests has been extensively researched upon and behavioral tests have been shown to be useful in the diagnosis of different aspects of (C)APD (Iladou, Kaprinis, Kandylis & Kaprinis, 2010; King, Lombardino, Crandell & Leonard, 2003; Moncrieff & Musiek, 2002). Iladou et al. (2010) investigated the hemispheric laterality in adults with dyslexia, auditory processing disorders (APD) and co-morbidity of both dyslexia and APD. There were 30 participants in each category in the age range of 17 to 46 years. Dichotic digit testing was carried out and the results were compared with that of an age matched control group. While adults with APD exhibited right hemisphere dominance, left hemisphere dominance was observed in adults with co-morbidity of APD and dyslexia in comparison to control group. The group of individuals with dyslexia alone was marked by an absence of cerebral dominance. In addition, the individuals of all the groups demonstrated deficiencies in the auditory performance in the presence of competing auditory signal.

King et al. (2003) investigated the performance of 11 young adults with dyslexia on auditory processing tasks such as frequency pattern test (FPT) and duration pattern test (DPT) and found that 5 out of the 11 subjects failed in both tests. Moncrieff and Musiek (2002) also compared the performance of 10 children with dyslexia who were 11 year old against typically developing age matched children on dichotic digit test, dichotic consonant-vowel test and competing words test, a subtest of SCAN. The performance of the children from both the groups was significantly different on all the dichotic tests.

Other studies have used different behavioral tasks such as auditory discrimination (Tallal,1980), identification of rapidly presented high-low frequency tones (Farmer & Klein, 1993; Tallal,1980), or gap detection (Farmer & Klein, 1993) to investigate auditory processing in children and adults with reading disorders. They found significant difference in scores obtained by individuals with reading disorder and individuals without reading disorder. In contrast, Walker, Shinn, Cranford, Givens and Holbert (2002) studied temporal processing abilities of 9 college going students with a mean age of 20.6 years who had reading disorder. The performances on DPT and FPT were compared with 9 age matched participants without reading disorder. Results revealed a significant difference between adults with reading disorders and control group for DPT scores but not for FPT scores. They also reported a significant correlation between reading abilities and temporal processing abilities.

NEED FOR THE STUDY

Reviewing the literature, a substantial proportion of children with auditory based learning problems such as dyslexia displayed an abnormal encoding of speech signal as measured by the speech evoked auditory brainstem response despite normal click evoked auditory brainstem responses (Banai et al., 2009; King, Warrier, Hayes, & Kraus, 2002; Warrier, Johnson, Hayes, Nicol, & Kraus, 2004). It should be noted that a disruption in latency as minimal as fractions of a millisecond may be diagnostically significant. Specifically, delayed peak latencies for wave V, A, C, and O and a shallow slope for the V/A complex have been found in children with language based learning problems (Banai et al., 2009, 2005; Johnson et al., 2005; Johnson, Nicol, Zecker, & Kraus, 2007; King et al., 2002; Wible, Nicol, & Kraus, 2005). Interpeak latencies and magnitude of wave D, E, and F typically do not differ between normal children and children with language based learning problems (Johnson et al., 2005, 2007). However, no study to date has investigated how a BioMARK result varies in children at risk for (C)APD only. Researchers have also investigated the performance of children with (C)APD through behavioral central auditory function tests (Farmer & Klein, 1993; Tallal, 1980; King et al, 2003). In spite of that there is a dearth of the studies that have tried to bring out a correlation between the two set of evaluations.

In the present scenario there is a need to see if there is any relationship exists between the speech evoked ABR responses and behavioral tests of (C)APD in children with (central) auditory processing disorders. Scientific evidence supports the relationship between auditory processing and dyslexia in at least some children. The fact that central auditory processing is not affected in all children with reading deficits and reading deficits are not exhibited by all children with (C)APD demonstrate the heterogeneous nature of the disorders (ASHA, 2005; Bellis, 2003). Therefore, the present study will focus on how the relationship between two set of evaluations in children with (C)APD differs from others. Also there is a need to see the pattern across the different age group. Hence, the present study aimed to focus on how the speech evoked auditory brainstem responses relates to the performance on behavioral tests of central auditory processing across different age groups.

AIM OF THE STUDY

- To check the relationship between speech evoked ABR and a set of behavioral tests of central auditory function in children with (C)APD.

OBJECTIVES OF THE STUDY

- To investigate the performance of children with (central) auditory processing disorders and children without (central) auditory processing disorders on different behavioral tests of (C)APD.
- To investigate the performance of children with (central) auditory processing disorders and children without (central) auditory processing disorders on speech evoked ABR.
- To investigate the relationship between speech-evoked ABR and behavioral tests of (C)APD in children with (central) auditory processing disorders.

CHAPTER 2: METHOD

The present study aimed to investigate the auditory processing at sub-cortical levels in children with (Central) auditory processing disorders by means of behavioral and electrophysiological tests. Following method was adopted to accomplish the aim.

The study was carried out in two phases. Phase I involved a preliminary screening session of children by using Screening Checklist for Auditory Processing (SCAP) and click evoked ABR. Phase II consisted of a detailed behavioral (central) auditory processing disorder assessment and speech evoked ABR. Informed consent was obtained from all the participants and their parents.

2.1 Research Design

A two group random selection, post test only design was used for the study.

2.2 Participants

The study included 336 school going children in the age range of 8 to 14 years as participants. Initial screening for (C)APD was carried out for all the participants using SCAP questionnaire developed by Yathiraj and Mascarenhas (2004). SCAP was adopted for screening since the sensitivity and specificity of the tests in identifying children with (C)APD is determined to be 71% and 68% respectively (Muthuselvi & Yathiraj, 2009). Among the 51 children who were identified as at the risk of (C)APD, 10 children each in the age range of 8-10 years, 10-12 years and 12-14 years were considered in experimental group. Similarly, 10 age matched typically developing children in each of the age group who were not at risk of (C)APD were included in the control group. Hence, the research design of the study adopted was two group random selections, post test only. The mean age along with standard deviation of participants in each age group are given in table 1.

Table 2.1: Mean and standard deviation of age of participants in each of the age group

Group	Age range (Years)	Mean age (Years)	SD
Control I	8-10	8.6	0.52
Control II	10-12	10.8	0.42
Control III	12-14	12.8	0.42
Experimental I	8-10	8.5	0.52
Experimental II	10-12	10.6	0.51
Experimental III	12-14	12.3	0.48

SD: Standard deviation

2.3 Subject Selection Criteria

Inclusion Criteria for participants in both the groups

Participants with normal hearing sensitivity (thresholds of Ò 15 dBHL) in the frequency range of 250 to 8000 Hz, normal click evoked ABR, and normal middle ear functions were included. Further, all participants had speech identification scores (SIS) more than 90% in both ears. Both the groupsô participants also had above average IQ.

Exclusion Criteria for participants in both the groups

Participants with peripheral hearing loss, clinically abnormal/absent click-evoked ABR, and any middle ear pathology were excluded from the study. Further, they were also ruled out for any attention deficit hyperactivity disorder (ADHD) and learning problems based on structured case history as well as early reading skills test (Loomba, 1995).

2.4 Instrumentation and test protocol

- A calibrated diagnostic audiometer, Orbitor-922 with TDH-39 headphones, was used for estimating the air conduction thresholds at octave frequencies between 250 Hz and 8000 Hz. The above audiometer with Radio ear B-71 bone vibrator was used for bone conduction testing at octaves frequencies between 250 Hz and 4000 Hz through modified Hughson Westlake procedure (Carhart & Jerger, 1959).

- A calibrated middle ear analyzer, GSI tympstar, was used to obtain tympanogram with a probe tone frequency of 226 Hz and the acoustic reflex thresholds was measured for octave frequency between 500 Hz and 4000 Hz.
- A personal computer (PC) was used to play the test items of behavioral tests for identifying (central) auditory processing disorders which was routed through a clinical audiometer.
- Brainstem responses to click and speech stimuli were recorded using Biologic Navigator Pro EP system (version 7.0). The site of electrode placement was prepared with abrasive gel. Silver chloride electrodes were used with a conducting paste. Responses were differentially recorded from Ag-AgCl electrodes. Each electrode had impedance less than 5 kq and inter electrode impedance were maintained within 2 kq . The following test protocol was used for the recording of click and speech evoked auditory brainstem responses.

Table 2.2: *Recording parameters of click-evoked ABR as well as speech-evoked ABR*

S.No	Parameters	Click-evoked ABR	Speech-evoked ABR
1)	Stimulus	Click (100 µs duration)	40-ms /da/ stimulus
2)	Electrode Placement	Inverting- M1 Non Inverting- Cz Ground- M2	Inverting- M1 Non Inverting- Cz Ground- M2
3)	Intensity	90 dB nHL	80 dB SPL
4)	Polarity	Rarefaction	Alternating
5)	Filter setting	100 ï 3000 Hz.	100 ï 2000 Hz.
6)	Repetition rate	11.1/sec	10.9/sec
7)	Total no. of sweeps	2000	2000
8)	Impedance	< 5k q	< 5k q
9)	Amplification	1,00,000	1,00,000
10)	No. of Channels	One	One
11)	Analysis Time	10 ms	60 ms

2.5 Test Environment

Pure tone audiometry, speech audiometry and immittance evaluation was conducted in sound treated room set up. Further, behavioral tests for (C)APD as well as electrophysiological tests were also carried out in sound treated rooms within the permissible ambient noise (ANSI; 1991).

2.6 Test Procedure

The study was carried out in two phases. Phase I involved a preliminary screening session of children using SCAP questionnaire and click evoked ABR. Phase II consisted of a detailed behavioral central auditory function tests and speech evoked ABR.

Phase I: Preliminary screening

Screening checklist for auditory processing was administered on all the participants in both the groups. There are 12 questions in SCAP checklists, which consist of two points rating scale (Yes/No). Those children who scored more than 50% in that questionnaire were considered for participation in the experimental group.

Pure-tone audiometry and Immittance evaluation were carried out on all the participants in both the groups to estimate their hearing thresholds and to rule out any middle ear pathology. Click evoked ABR testing was performed on all the participants to verify normal transmission of auditory stimuli through the brainstem auditory pathway.

Phase 2: Behavioral central auditory function test and Speech evoked ABR

Once the normal click-evoked ABR and normal hearing sensitivity were confirmed, behavioral tests for the identification of deficits pertaining to (C)APD were carried out on children of both experimental as well as control groups. These tests included were Pitch Pattern Test (PPT) developed by Shivani (2003), Gap Detection Test (GDT) developed by Shivaprakash (2003), Dichotic Consonant Vowel (CV) test developed by Yathiraj (1999), Speech perception in noise (SPIN) and Masking level difference (MLD) test.

The PPT included thirty test items in addition to 6 practice items. Each set of stimulus consisted of three pure tones each of 500 ms duration which were separated by an inter stimulus interval of 300 ms. The frequencies of the tones were 880 Hz and 1430 Hz, thus resulting in two alike and one different tone in each stimulus set. These stimuli were presented at 40 dBSL (Ref SRT) and subjects were instructed to repeat the pattern of sequences verbally.

The GDT consisted of 60 stimuli with 4 practice items and 6 catch trials. The stimuli were a sequence of three 300 ms noise bursts separated by 750 ms silence with a gap inserted in one of those three noise bursts. The duration of the gap reduces progressively from 20 ms to 1 ms. These stimuli were presented at 40 dBSL (Ref. SRT) and the participantsô task was to identify the number in the sequence which possessed the gap.

Dichotic CV test consisted of 30 stimuli at 0 ms lag between the ears. There were six consonants associated with vowel /a/ in the form of CV syllables as /pa/, /ta/, /ka/, /ba/, /da/, and /ga/ served as stimuli. The pair of CV syllables was presented to each ear simultaneously. These stimuli were presented at 40 dBSL (Ref. SRT) and the participants were instructed to write down the stimuli as they are heard. Scores for right ear and left ear were separately analyzed along with double correct scores.

For SPIN test, Kannada word list developed by Yathiraj and Vijayalakshmi (2005) was delivered at 0 dB signal to noise (speech-shaped noise) ratio and the participants were asked to repeat the words. Twenty five words were presented to each ear at the specified signal to noise ratio and the SPIN score was considered as percentage of words identified correctly for each ear. These stimuli were presented at 40 dBSL (Ref. SRT) in both ears.

For MLD test, the signal and noise were given in both homophasic and antiphasic conditions. The test was carried out at 500 Hz as well as 1000 Hz. The difference in the threshold between homophasic and antiphasic condition was considered as the amount of masking level difference at each frequency. Further, MLD test was carried out at 40 dBSL (Ref SRT).

Participants of both the groups also underwent speech-evoked ABR recording using the default BioMARK protocol of the Biologic Navigator Pro evoked potential system. For acquisition of the responses to auditory stimulus from the scalp, the electrode placement involved securing of the non-inverting electrode at the vertex, inverting at the mastoid of the ear of acoustic stimulation and ground on the opposite mastoid. This protocol uses the synthetic /da/ stimulus for eliciting transient and sustained portions of speech-evoked ABR. The speech stimulus /da/ is a 40 ms synthesized speech syllable obtained using KLATT synthesizer (Klatt, 1980). The waveforms corresponding to the two runs were added using the option of óweighted addô and analyzed for the latencies of wave V, wave A and V/A slope after visual inspection and marking in the Biologic software. Fast Fourier Transform (FFT) was done using the default ánalysisô option in order to obtain the amplitudes corresponding to first formant frequency and higher frequencies.

Parameters that are assessed in BioMARK includes absolute latencies of wave V, wave A, wave C, wave D, wave E, wave F and wave O, V/A slope, first formant frequencies, higher frequencies and BioMARK score. Wave V to A slope is calculated using the following formula, (wave V to A amplitude)/ (wave V to A latency). First formant frequencies shows the average amplitude for frequencies between 454 Hz to 720 Hz and higher frequencies shows the average amplitude for frequencies between 721 Hz to 1154 Hz. Overall BioMARK scores, is a composite score derived from all the 5 parameters it assesses. The BioMARK software considers a score lesser than 5 as normal and scores from 6 to 22 as abnormal.

2.7 Statistical Analysis

Descriptive statistics were obtained and non-parametric tests were carried out for further analyses of the data, since the distribution of most of the variables were significantly different from normal distribution. Non-parametric tests includes Kruskal Wallis test, Wilcoxon signed rank tests and Man Whitney U test was done. In addition to that, Spearmanȏs correlation test was done to study the correlation between different behavioral test findings and speech evoked ABR parameters.

CHAPTER 3: RESULTS

The aim of the present study was to investigate the relationship between speech evoked ABR and a set of behavioral test results of central auditory function in children at risk for (C)APD and typically developing children. Sequence of statistical tests was carried out for investigating the differences between the groups and to explore the relationship between speech evoked ABR results and a set of behavioral APD tests.

Kolmogorov-Smirnov test for normality was carried out initially which revealed that the distribution of most variables were significantly different from normal distribution. Hence, non parametric tests were used for further statistical analysis. *Descriptive statistics* were also carried out to obtain mean and standard deviations for different parameters of speech evoked ABR along with that of different behavioral tests scores.

Wilcoxon signed rank test was done to check ear differences for different behavioral central auditory function tests (GDT, PPT, DCV, SPIN, & MLD) as well as for different parameters of speech evoked ABR (wave V, A, V/A slope, first formant, higher frequencies, wave C, D, E, & F) in both control and experimental groups. The results revealed no significant ear differences for any of the behavioral tests ($p>0.05$) except dichotic CV test which revealed significant ear differences for single correct score in the age groups of 10-12 years and 12-14 ears in both the groups ($p<0.05$). For the speech-evoked ABR, there was no ear difference for any of the parameters ($p>0.05$) other than the significant difference portrayed by wave V latency and higher formantsô amplitude only for the age range of 12-14 years ($p<0.05$). The details are shown in Appendix I.

Kruskal Wallis test was administered to check the effect of age on different behavioral central auditory function tests and different parameters of speech evoked ABR. In behavioral measures, the results revealed significant effect of age only for PPT and dichotic CV tests ($p<0.05$). However, significant differences between the age groups were not observed for GDT, SPIN and MLD. In speech evoked ABR parameters, there was no significant difference between the age groups ($p>0.05$) except wave A and overall BioMARK scores of right ear and V/A slope of left ear. The outcome of Kruskal Wallis test is mentioned in Appendix II.

Mann Whitney U test was carried out to compare results of various behavioral tests between control and experimental group. It was also done to examine the effects of age within the control and the experimental groups. In addition, *Spearman's correlation test* was carried out to study the correlation between different behavioral central auditory function test findings and speech evoked ABR parameters.

3.1. Behavioral assessment of central auditory function

There were five different behavioral tests of central auditory function done in the present study. These tests assessed different domains of central auditory functions such as temporal processing, temporal resolution, binaural integration, auditory closure and binaural interaction. The outcomes of different domains are mentioned under separate sub-headings below.

3.1.1. Behavioral assessment of temporal processing

Gap detection test and pitch pattern test were carried out to assess the temporal processing in children of both the groups. The mean GDT values did not appear to increase with increasing age irrespective of the ear. However, the mean values were found to suggest towards higher (larger) gap detection threshold in the experimental group when compared to the control group. The mean and standard deviation of the results of gap detection test are shown in Table 3.1. The significance of these observations were further analyzed using various statistical measures. Figure 3.1 shows bar graphs representing mean and 95% confidence intervals (CI) of gap detection thresholds.

Table 3.1: Mean and standard deviation (SD) of GDT results in both the groups

Group	Ear	8-10 years		10-12 years		12-14 years	
		Mean *	SD	Mean*	SD	Mean*	SD
Control	RE	3.70	0.67	3.30	0.82	3.90	0.87
	LE	3.70	0.67	3.40	1.07	3.80	0.92
Experimental	RE	5.60	3.47	5.10	1.72	4.60	0.84
	LE	5.50	3.06	5.00	1.49	4.70	0.82

**in millisecond; RE= right ear; LE= left ear; GDT= gap detection test*

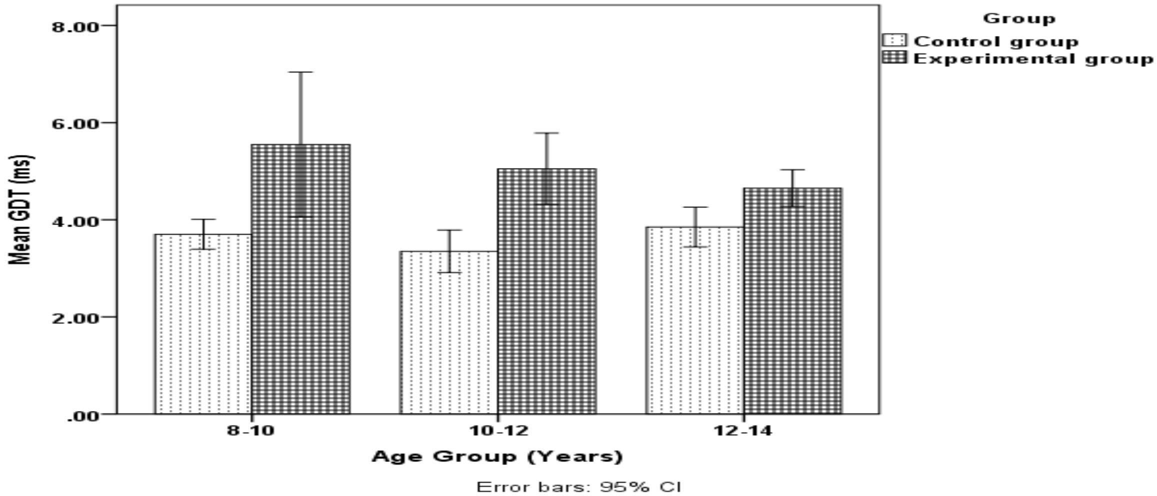

Figure 3.1: Mean and 95% confidence intervals (CI) of GDT in control and experimental groups for different age ranges (8-10 years; 10-12 years; 12-14 years)

The *outcome of Mann Whitney U test* showed a statistically significant difference in the overall gap detection threshold between the typically developing children and those at risk for (C)APD ($p < 0.05$). The within age group comparison between the two groups also demonstrated the existence of statistically significant difference for 10-12 years and 12-14 years. However, the difference between the groups was statistically not significant in the 8-10 years old age group. The specific comparisons have been shown in Table 3.2. In addition to the above, from figure 3.1, it can be observed that among all the age groups, children at risk for (C)APD in older age group (12-14 years) obtained lowest (better) gap detection threshold in comparison to 8-10 years and 10-12 years old children.

Table 3.2: The outcome of Mann Whitney U statistics for Gap detection test and Pitch pattern test

Tests	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*p*	Z	*p*	Z	*p*	Z	*p*
GDT	RE	-1.42	0.15	-2.82	**0.00**	-1.68	0.09	-3.58	**0.00**
	LE	-1.11	0.27	-2.41	**0.02**	-2.16	**0.03**	-3.43	**0.00**
PPT	RE	-0.34	0.73	-2.43	**0.02**	-3.26	**0.00**	-3.21	**0.00**
	LE	-0.46	0.65	-2.01	**0.04**	-3.31	**0.00**	-2.99	**0.00**

RE= right ear; LE= left ear; GDT: Gap detection test; PPT: Pitch pattern test

Pitch pattern test (PPT) was administered on all the children of both the groups. There appeared a trend towards increase in the scores of PPT with increasing age in the control group. However, such an increase in scores with age is not reflected in the experimental group. Additionally, the PPT scores in the older age group (12-14 years) exhibited larger differences between the control and the experimental groups whereas similar pattern did not notice in the younger age group (8-10 years). The mean PPT scores were lesser (poorer) for experimental groups in comparison to control groups for age groups 10-12 and 12-14 years. However, 8-10 age group children had almost equal mean scores for pitch pattern test. The mean and standard deviation of PPT scores has been shown in Table 3.3.

Table 3.3: Mean and standard deviation of Pitch pattern test scores

Group	Ear	8-10 Years		10-12 Years		12-14 Years	
		Mean	SD	Mean	SD	Mean	SD
Control	RE	16.80	7.31	23.00	8.18	24.7	4.78
	LE	16.60	7.26	22.20	4.71	26.00	4.24
Experimental	RE	17.00	6.23	14.00	8.41	15.00	3.80
	LE	17.70	6.21	15.10	8.18	15.00	4.42

RE= right ear; LE= left ear; Maximum possible score was 30

Mann Whitney U test was used to compare the PPT scores of typically developing children and at risk for (C)APD children. The results revealed a statistically significant difference between the two groups ($p < 0.05$). Using the same statistical tool, groupôs comparisons within each age group demonstrated statistically significant difference in the older age groups children (10-12 & 12-14 years) but not for the younger aged ones (8-10 years). The specific óZô and ópô values have been shown in Table 3.2. Figure 3.2 shows the mean and 95% confidence intervals of PPT scores for typically developing children and those at risk for (C)APD.

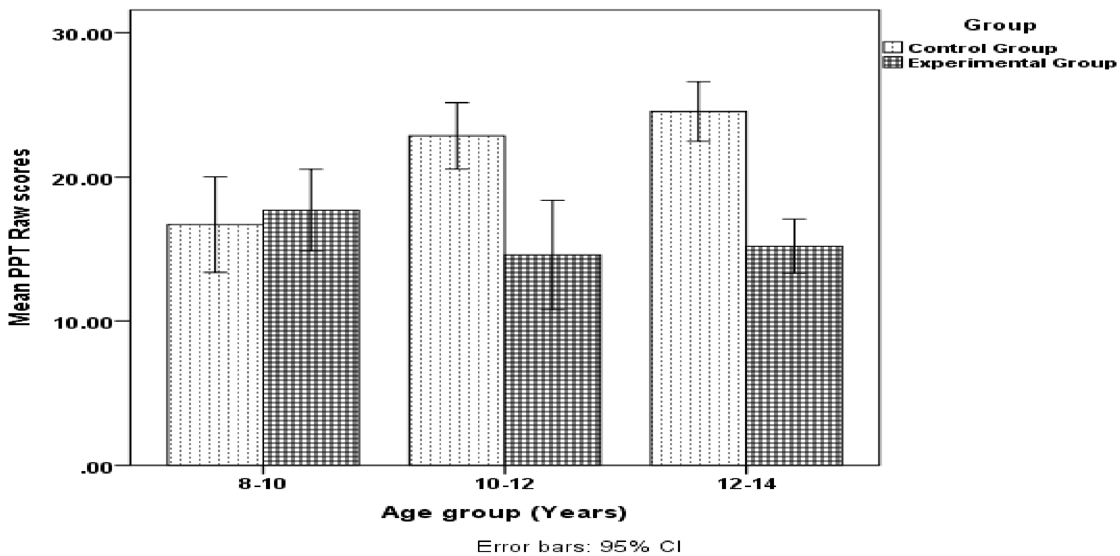

Figure 3.2: Mean and 95% confidence intervals (CI) of PPT scores by children with different age range in control and experimental groups.

3.1.2. Behavioral assessment of binaural integration

Dichotic CV test was administered for assessing the binaural integration for children from both the groups. The single correct scores (SCS) demonstrated a tendency for higher scores from right ear than the left irrespective of the groups. The single as well as double correct scores (DCS) appeared to increase with increasing age in the control group but not in the experimental group. Further, SCS and DCS of dichotic CV test also portrayed a tendency for higher mean scores in the control group than the experimental group. Table 3.4 shows mean and standard deviation of dichotic CV test for the three different age groups within each population of the study. SCS and DCS of dichotic CV test were further analyzed using statistical tools.

Table 3.4: Mean and standard deviation of Dichotic CV scores from both the groups

Group		Ear	8-10 Years		10-12 Years		12-14 Years	
			Mean	SD	Mean	SD	Mean	SD
Control group	SCS	RE	12.90	3.60	20.50	5.54	19.70	4.62
		LE	12.20	2.57	15.70	4.85	16.50	4.19
	DCS		5.40	2.59	9.30	4.72	11.40	3.30
Experimental Group	SCS	RE	15.20	6.06	12.50	6.96	13.60	3.92
		LE	12.10	5.42	11.20	7.17	11.60	4.08
	DCS		6.90	4.40	5.40	7.16	5.20	2.44

SD= standard deviation; RE= right ear; LE= left ear; DCV= dichotic CV test; SCS= single correct score; DCS= double correct score; Maximum possible score was 30.

Comparison of the performances of children between control and experimental group was carried out using Mann Whitney U test. The results revealed a statistically significant difference in SCS between the ears as well as the groups (control & experimental) ($p<0.05$). The DCS of the control group also differed significantly from that of the experimental group ($p<0.05$). In terms of the age group, the SCS as well as DCS of the older children (12-14 years) in control group was significantly different for the same age group in experimental group. However, there was no statistically significant inter-group difference for the younger age group (8-10 years) for either of the scores ($p>0.05$). The details of Mann Whitney U test results are shown in Table 3.5. Figure-3.3 represents the outcomes of SCS as well as DCS of dichotic CV test for typically developing children and children at risk of (C)APD.

Table 3.5: Z and *p* values for comparison of SCS and DCS results between control and experimental groups using *Mann Whitney U test*

Tests	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	p	Z	p	Z	p	Z	p
SCS	RE	-1.06	0.29	-2.31	**0.02**	-2.55	**0.01**	-2.45	**0.01**
	LE	-0.07	0.94	-1.74	0.08	-2.09	**0.04**	-2.40	**0.02**
DCS		-0.49	0.62	-1.67	0.09	-3.27	**0.00**	-2.63	**0.01**

RE= right ear; LE= left ear; SCS= single correct score; DCS= double correct score

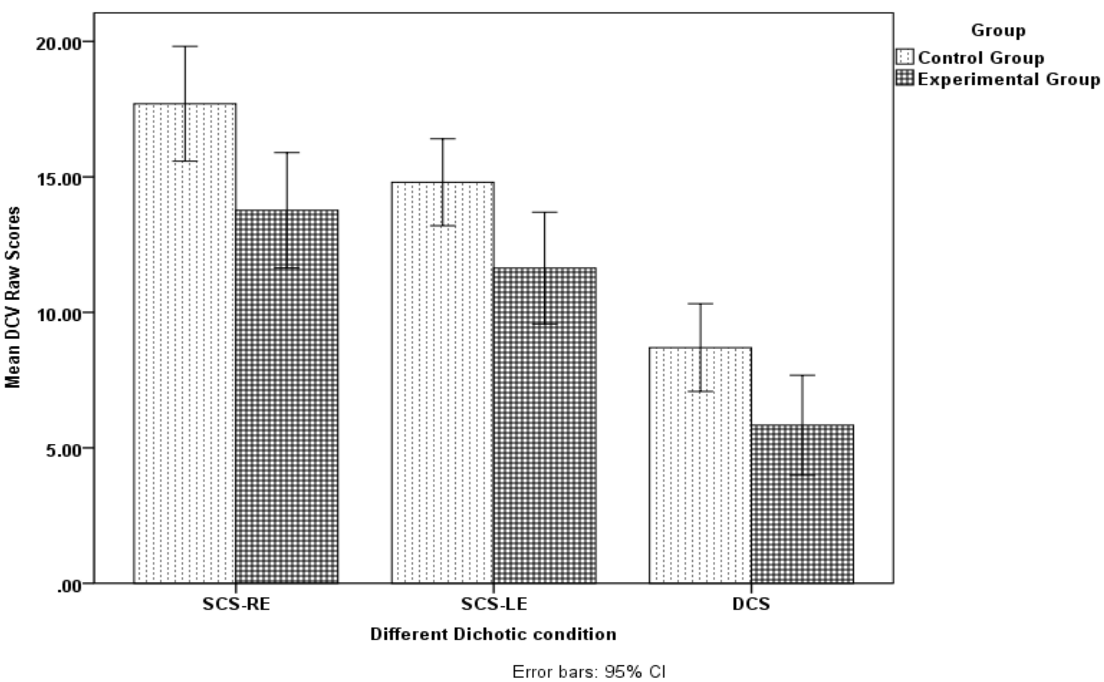

Figure 3.3: Mean and 95% confidence intervals (CI) of DCV test represented as SCS of right and left ear and DCS (*Hints: SCS- Single Correct Scores, DCS: Double correct scores; DCV-Dichotic CV)*

3.1.3. Behavioral assessment of auditory closure

Speech perception in noise was carried out to explore the auditory closure abilities of participants of both the groups. Table 3.6 shows mean and standard deviation of raw SPIN scores and in percentage for children at risk for (C)APD and typically developing children. The performance on SPIN appeared to be similar between the ears in each age group and also between the age groups. However, the performance of children in experimental group seemed to be poorer (lower scores) than the children in control group.

Table 3.6: Mean and standard deviation of SPIN scores (Raw scores & Percentage)

Group	Ear	8-10 Years		10-12 Years		12-14 Years	
Control		Mean (SD)*	Mean (SD) (%)	Mean (SD)*	Mean (SD) (%)	Mean (SD)*	Mean (SD) (%)
	RE	17.70 (1.56)	70.80 (6.26)	17.40 (1.26)	69.60 (5.05)	17.10 (1.10)	68.40 (4.40)
	LE	17.70 (0.94)	70.80 (3.79)	17.40 (1.07)	69.60 (4.29)	17.10 (1.10)	68.40 (4.40)
Experimental	RE	16.80 (1.81)	67.20 (7.25)	16.10 (2.13)	64.40 (8.52)	16.16 (2.08)	62.40 (9.27)
	LE	16.30 (1.63)	65.20 (6.54)	16.00 (2.53)	64.00 (10.15)	15.60 (1.34)	62.40 (5.39)

**Raw scores; SD= standard deviation; RE= right ear; LE= left ear; SPIN= speech perception in noise*

Comparison between control and experimental group using Mann Whitney U tests revealed the SPIN scores for children in the experimental group to be significantly lower (poorer) than that of the children in the control group ($p < 0.05$). The scores obtained by children in each of the age range were also compared between the control and experimental groups. It was observed that the performances between two groups did not vary significantly with respect to age except for left ear of older children (12-14 years). The results of Mann Whitney U test are shown in Table 3.7. Figure 3.4 depicts the outcomes of SPIN test.

Table 3.7: Z and *p* values for comparison of SPIN results between control and experimental groups using *Man Whitney U test*

Tests	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*p*	Z	*p*	Z	*p*	Z	*p*
SPIN	RE	-1.08	0.28	-1.65	0.10	-1.91	0.06	-2.59	**0.01**
	LE	-1.91	0.06	-1.23	0.22	-2.49	**0.01**	-3.27	**0.00**

RE= right ear; LE= left ear; SPIN= speech perception in noise

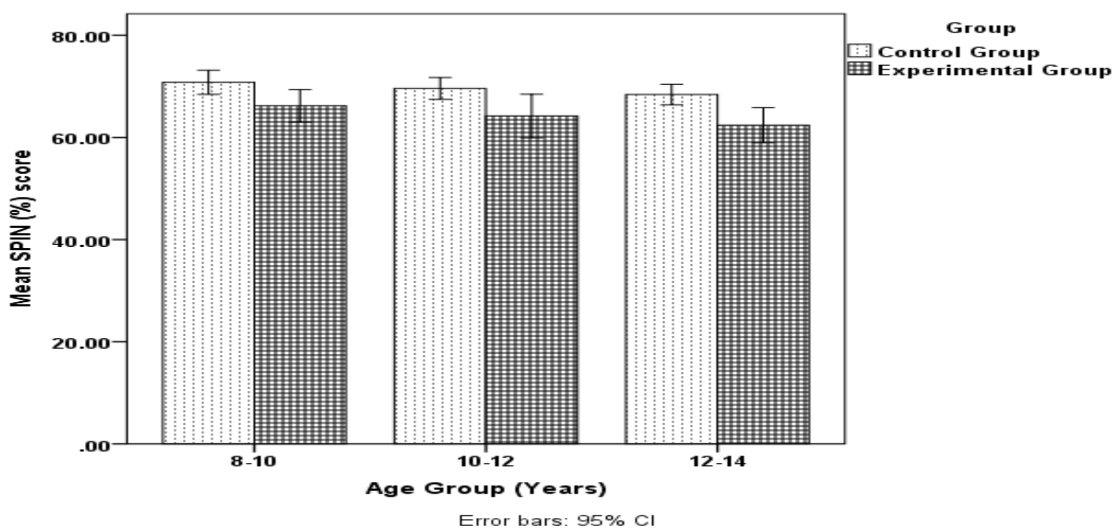

Figure 3.4: Mean and 95% confidence intervals (CI) scores (%) obtained in SPIN test for different age range children in both groups

3.1.4. Behavioral assessment of binaural interaction

MLD at 500 Hz and 1 kHz were obtained to assess the binaural interaction function. Change in performance with age and differences in scores between control and experimental groups were studied. There seemed to be a lack of difference in mean MLD values between the age ranges. Within each of the age range, the mean MLD values were appeared marginally higher in the experimental group compared to the control group. The mean and standard deviation of children in control and experimental groups are mentioned in Table 3.8.

Table 3.8: Mean and standard deviation of MLD results in both the groups

Group	Frequency (Hz)	8-10 Years		10-12 Years		12-14 Years	
		Mean (dB)	SD	Mean (dB)	SD	Mean (dB)	SD
Control	500	7.0	2.58	7.0	2.58	6.0	2.10
	1000	7.0	2.58	7.0	2.58	7.0	2.58
Experimental	500	8.0	2.58	7.5	2.63	7.5	2.63
	1000	8.5	2.41	7.5	2.63	9.5	1.58

SD= standard deviation; MLD= masking level difference

Comparison between the control and experimental group using Mann Whitney U test revealed no significant difference in the MLD at 500 Hz between the groups ($p < 0.05$) in any of the age ranges. However, this was not the case with the MLD at 1 kHz. Though first two age groups (8-10 & 10-12 years) children did not show a significant inter-group difference, there was a significant difference observed for older children (12-14 years). When age was not considered a criterion, there was also an overall inter-group difference for 1 kHz ($p < 0.05$) but not for 500 Hz ($p > 0.05$). The óZô and ópô values of Mann Whitney U test have been depicted in Table 3.9. Figure 3.5 shows the performance of children in control as well as experimental groups on MLD test.

Table 3.9: Z and *p* values for comparison of MLD results between control and experimental groups using *Mann Whitney U test*

Tests	Frequency	8-10 Years	10-12 Years	12-14 Years	Overall

	(Hz)	Z	p	Z	P	Z	p	Z	p
MLD	500	- 0.87	0.38	-0.44	0.66	-1.37	0.17	-1.55	0.12
	1000	-1.31	0.19	-0.44	0.66	-2.29	**0.02**	-2.32	**0.02**

MLD= masking level difference

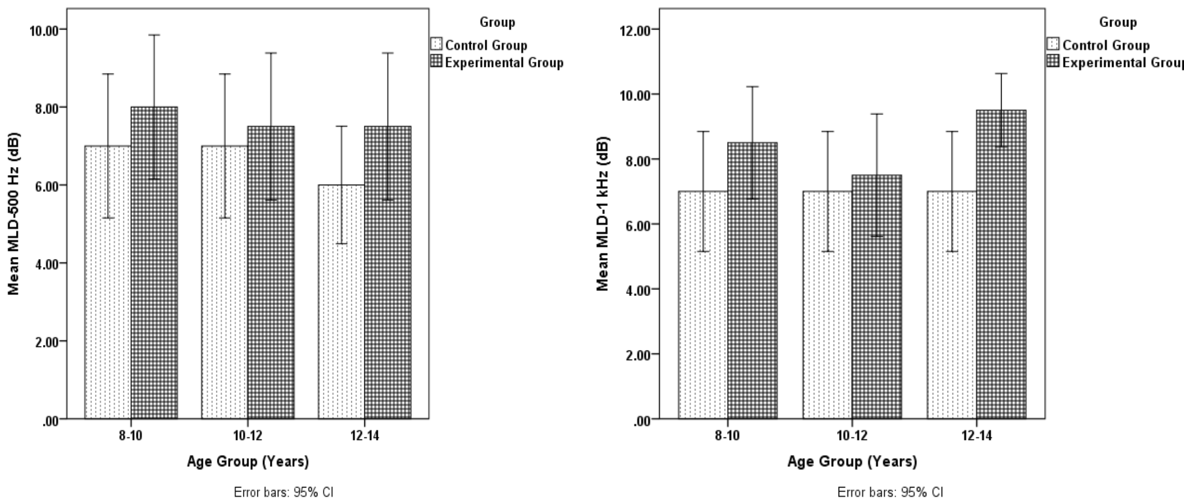

Figure 3.5: Mean and 95% confidence intervals (CI) of MLD (dB) test at 500 Hz and 1 kHz for different age range children

3.2. Electrophysiological assessment using speech evoked ABR

Speech evoked ABR using BioMARK protocol was carried out for assessing the integrity of the auditory system for children in both the groups. The responses were analyzed as transient as well as sustained along with overall BioMARK scores. Transient responses included wave V, wave A, V/A slope, and wave C. Sustained responses consisted of amplitude of response to first formant, amplitude of response to higher frequencies, latency of waves D, E, and F. Overall BioMARK score is generated automatically by the software based on all the parameters assessed. Effect of age, ear and the differences between the groups in various parameters were analyzed.

3.2.1. Transient responses of speech evoked ABR

Transient responses of speech evoked ABR includes latency of wave V, latency of wave A and amplitude of V/A slope. The latency of wave V and A were measured for both groups of children at risk for (C)APD and typically developing children in different age range (8-10 years; 10-12 years; & 12-14 years).

3.2.1.1. Wave V and Wave A latency measure

The mean and standard deviation of wave V and wave A latency of speech evoked ABR for both the groups of children are mentioned in table 3.10. The latency differences between control and experimental groups were observed for different age groups children and the significance of these findings were validated through further statistical analysis.

Table 3.10: Mean and standard deviation (SD) of latencies of wave V and A in both the groups

Group	Wave	Ear	8-10 Years		10-12 Years		12-14 Years	
			Mean*	SD	Mean*	SD	Mean*	SD
Control	V	RE	6.27	0.21	6.35	0.23	6.35	0.22
		LE	6.25	0.20	6.33	0.15	6.25	0.20
	A	RE	7.25	0.27	7.25	0.30	7.19	0.25
		LE	7.23	0.31	7.21	0.30	7.22	0.26
Experimental	V	RE	6.47	0.33	6.59	0.22	6.47	0.20
		LE	6.44	0.24	6.61	0.19	6.56	0.22
	A	RE	7.85	0.40	7.53	0.25	7.44	0.28
		LE	7.57	0.39	7.55	0.21	7.59	0.25

SD= standard deviation; RE= right ear; LE = left ear;= in millisecond*

Mann Whitney U test were done to compare the significance differences between two groups of children. The results revealed that overall there were significant difference in latency measure of wave V and A between two groups (table 3.11). When comparison was made between two groups within each age range children, significance differences were observed for older age groups of children (10-12 years & 12-14 years) for both ears except wave V of right ear. However, younger age group (8-10 years) did not show such differences between two groups for both ears except wave A of right ear. Figure 3.6 shows the graphical representation of latency of wave V and wave A in children at risk for (C)APD and typically developing children.

Table 3.11: Z and *p* values for comparison of wave V and A between control and experimental groups using *Mann Whitney U test*

Tests	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*P*	Z	*p*	Z	*p*	Z	*p*
Wave V	RE	-1.45	0.15	-1.87	0.06	-0.99	0.32	-2.61	**0.01**
	LE	-1.61	0.11	-2.86	**0.00**	-2.59	**0.01**	-4.07	**0.00**
Wave A	RE	-2.92	**0.00**	-2.05	**0.04**	-2.02	**0.04**	-4.06	**0.00**
	LE	-1.86	0.06	-2.44	**0.02**	-2.59	**0.01**	-3.95	**0.00**

RE= right ear; LE = left ear

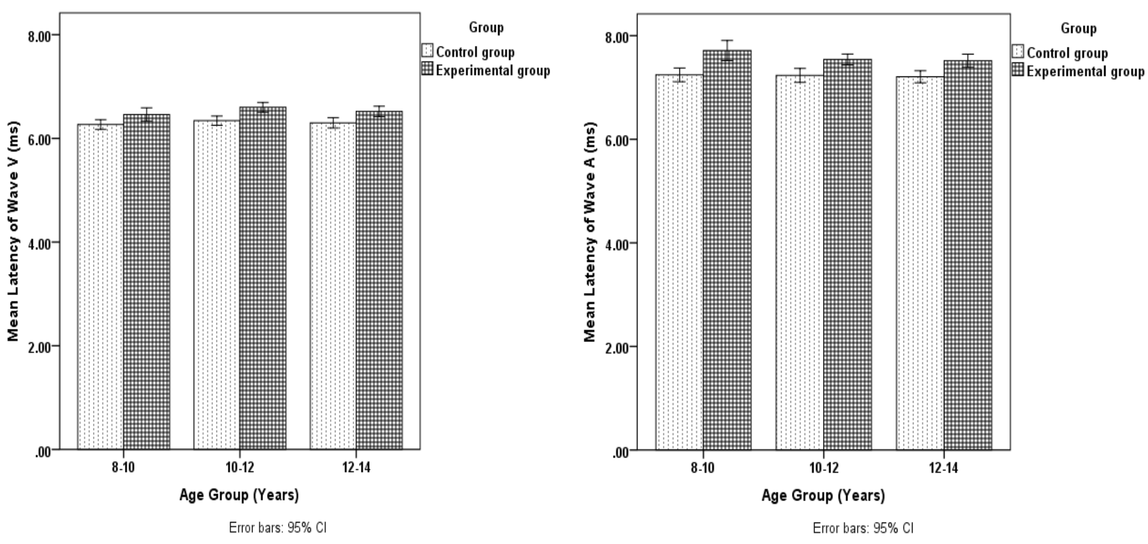

Figure 3.6: Mean and 95% confidence intervals (CI) of Wave V and A latency (ms) in both groups for different age range children

3.2.1.2. V/A slope measure

V/A slope is another important parameter of speech evoked ABR that was studied. The mean and standard deviation of the amplitudes of V/A slope is given in table 3.12. In control group, the mean values of V/A slope did not show much change with age in both ears. However, in experimental group, some changes in both ears in terms of amplitude of V/A slope noticed for different age group. Detailed statistical analysis was carried out further.

Table: 3.12: Mean and standard deviation of V/A slope in speech evoked ABR of both the groups

Group	Ear	8-10 Years		10-12 Years		12-14 Years	
		Mean*	SD	Mean*	SD	Mean*	SD
Control	RE	-0.37	0.15	-0.37	0.16	-0.39	0.18
	LE	-0.37	0.18	-0.48	0.23	-0.33	0.23
Experimental	RE	-0.26	0.15	-0.38	0.14	0.43	0.23
	LE	-0.26	0.09	-0.33	0.16	0.44	0.08

*SD= standard deviation; RE= right ear; LE = left ear; ABR= auditory brainstem response; *= (µV/ms); ms= millisecond; µV= micro volt*

Comparison of the V/A slope between the experimental and control group was carried out using Mann Whitney U test. The results revealed that the V/A slope did not show statistically significant differences between two groups of populations within each age group as well as overall the groups in each age range of children as well as in terms of overall performance at 0.05 levels (table 3.13). Figure 3.7 shows the graphical representation of V/A slope.

Table 3.13: Z and *p* values of V/A slope results between control and experimental groups using Man Whitney U test

Parameter	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*P*	Z	*p*	Z	*p*	Z	*p*
V/A slope	RE	-1.55	0.12	-0.04	0.97	-0.27	0.79	-0.89	0.37
	LE	-1.40	0.16	-1.63	0.10	-1.78	0.08	-0.67	0.51

RE= right ear; LE= left ear

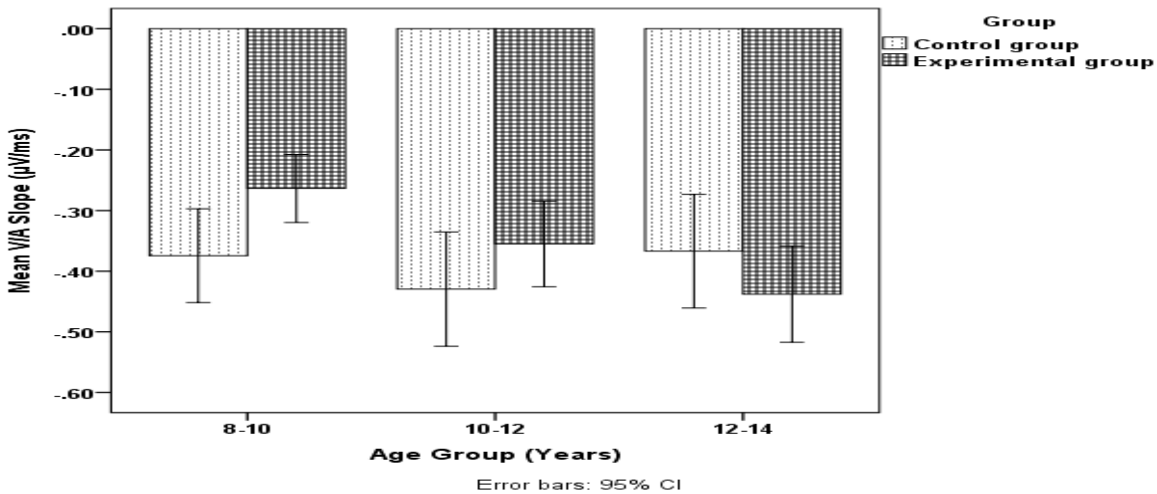

Figure 3.7: Mean and 95% confidence intervals (CI) of Amplitude (µV- Microvolt; ms-millisecond) of V/A slope in both groups for different age range children

3.2.1.3. Wave C latency measure

The speech-evoked ABR was also analyzed in terms of latency of wave C. The mean latency and standard deviation of wave C is given in table 3.14. Observation of mean data reflects that the latencies did not vary much with age in both the groups. The results of the Mann Whitney U test revealed that the latency of wave C in the left ear were varied significantly between control and experimental group while the latency of wave C in the right ear did not demonstrate such a difference (table 3.15). Further comparison between the groups for wave C in each age range of children revealed that a significant difference exists only in the left ear of middle age range children (10-12 years) while such a difference was not observed in younger and older age range children. Figure 3.8 depicts the mean and 95% confidence intervals (CI) of latencies of wave C.

Table: 3.14: Mean and standard deviation of wave C in both the groups

Group	Ear	8-10 Years		10-12 Years		12-14 Years	
		Mean*	SD	Mean*	SD	Mean*	SD
Control	RE	17.83	0.81	17.77	1.10	18.08	0.44
	LE	17.61	0.81	17.20	1.25	17.96	0.95
Experimental	RE	18.37	0.36	17.69	1.06	17.97	0.88
	LE	18.29	0.52	18.25	0.60	17.95	0.88

*SD= standard deviation; RE= right ear; LE = left ear; * ms= millisecond*

Table 3.15: Z and *p* values of wave C results between control and experimental groups using Mann Whitney U test

Parameter	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*p*	Z	*p*	Z	*p*	Z	*p*
	RE	-1.59	0.11	-0.74	0.46	-0.19	0.85	-0.61	0.54
Wave C	LE	-1.48	0.14	-2.29	**0.02**	-0.30	0.76	-2.77	**0.01**

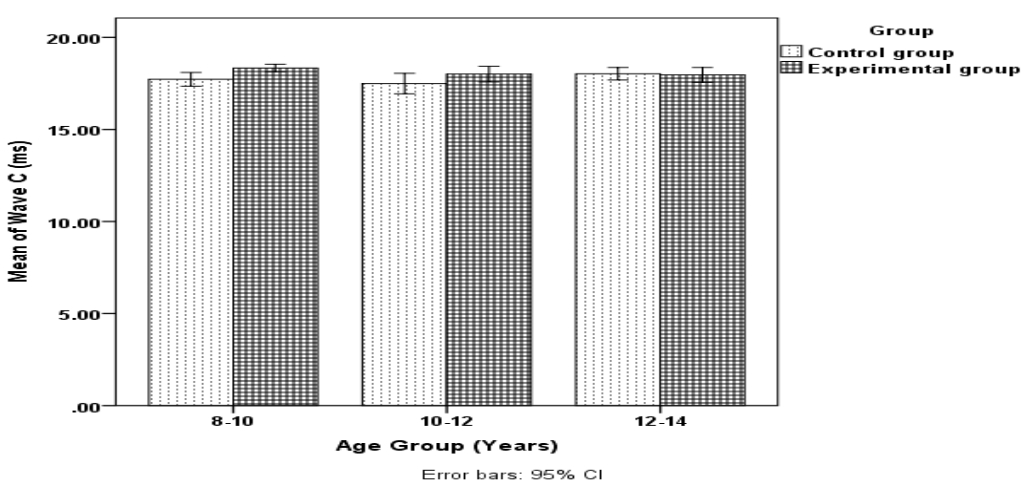

Figure 3.8: Mean and 95% confidence intervals (CI) of Wave C latency in both groups for different age range children

3.2.2. Sustained responses

Sustained responses in speech evokes ABR that were analyzed includes amplitudes in response to first formant and higher frequencies, latencies of wave D, E, and F. The amplitudes and latencies of these parameters were calculated in both control and experimental groups and analyzed.

3.2.2.1. Amplitude of response to first formant

Amplitudes of response to first formant was obtained automatically from the software and analyzed further. Mean and standard deviation of amplitude in response to first formant in both the groups are given in table 3.16. It was observed from that the amplitudes of response to first formant increased with age in the right ear for both the groups. However, the amplitudes in the left ear failed to show such pattern in both the groups. It can also be noted that the amplitudes of first formant is higher in control group compared to the experimental group. Further statistical analysis followed these observations.

Table: 3.16: Mean and standard deviation of amplitudes of response to first formant in speech evoked ABR of both the groups

Group	Ear	8-10 Years		10-12 Years		12-14 Years	
		Mean	SD	Mean	SD	Mean	SD
Control group	RE	2.65	0.46	2.72	0.64	2.78	0.87
	LE	2.54	0.46	3.14	1.22	2.90	1.30
Experimental Group	RE	1.83	0.93	2.25	0.56	2.99	1.30
	LE	2.57	1.10	2.06	0.55	2.37	1.22

SD= standard deviation; RE= right ear; LE= left ear

Statistical analysis using Mann Whitney U test revealed overall statistically significant differences between two groups for amplitude of responses for first formant at 0.05 levels. However significant difference between two groups were not observed for each age range of children in both ears except right ear of younger (8-10 years) ones and left ear of middle age (10-12 years) range children (table 3.17). Figure 3.8 shows the graphical representation of the amplitude of response to first formant.

Table 3.17: Z and *p* values for comparison of amplitude of response to first formant between control and experimental groups using *Man Whitney U test*

Parameter	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*p*	Z	*p*	Z	*p*	Z	*p*
Response to first formant	RE	-2.04	**0.04**	-1.48	0.14	-0.08	0.94	-2.14	**0.03**
	LE	-.19	0.85	-2.19	**0.03**	-0.87	0.38	-1.99	**0.05**

RE= right ear; LE= left ear

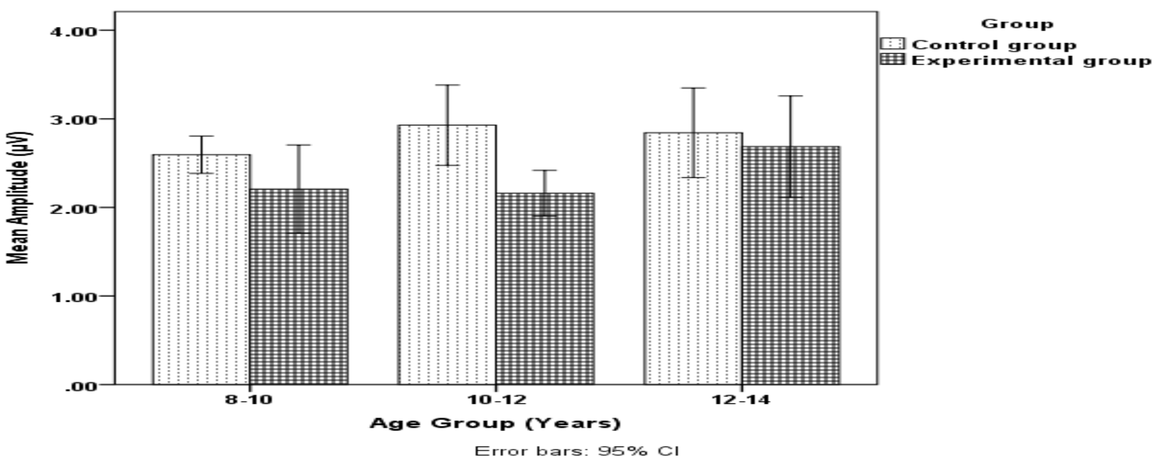

Figure 3.9: Mean and 95% confidence intervals (CI) of amplitude (µV) of responses to first formant for both groups in different age range children

3.2.2.2. Amplitude of response to higher frequencies

Amplitudes of response to higher frequencies were also calculated automatically by the software which is further analyzed statistically. Mean and standard deviation of amplitude in response to higher frequencies in both the groups are given in table 3.18. It was observed that the amplitude of response for higher frequencies in both the ears did not vary much with age in both control and experimental groups.

Table: 3.18: Mean and standard deviation of amplitudes of response to higher frequencies in speech evoked ABR of both the groups

Group	Ear	8-10 Years		10-12 Years		12-14 Years	
		Mean	SD	Mean	SD	Mean	SD
Control	RE	1.06	0.33	0.99	0.39	0.86	0.27
	LE	1.09	0.55	1.05	0.31	1.03	0.37
Experimental	RE	0.87	0.41	0.82	0.25	1.12	0.43
	LE	0.99	0.58	1.47	1.48	0.99	0.44

SD= standard deviation; RE= right ear; LE= left ear

From table 3.19, Mann Whitney U test did not show statistically significant differences between two groups for overall performance as well as for each age range of children except right ear of younger age range children (8-10 years). The above finding indicates the performance were comparable between two groups in terms of amplitude of responses to higher frequencies. Figure 3.10 depicts the mean and 95% confidence intervals (CI) of amplitude of response to higher frequencies.

Table 3.19: Z and *p* values for comparison of amplitude of response to higher frequencies between control and experimental groups using Man Whitney U test

Parameter	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*p*	Z	*p*	Z	*p*	Z	*p*
Higher frequencies	RE	-1.70	**0.04**	-0.68	0.49	-1.78	0.08	-0.44	0.48
	LE	-1.17	0.24	-0.79	0.43	-0.45	0.65	-1.28	0.20

RE= right ear; LE= left ear

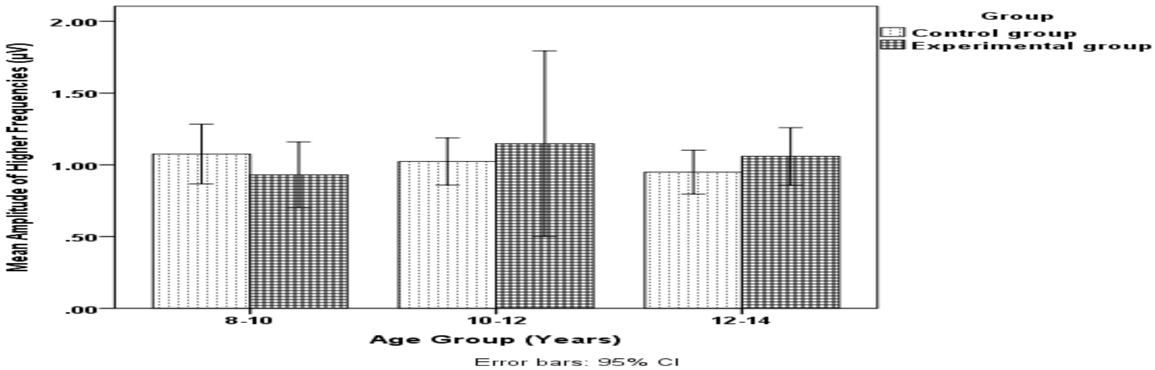

Figure 3.10: Mean and 95% confidence intervals (CI) of amplitude (µV) of responses to higher frequencies for both groups.

3.2.2.3. Latency of wave D, E, and F (FFR component)

The latencies of was D, E, and F were also measured and analyzed in both the groups. The mean latency and standard deviation of wave D, E, and F are shown in table 3.20.

Table 3.20: Mean and standard deviation of latencies of wave D, E, and F in speech evoked ABR of both the groups

Group	**Parameter**	**Ear**	**8-10 Years**		**10-12 Years**		**12-14 Years**	
			Mean*	SD	Mean*	SD	Mean*	SD
	Wave D	RE	21.72	0.46	22.17	0.46	21.82	0.46
		LE	22.01	0.98	22.06	1.03	22.10	0.60
Control	Wave E	RE	30.68	0.60	30.90	1.38	30.17	0.85
		LE	27.58	9.55	30.40	0.65	30.47	0.37
	Wave F	RE	39.03	0.28	39.16	1.25	38.87	0.74
		LE	37.98	3.18	38.87	1.35	39.09	0.24
	Wave D	RE	23.19	0.46	22.27	0.46	22.78	0.46
Experimental		LE	22.35	0.56	22.95	1.39	22.35	0.77
	Wave E	RE	31.18	0.39	30.50	0.78	31.03	0.59
		LE	31.09	1.04	30.89	0.31	31.21	1.11
	Wave F	RE	39.74	0.77	39.31	0.35	39.45	0.70
		LE	39.34	0.55	39.38	0.30	39.25	0.29

*SD= standard deviation; RE= right ear; LE = left ear; *= in millisecond*

Mann Whitney U test was done for the comparison of latencies between the groups for different age range children (table 3.21). The results revealed that overall wave D, E, and F latencies showed statistically significant differences between two groups for both ears at 0.05 levels. Further, each age group children did not revealed uniform pattern of differences between groups in both ears. Figure 3.11 depicts the mean and 95% confidence intervals (CI) of wave D, E, and F in both the groups.

Table 3.21: Z and *p* values for comparison of latencies of wave D, E, and F in speech evoked ABR between control and experimental groups using Mann Whitney U test

Parameter	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*p*	Z	*p*	Z	*p*	Z	*p*
Wave D	RE	-1.97	**0.05**	-0.53	0.59	-2.65	**0.01**	-3.14	**0.00**
	LE	-1.02	0.31	-1.86	0.06	-0.87	0.38	-2.15	**0.03**
Wave E	RE	-2.12	**0.03**	-0.98	0.33	-3.12	**0.00**	-2.23	**0.03**
	LE	-0.99	0.32	-1.75	0.08	-1.89	0.06	-2.93	**0.00**
Wave F	RE	-2.48	**0.01**	-1.18	0.24	-1.90	0.06	-3.16	**0.00**
	LE	-1.33	0.18	-2.22	**0.03**	-1.29	0.19	-2.98	**0.00**

RE= right ear; LE= left ear

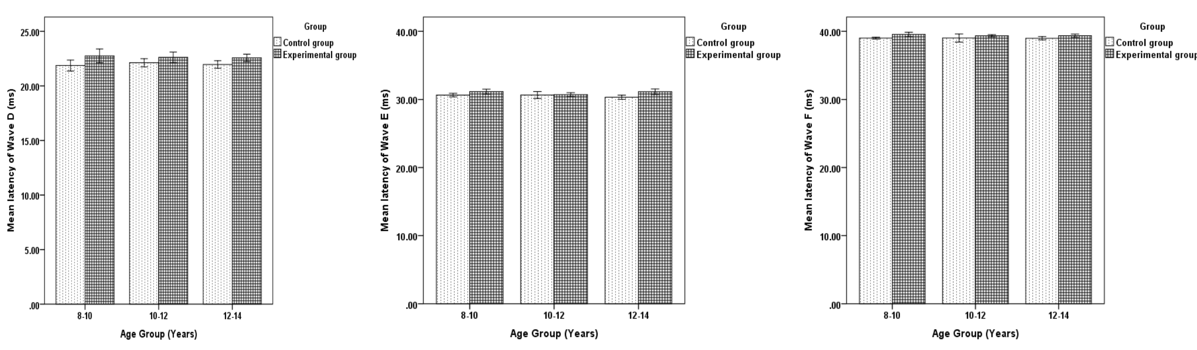

Figure 3.11: Mean and 95% confidence intervals (CI) of latency measures for wave D, E, and F for different age range children in control and experimental groups.

3.3. BioMARK score

BioMARK score is generated automatically by the software based on all the other parameters. Mean and standard deviation of BioMARK scores of both the groups are given in table 3.22. It can be noticed that the BioMARK scores did not vary much bilaterally with age in the control group. However, the experimental group demonstrated variation in scores with age. Detailed statistical analysis was carried out further.

Table: 3.22: Mean and standard deviation of overall BioMARK scores of both the groups

Group	Ear	8-10 Years		10-12 Years		12-14 Years	
		Mean	SD	Mean	SD	Mean	SD
Control	RE	1.1	1.91	1.3	1.82	1.2	1.39
	LE	0.6	0.84	0.4	0.96	1.7	1.82
Experimental	RE	8.0	4.54	3.9	3.75	2.3	2.31
	LE	3.9	4.22	3.6	3.16	2.3	2.35

SD= standard deviation; RE= right ear; LE = left ear

BioMARK scores obtained between control and experimental groups were compared using Mann Whitney U test (Table 3.23). The results revealed that overall BioMARK scores showed a significant difference between two groups for both ears at 0.05 levels. Further, in each age range there were significant differences between groups observed only for younger age (8-10 years) children in comparison to older children (12-14 years) for both ears. However, middle age range (10-12 years) children showed statistical significant differences between groups only for left ear at 0.05 levels. Figure 3.12 depicts the BioMARK score obtained by children in control and experimental groups.

Table 3.23: Z and *p* values for comparison of overall BioMARK scores between control and experimental groups using Man Whitney U test

Parameter	Ear	8-10 Years		10-12 Years		12-14 Years		Overall	
		Z	*P*	Z	*p*	Z	*p*	Z	*p*
BioMARK scores	RE	-3.09	**0.00**	-1.52	0.13	-1.06	0.29	-3.52	**0.00**
	LE	-2.50	**0.01**	-2.75	**0.01**	-0.28	0.78	-3.29	**0.00**

RE= right ear; LE= left ear

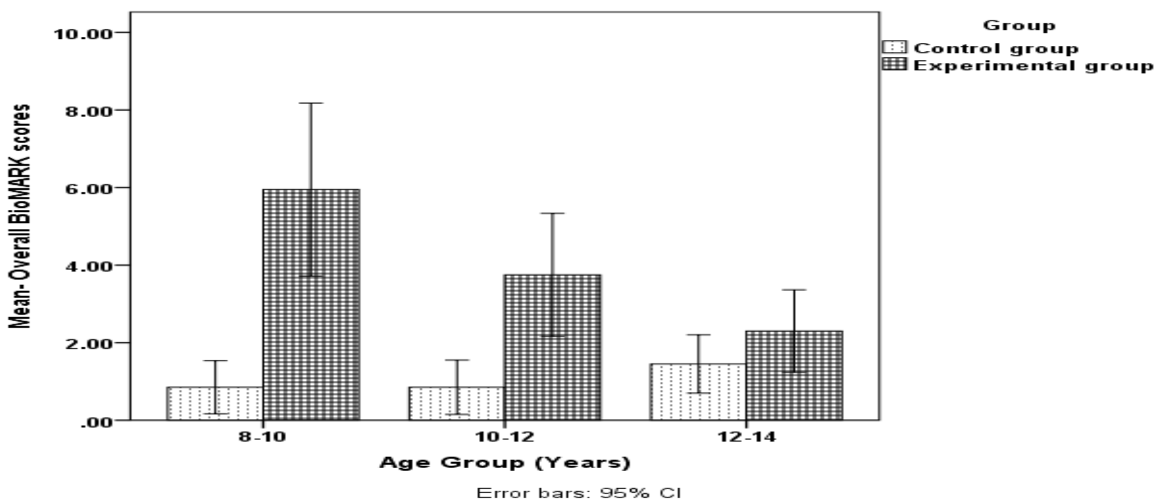

Figure 3.12: Mean and 95% confidence intervals (CI) of overall BioMARK scores in control and experimental groups for different age range children.

3.4. Correlation between behavioral test results and speech evoked ABR

Spearmanốs correlation test was carried out to study the existence of any significant correlations between various behavioral test results and different parameters of speech-evoked ABR in both control and experimental groups. It was observed that most of the parameters of speech evoked ABR did not showed statistically significant correlation with different central auditory function tests (Appendix III). However, a few parameters did show significant correlation in both the groups (Table 3.24 & 3.25).

In control group, there were significant negative correlations observed between SPIN scores and wave A latency of speech evoked ABR (ɉ = -0.38, $p<0.05$) in right ear. Similarly, significant negative correlation obtained between gap detection threshold of right ear with the response of amplitude to first formant (ɉ = -0.38, $p<0.05$) of speech evoked ABR in right ear. Further, a significant positive correlation was observed between PPT score with the latency of wave C (ɉ =0.36, $p<0.05$) in right ear. However, significant negative correlation was observed between SPIN score and latency of wave F (ɉ = -0.38, $p<0.05$) in left ear. It was also observed that the MLD at 500 Hz show positive correlation with latency of wave F (ɉ =0.38, $p<0.05$) in left ear. None of the other parameters within control group showed significant correlation for either ear.

Table 3.24: Correlation between behavioral and electrophysiological test results in control group

Parameters	ρ	p-value
GDT (RE) and response of amplitude to 1^{st} formant (RE)	-0.38	0.03
SPIN (RE) and latency of wave A (RE)	-0.37	0.03
PPT (RE) and latency of wave C (RE)	0.36	0.04
SPIN (LE) and latency of wave F (LE)	-0.38	0.03
MLD (500 Hz) and latency of wave F (LE)	0.38	0.03

RE- Right ear, LE- Left ear, ρ= rho

Similar correlation study in experimental group revealed that within the right ear there is a significant negative correlation between SPIN scores and response to higher frequencies (ɉ = -0.47, $p<0.05$). MLD at 500 Hz was shown to have significant positive correlation with the latency of wave C in the right ear (ɉ =0.39, $p<0.05$) and MLD at 1 kHz correlated negatively with the latencies of wave V (ɉ = -0.39, $p<0.05$) and positively with the latency of wave C (ɉ =0.39, $p<0.05$) in the right ear. In the left ear, SPIN score show positive correlation with the overall

BioMARK score (ɟ =0.43, $p<0.05$). None of the other results and parameters were significantly correlated in children who were at the risk of (C)APD. The results of Spearmanôs correlation in control and experimental groups are given in table 3.24 and 3.25 respectively.

Table 3.25: Correlation between behavioral and electrophysiological test results in experimental group

Parameters	ρ	p-value
MLD (1kHz) and latency of wave V (RE)	-0.38	0.03
SPIN (RE) and response to higher frequencies (RE)	-0.47	0.00
MLD (500 Hz) and latency of wave C (RE)	0.39	0.03
MLD (1kHz) and latency of wave C (RE)	0.39	0.03
SPIN (LE) and BioMARK score (LE)	0.42	0.02

RE- Right ear, LE- Left ear; ρ= rho

CHAPTER 4: DISCUSSION

The performance of children who are at risk of (C)APD and not at the risk of (C)APD were assessed using different behavioral tests and speech evoked ABR in the present study. Further, these findings were studied to identify the existence of significant correlation between the set of behavioral test results with that of speech evoked ABR.

4.1 Behavioral assessment of children at risk for (C)APD

4.1.1 Behavioral assessment of temporal processing

The statistical evaluation was carried out to study the effect of *maturation* on the performance of children in control as well as experimental groups in temporal processing tasks. The results revealed that the score of GDT did not vary with age in both the groups. This finding is in accordance with the previous findings reported (Shivaprakash & Manjula, 2003). It was also observed that the children who are at the risk of (C)APD exhibited elevated GDT along with lower PPT score in comparison to their typically developing counterparts. These findings are in accordance with those reported earlier in related clinical population (Tallal, 1980; Ingelgham et al, 2001). Ingelghem et al (2001) tested the rapid temporal processing efficiency in individuals with dyslexia using auditory gap detection test and reported elevated gap detection threshold in such individuals. Tallal (1980) studied the efficiency to perceive temporal order in individuals with reading impairment. Non-verbal auditory perceptual tests were used and the results revealed a significantly higher rate of errors in the performance of children with reading impairment. The study concluded that certain reading impairments may be related to auditory perceptual deficits. Thus the results are suggestive of a generalized temporal processing deficit in these children.

The developmental pattern of PPT with advancement of age was studied which revealed that the PPT scores improved with age in control group. These findings are also in accordance to previous reports (Shivani & Vanaja, 2003). It was also noted that such a difference with age was not demonstrated in children who are at the risk of (C)APD. This further suggests a possible deviation of the developmental pattern of temporal processing in children who are at the risk of (C)APD.

Children at risk for (C)APD were also found to score significantly poorer on PPT than children who were not at the risk of (C)APD. While Singh and Kumar (2012) reported poorer performance among children with Dyslexia compared to their typically developing peers, Walker, Shinn, Cranford and Givens (2001) reported no difference in performance on frequency pattern test between individuals with reading disorders and healthy controls. The differences in the findings might be attributed to the use of different population in the two set of studies. Alike GDT results, the findings on PPT in the present study indicate towards the existence of temporal processing deficits among children at risk for (C)APD.

4..1.2 Behavioral assessment of binaural integration

Dichotic CV test was carried out in the present study to investigate the binaural integration processing in children who are at the risk of (C)APD. Single correct scores and double correct scores of dichotic CV tests were calculated and analyzed. The change in SCS and DCS scores with age was studied to identify the pattern of development of dichotic performance in both the groups. It was noted that the SCS and DCS increases with age in control group. This pattern of development is in consonance with the reports of Gowri (2001) and Parachi, (2000). It was interesting to note that such an increase in the performance with age was not observed in children within the experimental group. Hence, it may be supposed that, the developmental pattern in the dichotic performance may be altered in children who are at the risk of (C)APD which is reflected in the absence of improved performance with age in the experimental group. During visual inspection of raw data, it was observed that there were few extreme values even though it was not reflected while performing box plot to find out outliers in the raw data. Hence, the lack of developmental trends in experimental groups could be because of heterogeneity in individuals with (C)APD. Further, the outcome of present study finding in dichotic CV test needs to be validated on large population and considered with caution.

The investigation of performance across ears revealed that, children within the age group of 12-14 years in the control group showed a significant right ear advantage while such a trend was not obvious in younger age groups. This finding is suggestive of a developmental pattern of ear advantage with age in typically developing children. However, such a significant ear advantage was not observed in any of the age groups in the experimental group. This finding is contradictory to previous studies which has reported an increased right ear advantage in children with APD (Bellis, Billet & Rose, 2008) and left ear advantage in children with dyslexia (Gupta & Kumar, 2012). However, the methodology of these studies varies from that of the present study. Further, studies also showed that in individuals with dyslexia there is a possibility of either right ear advantage, left ear advantage or, no ear advantage due to heterogeneity among individuals. In dyslexic children, the ear advantage also depends upon the severity of reading and writing impairment (Moncrieff & Black, 2008).

Bellis, Billet and Rose (2008) studied the dichotic performance using dichotic digit test which is different in the linguistic load associated and the complexity involved from dichotic CV test. Hence, dichotic CV test is preferred in present study rather than dichotic digit test. In addition, free recall mode of response was obtained for the dichotic CV test in the present study. However, it has been reported in the literature that the amount of variability in the free recall condition is high and that the results may vary from the expected one (Moncrieff & Musiek, 2002). Study reported by Gupta and Kumar (2012) was carried out in children with dyslexia while the present study was carried out in children who are at the risk of (C)APD. These methodological variations may account for the discrepancy in the findings of ear advantage in the present study.

The results revealed that the SCS of both the ears and DCS were significantly lesser in children who were at the risk of (C)APD when compared to the control group. The results of the present study are in consonance with various other studies reported previously in related clinical populations like Dyslexia (Moncrieff & Black, 2008; Billet & Bellis, 2011; Gupta & Kumar, 2012). While children with Dyslexia were reported to demonstrate significantly poorer performance on Dichotic CV test (Moncrieff & Black, 2008; Gupta & Kumar, 2012), a similar poor performance was reported on Dichotic digit test (Billet & Bellis, 2011). Associating the present study findings with that of the previous reports it may be assumed that a similar binaural integration deficit exists in the children who are at the risk of (C)APD.

4.1.3 Behavioral assessment of auditory closure

SPIN test was used in the present study for evaluating the auditory closure skills in children who were at the risk of (C)APD. Statistical analysis revealed that the performance of children in both the groups did not vary between ears and across different age groups. This suggest that the SPIN scores did not show a developmental trend with age from the age of 8 to 14 years. Further analysis suggested that the scores obtained by the children who are at the risk of (C)APD was significantly lower when compared to that of the typically developing children. This finding is in accordance with various reported findings in related clinical population. Chermak, Vonhof and Bendel (1989) studied the word identification in the presence of noise among adults with learning disability and reported significantly poorer performance in individuals with learning disability in comparison to the age matched controls. The results suggested a greater susceptibility of individuals with learning disability to acoustic masking.

Similar deficits in speech perception in the presence of noise were also reported in another study (Cameron & Dillon, 2008) in individuals with Learning disability. Correlating the finding of earlier studied with the present study findings it may be assumed that a similar susceptibility to acoustic masking persist in children who are at the risk of (C)APD. Analysis between the groups across age ranges revealed that the scores were significantly different between control and experimental group in the age range of 12-14 years while similar difference were not observed in younger age range. This difference is probably suggesting the heterogeneity that exists in the population.

4.1.4 Behavioral assessment of binaural interaction

MLD test was carried out for assessing the binaural interaction skills in children who are at the risk of (C)APD and in typically developing children in the present study. MLD was carried out at 500 Hz and 1 kHz. Effect of age on the MLD results and the comparison of findings between control and experimental group were also carried out. The results revealed that the MLD findings of both the frequencies did not vary with age. This finding proposes that the MLD scores also do not show maturation effects between the age range of 8 to 14 years.

Comparison between the groups revealed that the MLD scores at 500 Hz were comparable while that of 1 kHz varied significantly between the groups. MLD at 1 kHz obtained in the experimental group was significantly elevated when compared to that obtained from the participants in the control group. The findings of the present study are partly in congruence with those reported previously in related clinical group. Roush and Tait (1984) reported a lack of difference in MLD results between children with learning disabilities and typically developing peers. Based on the findings they suggested a lack of sensitivity of MLD in identifying auditory processing deficits in language-learning deficits.

Similar lack of difference in results of MLD has been shown among children with Dyslexia (Hill, Bailey, Griffiths, & Snowling, 1999) and in adults with reading disorders (Amitay, Ahissar, & Nelken, 2002). However, MLD at 1 kHz demonstrated a significant elevation in scores in children within the experimental group. This discrepancy appeared may be attributed to the difference in frequency used for MLD testing. The earlier studies made use of much lower frequencies for MLD testing while findings of MLD using 1 kHz tone lacks in literature. This discrepancy in findings may be a suggestive of the heterogeneity that exists in the population also.

4.1.5 Summary of Behavioral test findings

Tests for tapping various auditory processes were carried in the present study. These tests include GDT, PPT, DCV, SPIN test and MLD test. From the results attempt was made to comprehend the developmental pattern that exist in each of the test. The test results were compared between control and experimental groups also. It was observed that GDT, SPIN and MLD did not show changes with age suggesting that, further significant developmental changes lacks in these test following 8 years of age. However, PPT scores along with SCS and DCS of Dichotic CV test has shown an increase in performance with age in the control group which demonstrates a development pattern of performance in these tests. In Dichotic CV test, right ear advantage was observed in all age range children for both the groups though significant difference seen only in the older age range children.

Comparison between control and experimental groups revealed that overall scores of GDT, PPT, SPIN, SCS and DCS of dichotic CV test, and MLD at 1 kHz showed statistically significant differences at 0.05 levels. However, MLD at 500 Hz showed performance alike between two groups.

4.2. Electrophysiological assessment

Different parameters in the speech evoked ABR obtained using BioMARK protocols were also analyzed statistically. The transient responses obtained and studied were wave V, wave A, V/A slope, and wave C. The sustained responses included response to first formants, response to higher frequencies, and latencies of waves D, E, and F. Further, BioMARK score generated automatically by the software was also analyzed.

4.2.1. Transient responses

4.2.1.1. Latency of wave V and A

The latencies of wave V and A were noted and analyzed to study the effect of age and ear. Further, the latencies obtained in both the groups were compared. The results revealed that the latencies of wave V and A did not vary between the ears and with age. This finding suggests a lack of developmental pattern in the latency of wave V and A prior to 8 years of age. However, the latency of wave V varied significantly between the groups. Children in the experimental group demonstrated significantly delayed latencies in comparison to the control group. Comparison between the groups was also carried out across different age ranges. The results revealed that latency of wave V was significantly delayed in the left ear for experimental group in the age range of 10-12 years and 12-14 years. However, such a difference between the groups was not evident in the age range of 8-10 years. Similarly, significant delay in latency of wave A was observed in the experimental group when compared to the control group. Further evaluations revealed a significant delay of wave A in the age range of 8-10 years (right ear only) and of 12-14 years (both ears).

Findings of the present study are in agreement with earlier studies which were carried out in related populations like in children with learning difficulties (King et al, 2002; Wible, Nicol & Kraus, 2004; Wible, Nicol & Kraus, 2005, Singh & Kumar, 2012). Wave V and wave A being elicited by the onset feature of the speech stimulus might replicate the onset of voicing in the context of speech stimulus /da/ (Skoe & Kraus, 2010). Correlating these report with the finding of the present study, a probable deficit in the coding of voicing feature can be assumed in children who are at the risk for (C)APD.

4.2.1.2. Amplitude of wave V/A slope

Amplitude of wave V/A slope was studied for the effect of age and ear initially. It was observed from the results that V/A slope did not vary between the ears but there was an effect of age observed in the amplitude of V/A slope in the experimental group while such a difference was noted in the control group. Further analysis showed that the amplitude of V/A slope was significantly larger in the left ear in 12-14 years of age range children in the experimental group in comparison to 8-10 years of age range children in the same group. This finding suggests a delayed developmental pattern in the experimental group. Similar differences were not observed between other age ranges of children. Analysis between control and experimental group revealed that the V/A slope were comparable between the groups in all the age range. Similar results in related clinical population have been reported in an earlier study by Singh and Kumar (2012) in children with dyslexia.

V/A slope are reported to be a measure of synchronization of generation, transmission and summation of neural activity that underlies the processing of auditory stimulus (Wible, Nicol, & Kraus, 2004). Hence, in children who are at the risk of (C)APD such a deficit in the synchronization of generation, transmission and summation of neural activity underlying auditory processing is not anticipated.

4.2.1.3. Latency measure of wave C

Latency of wave C was studied for differences between ears and also for the effect of age on the latencies. The results revealed that the latencies did not vary between ears and with age. Comparison of latencies between the control and experimental groups in both the ears revealed that the children in the experimental group exhibited a significantly prolonged latency of wave C in the left ear. Further analysis showed that significant difference between control and experimental groups existed in the children within the age range of 10-12 years while such a difference was not obvious in other age ranges. Earlier literature also has reported similar prolongation of wave C in related clinical populations. Banai, Hornickel, Skoe, Nicol, Zecker and Kraus (2009) reported the prolongation of wave C along with other peaks in poor readers and suggested that poor timing of sub cortical auditory encoding might have resulted in prolongation of peaks. Hence, similar deficits in timing of sub cortical auditory encoding may be suspected in the present study population considering the fact that both the populations are closely related. Similar prolongation of wave C was reported in other related clinical populations like in children with learning problems and reading disorders (King, Warrier, Hayes & Kraus, 2002; Billet and Bellis, 2009) and suggested deficit in the acoustic representation of speech sound in the sub cortical areas.

4.2.2. Sustained responses

4.2.2.1. Amplitude of response to first formant and higher frequencies

Age effect on response to first formant along with differences between ears were studied which revealed that there was no effect of age and ear on the amplitude of response to first formant. This finding again suggests a lack of developmental change in the amplitude of response to first formant after the age of 8 years. Mann Whitney U test was further carried out to compare the results between control and experimental groups. The results revealed that the amplitudes of responses to first formant were significantly lower in the experimental group in comparison to the control group. This finding is in agreement with the earlier studies in related clinical population like language based learning problems (Wible, Nicol & Kraus, 2004) and learning impairment (Song, Banai, & Kraus, 2008). First formant frequency has been shown to be important for vowel perception and the formant transitions are reported to be a place of articulation cue for consonants (Delattre, Liberman, Cooper & Gerstman, 1950). Hence, vowel perception and perception of place of articulation cue for consonants may be expected to be compromised in children who are at the risk for (C)APD.

Effect of age on the amplitude of response to higher frequencies and the differences in the amplitude between the ears were studies using Kruskal Wallis test and Wilcoxon signed rank test respectively. It was observed from the results that there is no difference between the ears and with advancement of age in the amplitude of response to higher frequencies suggesting a lack of maturation effect on the amplitude of response to higher frequencies from the age of 8 years. Mann Whitney U test was again carried out to compare the finding between control and experimental groups. The results revealed that the amplitude of responses to higher frequencies were comparable between control and experimental groups. Earlier studies have also reported that the brainstem response to higher formant coding was affected in children with poor speech perception in noise (Anderson, Skoe, Chandrasekaran, Zeck & Kraus, 2010). Song et al. (2008) assumed the possibility of an abnormal corticofugal modulation in the auditory system behind the diminished first formant encoding among children with learning impairment. They assumed that the cortical function is disrupted which in turn results in abnormal brainstem coding. This finding may be applicable in the present study also since the clinical populations used in both the studies are closely related.

4.2.2.2. Latency of wave D, E, and F (FFR component)

The waves D, E, and F represents the sustained responses of speech evoke ABR which are also the frequency following response (FFR). Statistical analysis also revealed that there was no latency difference between the ears in control and experimental groups. Comparison between control and experimental group revealed that the latency of wave D in the experimental group was significantly prolonged when compared to the control group. Detailed analysis also revealed that the significant difference was not noticeable in the age range of 10-12 years while the differences were observed in the latencies of right ear in the other two age range of population. This difference between the age ranges in the latencies as well as between the groups in different age ranges may be suggestive of the heterogeneity that exists in the population.

Analysis to compare the latencies of wave E between the groups suggested a significant prolongation of the latency of wave E in the experimental group. It was also observed that such a difference in latency between the groups was evident in the age range of 8-10 years and 12-14 years and not in the age range of 10-12 years. Again the disparity in the latency difference between the groups in different age range implies the heterogeneity demonstrated in the population in sub cortical encoding of speech stimuli.

Statistical evaluations of the latency of wave F also revealed that there was a significant prolongation of latency in the experimental group in comparison to the control group. Detailed analysis showed that such a significant difference in latency between the groups was evident in the age range of 8-10 years and not in the older age range of children. This result may be understood with caution since such a disparity in the differences between control and experimental group across different age range children may be suggestive of the heterogeneity that exists in the clinical population or the delayed maturation of wave F in the experimental group.

Thus, it was observed that the children who are at the risk for (C)APD demonstrated abnormalities in various latency measure of FFR component. Similar deviancies in the coding of FFR components at the brainstem level has been reported in the literature (King, Warrier, & Hayes ,2002; Banai et al, 2009). Such abnormal encoding of FFR components at the brainstem level may alter the perception of filter cues that aid in the identification of vowels and consonants, which may lead to speech perception deficits in such children (Banai et al, 2009).

4.2.3. BioMARK score

BioMARK scores is a composite score generated automatically by the software based on all parameters it assess which are latencies of wave V and wave A along with the amplitude of V/A slope and amplitudes of responses to first formant and higher frequencies. The BioMARK software considers a score lesser than 5 as normal and scores from 6 to 22 as abnormal. From the raw data it was noted that 1 (1.66%) ear among the 60 ears studied in the control group displayed a score greater than 5, while 20 (33.33%) out of 60 ears studied in the experimental group exhibited scores greater than 5. Further statistical analysis revealed that there is a significant difference in the BioMARK scores between right and left ears in the age range of 8-10 years in experimental group. It was also noted that the BioMARK scores of right ear in the experimental group varied significantly between age range of 8-10 and 12-14 years. Similar differences between the ears and with age were not observed in the children within experimental group. These findings proposes the existence of heterogeneity in children who are at the risk for (C)APD.

Further statistical evaluations revealed that the BioMARK scores significantly varied between control and experimental groups. It was also observed that the differences in BioMARK scores between control and experimental groups are evident in both the ears within the age range of 8-10 years and 12-14 years and in right ear within the age range of 10-12 years. This suggests that despite the variability in the results across the separately analyzed parameters, the overall BioMARK scores are affected in children who are at risk of (C)APD compared to their typically developing counterparts. This appears to point towards the effectiveness of BioMARK protocol as an electrophysiological tool in evaluation of such children. Further, this finding is also in congruence with the earlier studies which have reported abnormal BioMARK findings among different clinical populations like learning problems and dyslexia (King, Warrier, Hays, & Kraus, 2002; Wible, Nicol, & Kraus, 2004; Wible, Nicol, & Kraus, 2005, Singh & Kumar, 2012).

4.3. Correlation analysis

Correlation analysis of various behavioral test results with different parameters of speech evoked ABR was carried out in both control and experimental groups. The results revealed that in control group a significant negative correlation exist between SPIN scores and latency of wave A along with a negative correlation between GDT results and amplitude of responses to first formant in right ear. A positive correlation also was observed in the right ear within the control group between PPT scores with the latency of wave C. Similarly, in the left ear within the control group a significant negative correlation between SPIN scores and latency of wave F was noted. A significant positive correlation was also noted between MLD at 500 Hz and latency of wave F. In the experimental group within right ear a significant negative correlation was observed between SPIN scores and amplitude of response to higher frequencies. In addition, MLD at 500 Hz and 1 kHz exhibited significant positive correlation with latency of wave C while MLD at 1 kHz correlated negatively with the latency of wave V. In the left ear within experimental group positive correlations were observed between SPIN scores and BioMARK scores.

It is clear from the results that within the control group, in the right ear tests for temporal processing and auditory closure had a low moderate correlation with the latency and amplitude parameters of the speech evoked ABR. Similarly in left ear, tests for auditory closure was noted to be related to the latency measure of speech evoked ABR. The reason for the above differences in both ears performance for temporal processing could be because of hemispheric lateralization. Further, these results suggest that as temporal resolution increases (better thresholds), the amplitude of parameters in speech evoked can be expected to increase (higher amplitude of ABR). Likewise, as the performance in difficult to listening conditions increases (better), a decrease in the latency of sustained response (better) can be expected in speech evoked ABR test. However it was also noted in the control group that the temporal pattern perception tests and binaural interaction test results correlated positively with the latency parameters of speech evoked ABR (wave C of right ear & wave F of left ear respectively). Similar trends were not noted between other parameters in the control group. In the experimental group negative correlations between MLD at 1 kHz and latency of wave V were observed. Thus, performance in behavioral tasks that taps binaural interaction and temporal resolution can be expected to be reflected in the latency parameters of speech evoked ABR. However, results also suggested a negative correlation between SPIN scores and amplitude of response to higher frequencies. In addition, positive correlations were observed between MLD at 500 Hz and 1 kHz with latency of wave C. In a similar line, positive correlation was observed between SPIN scores and BioMARK score. These correlations which do not follow the expected trend probably indicate both the tests assess different processes, mechanisms, and regions of the central auditory nervous system. Hence, present finding reinforce the need for a test battery approach in assessing (C)APD rather single gold standard test.

CHAPTER 5: SUMMARY AND CONCLUSION

The present study aimed at checking the relationship between speech evoked ABR and a set of behavioral tests of central auditory function in children who are at risk for (C)APD. A total of 336 school going children in the age range of 8-14 years were screened for (C)APD using SCAP. Out of the 51 children who were identified to be at risk for (C)APD, 30 children (10 randomly selected children each in 8-10 years, 10-12 years, & 12-14 years age range), constituted the experimental group. Thirty typically developing children, 10 each in the age range of 8-10 years, 10-12 years and 12-14 years were included in the control group. All the participants underwent detailed audiological evaluation to rule out peripheral hearing loss, middle ear infections and abnormal ABR. This was followed by a series of behavioral tests for auditory processing evaluation and speech evoked ABR.

The results of these evaluations revealed that the children who are at the risk for (C)APD perform poorly in various behavioral tests which indicates towards subtle auditory processing deficit in the population. Similarly, various parameters of speech evoked ABR was also observed to be deviant in children who are at risk for (C)APD. Study to establish any correlation between behavioral test finding and speech evoked ABR was also carried out and the results revealed significant correlation of some of the behavioural tests with certain peak latencies or amplitudes of speech evoked ABR in both the groups.

It can be concluded from the results of the present study that different behavioral tests and speech evoked ABR are capable of tapping subtle auditory processing deficits in children who are at risk for (C)APD. The lack of correlation of most of the behavioral test with different parameters of speech evoked ABR indicates that these two set of tests probably assesses different domains of auditory processing.

CHAPTER 6: REFERENCE

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APPENDIX - I

Table 1: Wilcoxon signed rank test results for ear effect

Group	Test	8-10 years		10-12 years		12-14 years	
		Z	*p*	Z	*p*	Z	*p*
Control group	GDT	0.00	1.00	-0.58	0.56	-0.58	0.56
	PPT	-0.54	0.59	-1.09	0.27	-0.43	0.67
	SCS	-0.57	0.57	-1.89	**0.05**	-2.10	**0.04**
	SPIN	-0.11	0.91	0.00	1.00	0.00	1.00
	Wave V	-0.51	0.61	0.00	1.00	-0.82	0.41
	Wave A	0.00	1.00	0.00	1.00	-1.71	0.09
	V/A slope	-0.56	0.58	-0.21	0.83	-0.35	0.73
	Response to first formant	-1.17	0.24	-1.48	0.14	-0.66	0.51
	Response to higher frequencies	-0.41	0.68	-1.27	0.20	-0.65	0.52
	Wave C	-0.89	0.37	-0.65	0.51	-1.17	0.24
	Wave D	-0.59	0.55	-1.43	0.15	-1.13	0.26
	Wave E	-0.97	0.33	-0.14	0.89	-0.77	0.44
	Wave F	-0.87	0.38	-1.28	0.20	-0.95	0.34
	BioMARK score	-0.74	0.46	0-.26	0.79	-0.56	0.58
Experimental group	GDT	0.00	1.00	-0.45	0.66	-0.45	0.66
	PPT	-0.07	0.94	-1.20	0.23	-0.41	0.68
	SCS	-1.32	0.18	-0.46	0.65	-1.85	0.07
	SPIN	-0.88	0.38	-0.21	0.83	-0.33	0.74
	Wave V	-0.45	0.66	0.00	1.00	-2.00	**0.05**
	Wave A	-0.07	0.94	-0.69	0.49	-0.92	0.36
	V/A slope	-1.89	0.06	-0.15	0.88	-1.72	0.09
	Response to first formant	-0.46	0.65	-1.33	0.19	-0.46	0.65
	Response to higher frequencies	-1.27	0.20	-0.97	0.33	-2.29	**0.02**
	Wave C	-1.22	0.22	-1.07	0.29	-0.87	0.39
	Wave D	-0.42	0.67	-1.41	0.16	-0.18	0.86
	Wave E	-1.12	0.26	-1.76	0.07	-1.33	0.19
	Wave F	-0.56	0.58	-0.98	0.31	-0.53	0.59
	BioMARK score	-0.54	0.59	-0.42	0.68	-0.65	0.51

APPENDIX - II

Table 1: *Kruskal Wallis test* outcomes of speech perception in noise (SPIN) test

Group	Ear	G2	df	p-value
Control group	RE	0.69	2	0.71
	LE	2.29	2	0.32
Experimental group	RE	1.41	2	0.49
	LE	0.52	2	0.77

RE= right ear; LE= left ear

Table 2: *Kruskal Wallis test* outcomes of masking level difference (MLD) test

Group	Frequency (Hz)	G2	df	p-value
Control	500	1.16	2	0.56
	1000	0.00	2	1.00
Experimental	500	0.26	2	0.88
	1000	3.68	2	0.16

Table 3: *Kruskal Wallis* outcomes for the latencies of wave V and wave A

Group	Ear	Parameter	G2	df	p-value
Control group	RE	Wave V	0.97	2	0.61
	LE	Wave V	1.19	2	0.55
	RE	Wave A	0.29	2	0.86
	LE	Wave A	0.15	2	0.92
Experimental group	RE	Wave V	1.42	2	0.49
	LE	Wave V	2.93	2	0.23
	RE	Wave A	5.91	2	**0.05**
	LE	Wave A	0.25	2	0.88

RE= right ear; LE= left ear

Table 4: Kruskal Wallis test outcomes for the amplitude of V/A slope

Group	Ear	G2	df	p-value
Control	RE	0.11	2	0.94
	LE	2.95	2	0.22
Experimental	RE	4.21	2	0.12
	LE	12.15	2	**0.00**

RE= right ear; LE= left ear

Table 5: *Kruskal Wallis* test outcomes for the amplitude of response to first format

Group	Ear	G2	df	p-value
Control	RE	0.09	2	0.95
	LE	0.89	2	0.64
Experimental	RE	5.64	2	0.06
	LE	1.99	2	0.37

RE= right ear; LE= left ear

Table 6: Kruskal Wallis test outcomes for the amplitude of response to higher frequencies

Group	Ear	G2	df	p-value
Control	RE	2.75	2	0.25
	LE	0.12	2	0.94
Experimental	RE	3.67	2	0.16
	LE	0.61	2	0.73

RE= right ear; LE= left ear

Table 7: Kruskal Wallis test results for age effect on latencies of wave C, D, E, and F in speech evoked ABR

Group	Ear	Parameter	G2	df	p-value
Control	RE	Wave C	0.10	2	0.95
	LE	Wave C	2.20	2	0.33
	RE	Wave D	1.32	2	0.52
	LE	Wave D	0.02	2	0.99
	RE	Wave E	3.56	2	0.17
	LE	Wave E	0.47	2	0.79
	RE	Wave F	0.14	2	0.93
	LE	Wave F	1.46	2	0.48
Experimental	RE	Wave C	3.69	2	0.16
	LE	Wave C	0.59	2	0.74
	RE	Wave D	4.25	2	0.12
	LE	Wave D	2.35	2	0.31
	RE	Wave E	4.91	2	0.09
	LE	Wave E	0.43	2	0.81
	RE	Wave F	1.67	2	0.43
	LE	Wave F	1.29	2	0.53

RE= right ear; LE= left ear

Table 8: Kruskal Wallis test outcomes for the BioMARK scores

Group	Ear	G2	df	p-value
Control group	RE	0.59	2	0.74
	LE	4.18	2	0.12
Experimental group	RE	8.19	2	**0.01**
	LE	1.05	2	0.59

RE= right ear; LE= left ear

Appendix III

Spearman correlation analysis between different parameters of Speech evoked ABR and Behavioral measures in control group

	Vr	Vl	Ar	Al	VAr	VAl	Istr	Istl	Higherr	Higherl	Cr	Cl	Dr	Dl	Er	El	Fr	Fl	Overallr	Overall
GDTrt	.184	.189	.168	.186	.232	.263	**-.381**	-.173	-.262	-.113	.089	.112	.163	.136	-.097	.156	.100	.110	.348	.338
	.330	.317	.376	.326	.216	.161	**.038**	.361	.162	.554	.641	.555	.389	.475	.611	.410	.599	.562	.059	.068
GDTlt	-.064	.096	.083	.178	.166	.000	.025	.056	-.058	-.113	.116	.040	.283	.359	.151	.109	-.066	.020	.188	.050
	.737	.613	.662	.346	.380	1.000	.895	.771	.762	.553	.543	.834	.130	.051	.425	.565	.729	.917	.321	.793
PPTrt	.039	.105	.122	.122	.079	.023	-.023	.022	-.055	-.070	**.368**	.133	.313	.091	.130	.211	-.099	.208	.053	.175
	.836	.580	.519	.521	.679	.904	.903	.907	.775	.714	**.045**	.484	.092	.634	.494	.263	.604	.270	.781	.354
PPTlt	.043	.040	.025	-.017	.029	-.054	-.020	-.002	-.069	.021	.350	.128	.263	.116	.080	.094	-.131	.078	.019	.132
	.823	.833	.895	.930	.881	.779	.915	.992	.716	.914	.058	.499	.161	.540	.674	.621	.489	.680	.920	.487
SCSrt	.271	.028	.029	-.164	-.115	-.215	-.102	.000	-.327	.103	.044	.019	.041	.207	.035	-.160	.042	-.067	-.031	-.006
	.148	.881	.879	.385	.544	.253	.592	.999	.078	.588	.818	.922	.829	.272	.853	.398	.825	.726	.869	.977
SCSlt	.061	.014	-.007	-.178	.126	-.212	-.242	.053	-.403	-.022	.211	.002	.033	.119	-.066	-.185	.135	-.011	.128	-.109
	.748	.942	.972	.347	.509	.261	.197	.782	.072	.909	.262	.992	.863	.531	.730	.328	.478	.954	.501	.565
DCS	.160	-.100	.025	-.143	.032	-.136	-.138	-.057	-.445	.006	.041	.090	.015	.183	-.056	-.316	.086	-.066	.137	.078
	.397	.599	.894	.450	.868	.473	.467	.765	.054	.976	.830	.635	.935	.334	.770	.088	.652	.730	.471	.683
SPINrt	-.067	-.151	**-.379**	-.346	-.085	-.153	-.075	.266	.103	.160	.002	-.133	.017	-.080	-.235	-.335	-.269	**-.500**	.068	-.272
	.724	.425	**.039**	.061	.655	.419	.693	.155	.589	.397	.993	.482	.929	.673	.212	.070	.151	**.005**	.721	.145
SPINlt	.035	-.130	-.346	-.224	-.222	.055	.082	.114	.135	.172	-.081	-.037	-.031	.040	-.044	-.141	-.147	**-.388**	-.079	-.175
	.855	.495	.061	.235	.238	.773	.668	.550	.478	.363	.669	.848	.870	.834	.818	.458	.438	**.034**	.679	.356

MLD500	-.008	-.041	.267	.350	.266	.294	-.274	-.163	-.061	-.082	.045	.074	.250	-.114	.119	.275	.238	**.367**	.232	.273
	.965	.829	.154	.058	.155	.114	.143	.388	.748	.668	.813	.699	.183	.547	.532	.141	.205	**.046**	.216	.144
MLD1K	-.115	-.202	-.016	.083	-.165	-.126	.028	-.051	-.193	-.047	.347	-.122	.134	.260	-.051	.194	-.071	.095	-.108	.022
	.545	.283	.934	.662	.382	.507	.885	.789	.308	.804	.061	.520	.481	.166	.788	.305	.709	.617	.572	.907

Vr: Wave V (Right ear); Vl: wave V (Left ear); Ar: Wave A (Right ear); Al: Wave A (Left ear); VAr: V/A slope (Right ear); VAl: V/A slope (Left ear); Istr: Ist Formant frequency (Right ear); Istl: Ist formant frequency (Left ear); Higherr: Higher frequencies (Right ear); Higherl: Higher frequencies (Left ear); Cr: Wave C (Right ear); Cl: Wave C (Left ear); Dr: Wave D (Right ear); Dl: Wave D (Left ear); Er: Wave E (Right ear); El: Wave E (Left ear); Fr: Wave F (Right ear); Fl: Wave F (Left ear); Overallr: Overall score (Right ear); Overall: Overall score (Left ear); rt: Right ear; lt: Left ear

Spearman correlation analysis between different parameters of Speech evoked ABR and Behavioral measures in control group

	Vr	Vl	Ar	Al	VAr	VAl	Istr	Istl	Higherr	Higherl	Cr	Cl	Dr	Dl	Er	El	Fr	Fl	Overallr	Overall
GDTrt	-.166	-.032	-.309	-.068	-.089	.157	.048	-.027	-.057	-.231	.322	.113	.135	.115	.110	.057	-.074	-.274	-.061	-.302
	.380	.866	.097	.720	.641	.408	.800	.888	.766	.219	.088	.553	.485	.544	.562	.765	.697	.150	.748	.105
GDTlt	.003	.264	-.194	.114	-.198	.059	-.029	-.069	-.204	-.158	.165	-.039	.302	.147	.135	.194	.115	-.120	-.036	-.183
	.988	.159	.304	.548	.295	.756	.877	.717	.279	.405	.393	.837	.112	.438	.477	.305	.545	.535	.851	.334
PPTrt	.100	-.200	.242	-.139	.059	.020	-.152	-.050	.048	.164	-.007	.119	.345	.028	.372	.090	.251	.214	.006	-.109
	.600	.290	.197	.463	.758	.916	.423	.792	.799	.388	.973	.530	.067	.883	.064	.636	.181	.264	.976	.565
PPTlt	.155	-.219	.155	-.176	.006	.054	-.163	-.120	.001	.216	.078	.220	.324	.131	.385	.121	.304	.268	-.029	-.124
	.415	.245	.412	.352	.976	.777	.389	.529	.995	.251	.689	.242	.087	.491	.066	.524	.102	.160	.881	.513
SCSrt	.126	.013	.271	-.040	.048	-.030	-.186	.097	.090	.054	-.008	-.251	.018	.155	-.011	-.057	-.024	.168	.171	.053
	.508	.948	.148	.835	.801	.877	.326	.611	.635	.778	.969	.181	.925	.413	.954	.763	.898	.384	.367	.780
SCSlt	-.117	.220	.085	-.005	-.172	-.117	.062	.056	.328	.349	-.195	-.198	-.020	.098	.013	.065	.031	-.051	-.155	.114
	.539	.243	.654	.980	.363	.538	.747	.767	.077	.059	.309	.294	.919	.607	.947	.734	.872	.794	.415	.550
DCS	.059	-.008	.153	-.213	-.104	-.019	-.041	.064	.250	.223	-.125	-.184	.123	.226	-.061	.082	.004	.102	-.006	.033
	.758	.967	.420	.258	.584	.920	.830	.738	.182	.237	.518	.331	.524	.231	.747	.666	.983	.600	.976	.864
SPINrt	.093	.158	.274	.279	.160	-.122	-.059	.026	**-.474**	-.203	.048	-.044	-.153	-.120	-.088	-.007	.138	.024	.233	.256
	.624	.403	.142	.135	.398	.522	.756	.890	**.008**	.282	.803	.816	.427	.529	.645	.970	.468	.903	.215	.173
SPINlt	.027	.121	.309	.203	.225	.008	-.164	-.098	-.129	-.100	.006	.112	-.102	-.113	.080	.233	.222	-.024	.278	**.428**
	.886	.524	.096	.283	.232	.968	.387	.606	.497	.601	.975	.557	.600	.553	.674	.215	.238	.901	.136	**.018**

MLD500	.078	-.238	-.140	.062	-.162	.046	.097	.262	-.193	-.015	**.388**	.117	-.128	-.027	.201	.019	.140	-.182	.062	-.262
	.683	.206	.461	.744	.391	.808	.612	.161	.307	.935	**.038**	.539	.507	.887	.286	.919	.462	.344	.744	.163
MLD1K	**-.385**	-.212	-.250	.178	.055	.038	.084	-.055	.198	-.147	**.397**	.127	.120	-.034	.228	-.122	-.232	-.242	-.161	-.068
	.035	.260	.184	.348	.774	.843	.659	.774	.295	.438	**.033**	.504	.534	.859	.226	.521	.217	.206	.395	.721

Vr: Wave V (Right ear); Vl: wave V (Left ear); Ar: Wave A (Right ear); Al: Wave A (Left ear); VAr: V/A slope (Right ear); VAl: V/A slope (Left ear); Istr: Ist Formant frequency (Right ear); Istl: Ist formant frequency (Left ear); Higherr: Higher frequencies (Right ear); Higherl: Higher frequencies (Left ear); Cr: Wave C (Right ear); Cl: Wave C (Left ear); Dr: Wave D (Right ear); Dl: Wave D (Left ear); Er: Wave E (Right ear); El: Wave E (Left ear); Fr: Wave F (Right ear); Fl: Wave F (Left ear); Overallr: Overall score (Right ear); Overall: Overall score (Left ear); rt: Right ear; lt: Left ear

Appendix IV

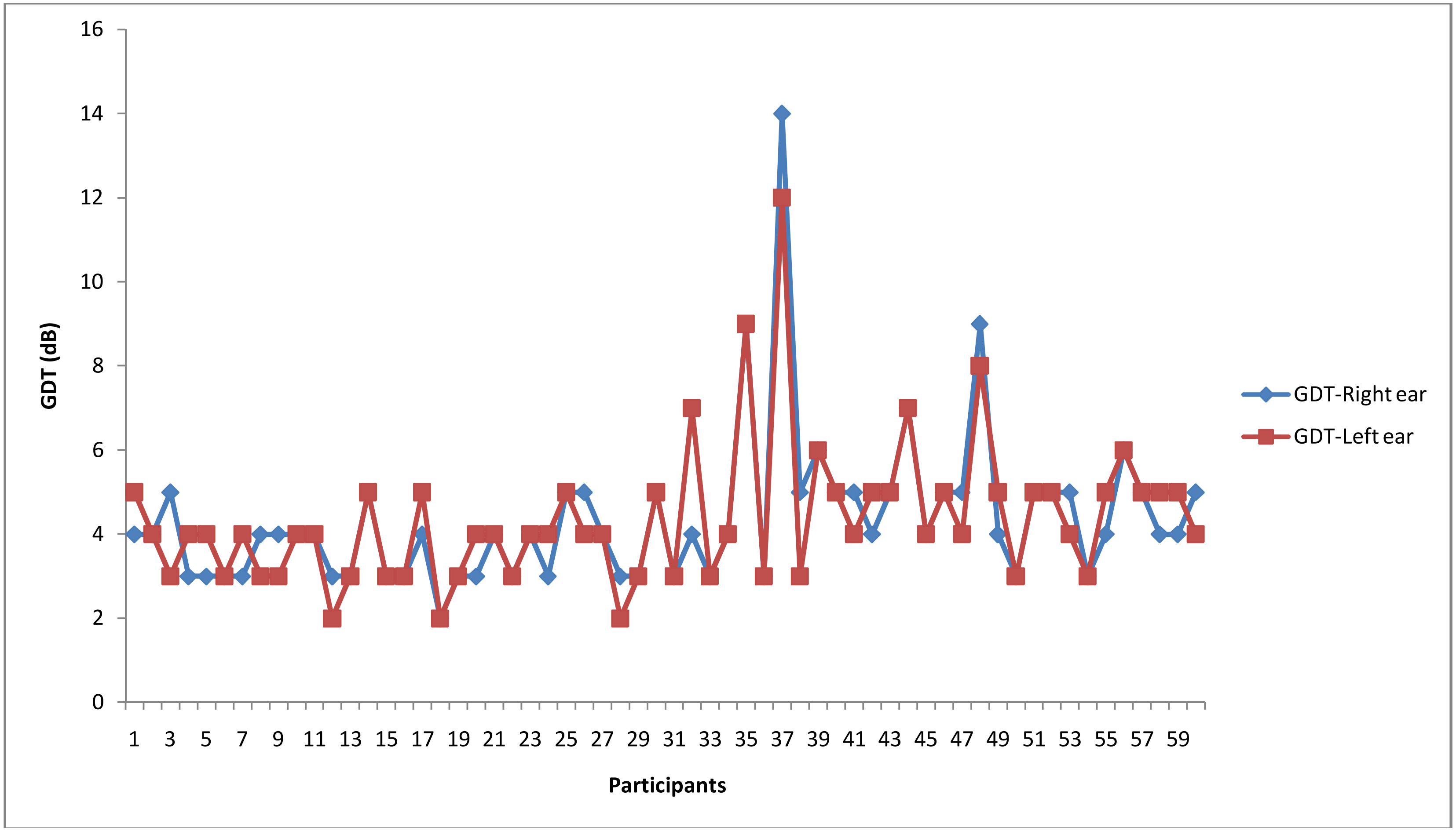

Figure 1: Individual raw scores of GDT in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

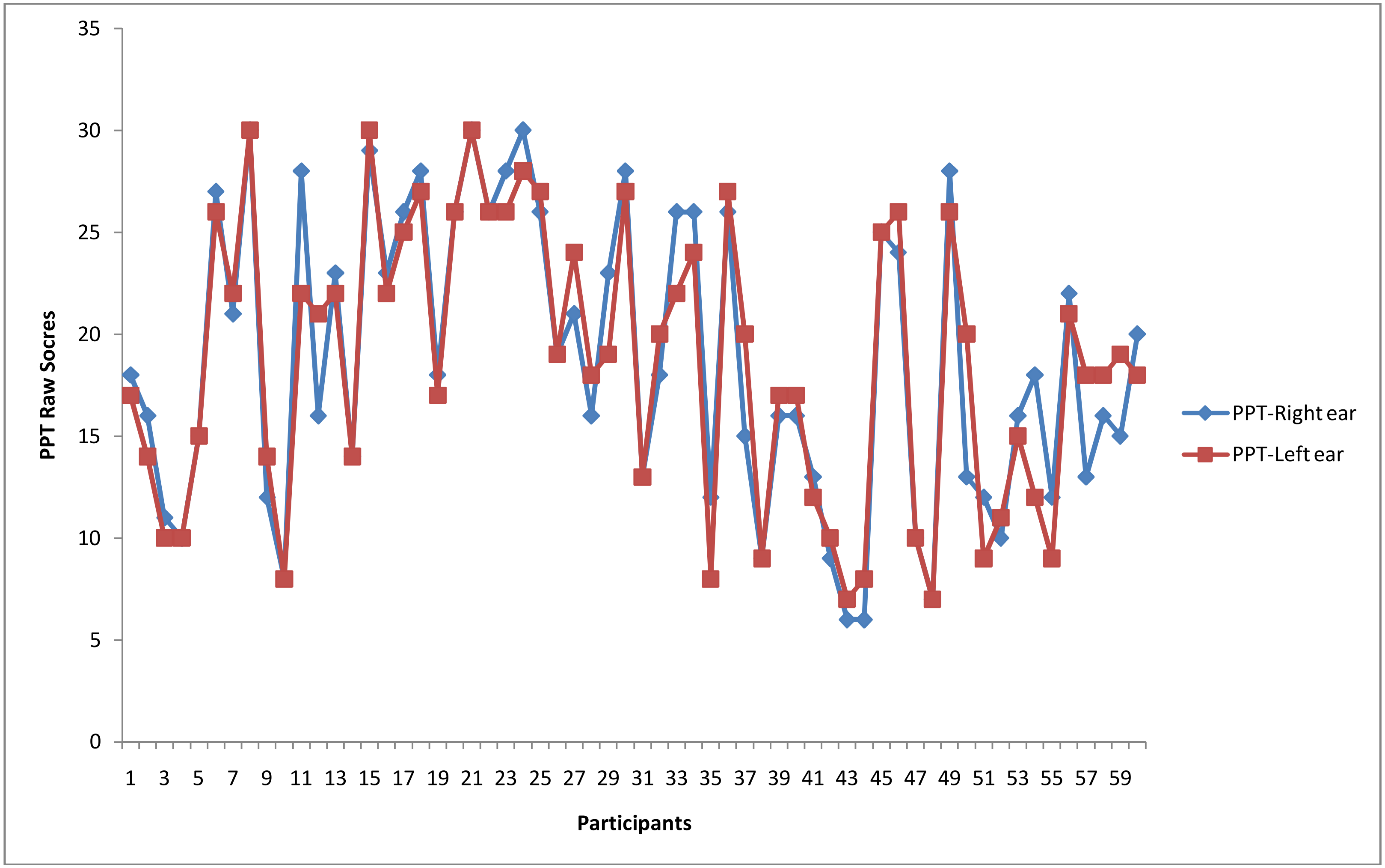

Figure 2: Individual raw scores of PPT in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

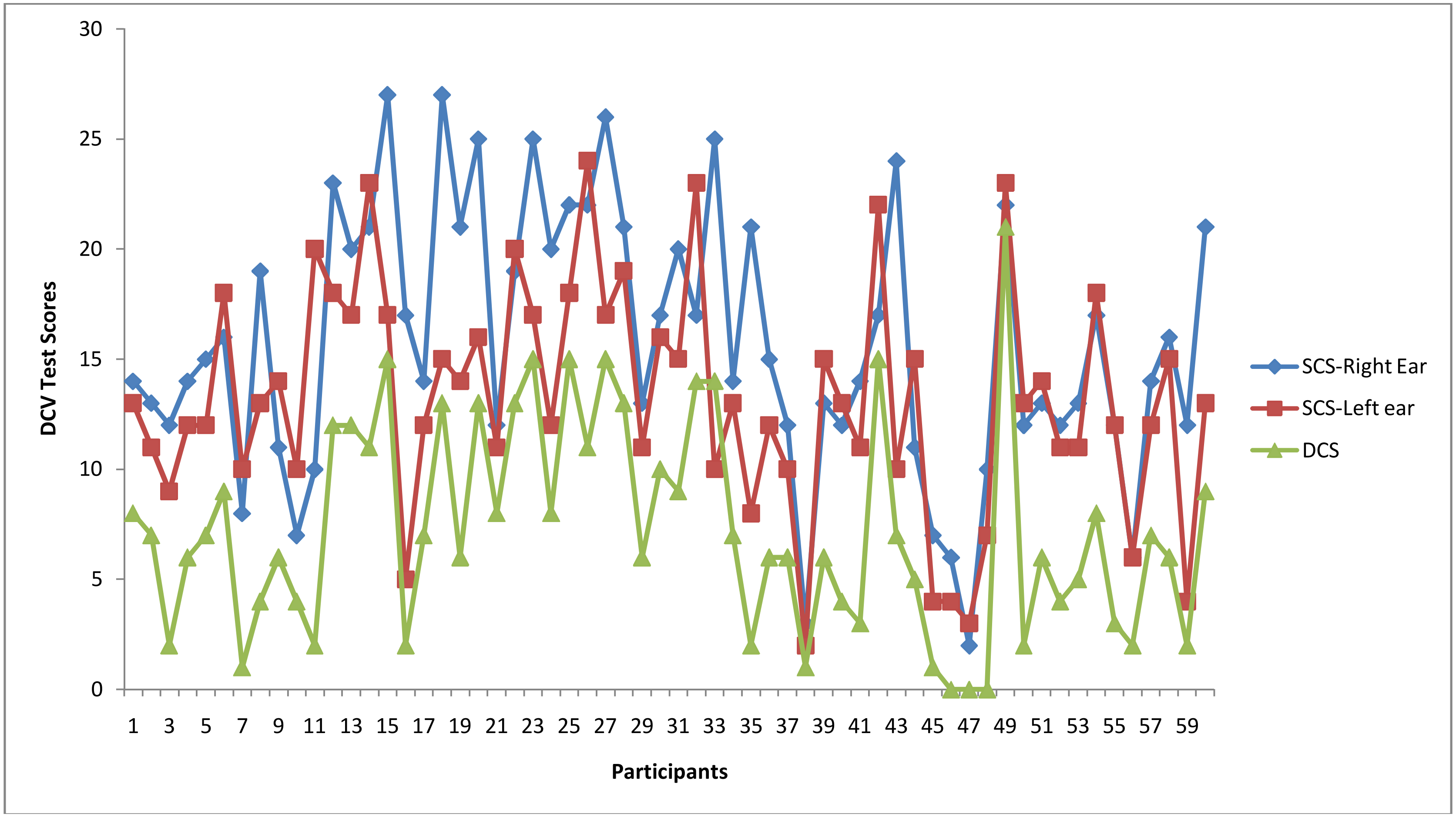

Figure 3: Individual raw scores of Dichotic CV tests as single correct score (SCS) and double correct scores (DCS) in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

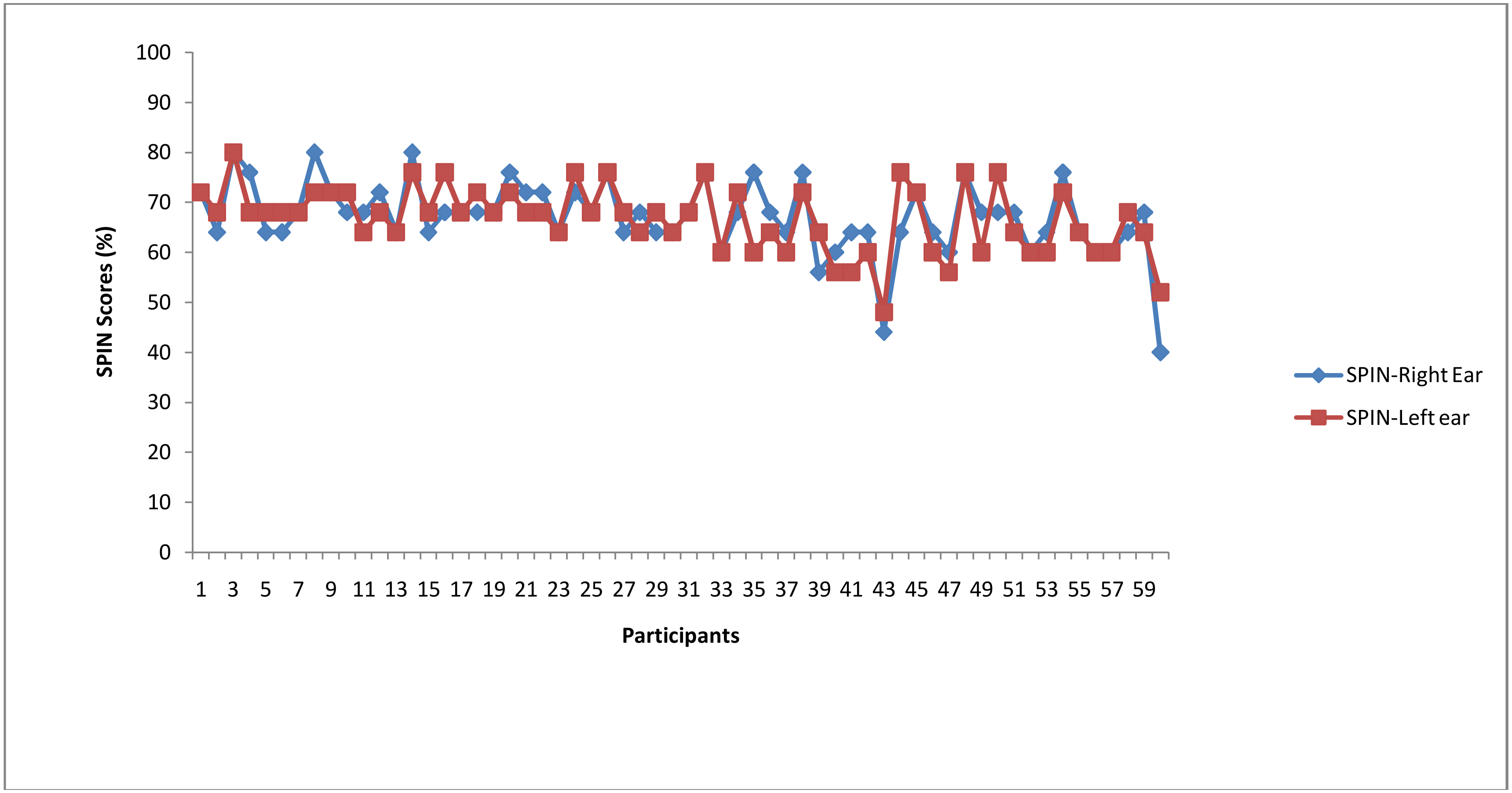

Figure 4: Individual raw scores of SPIN in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

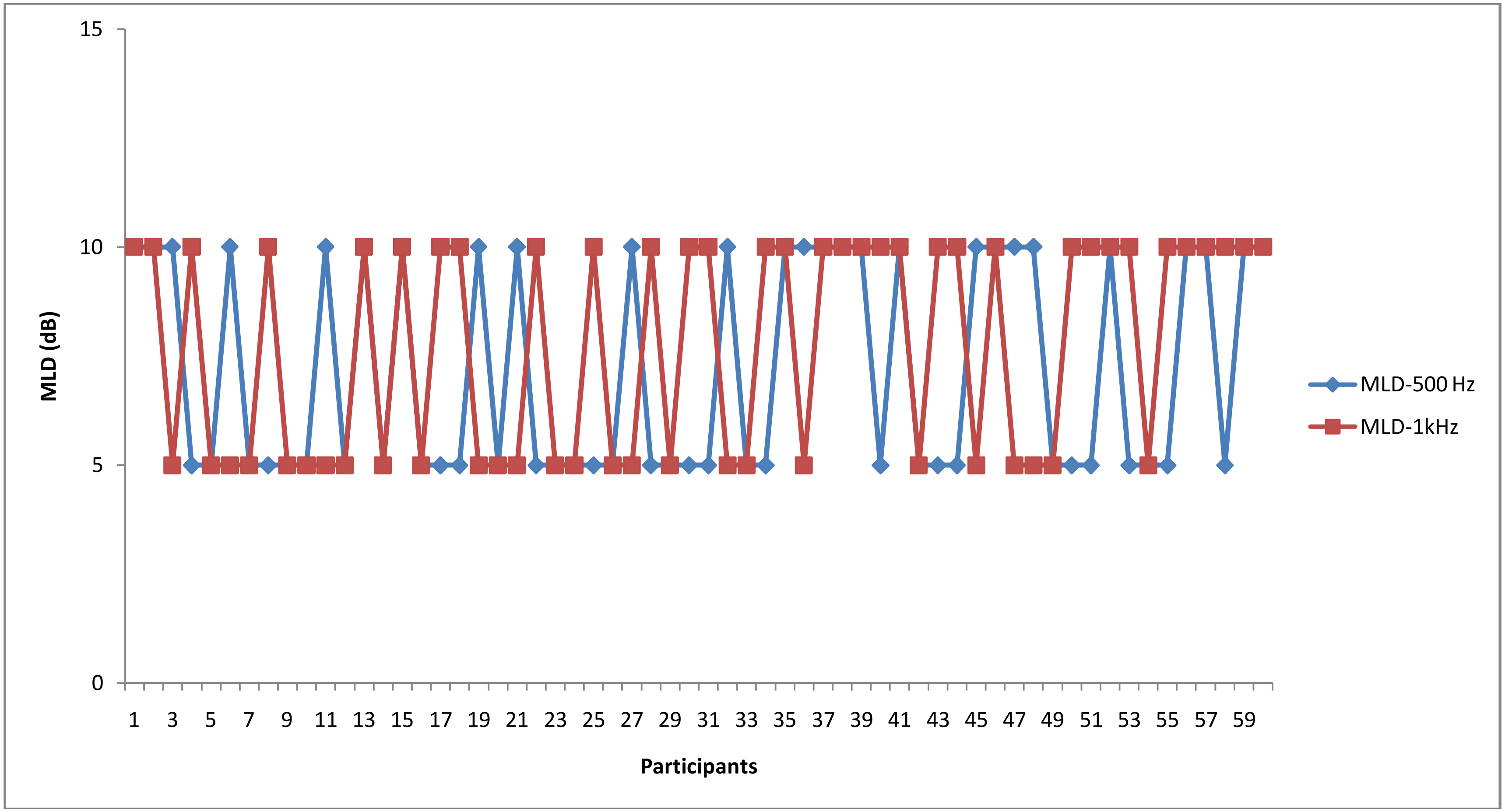

Figure 5: Individual raw scores of MLD in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

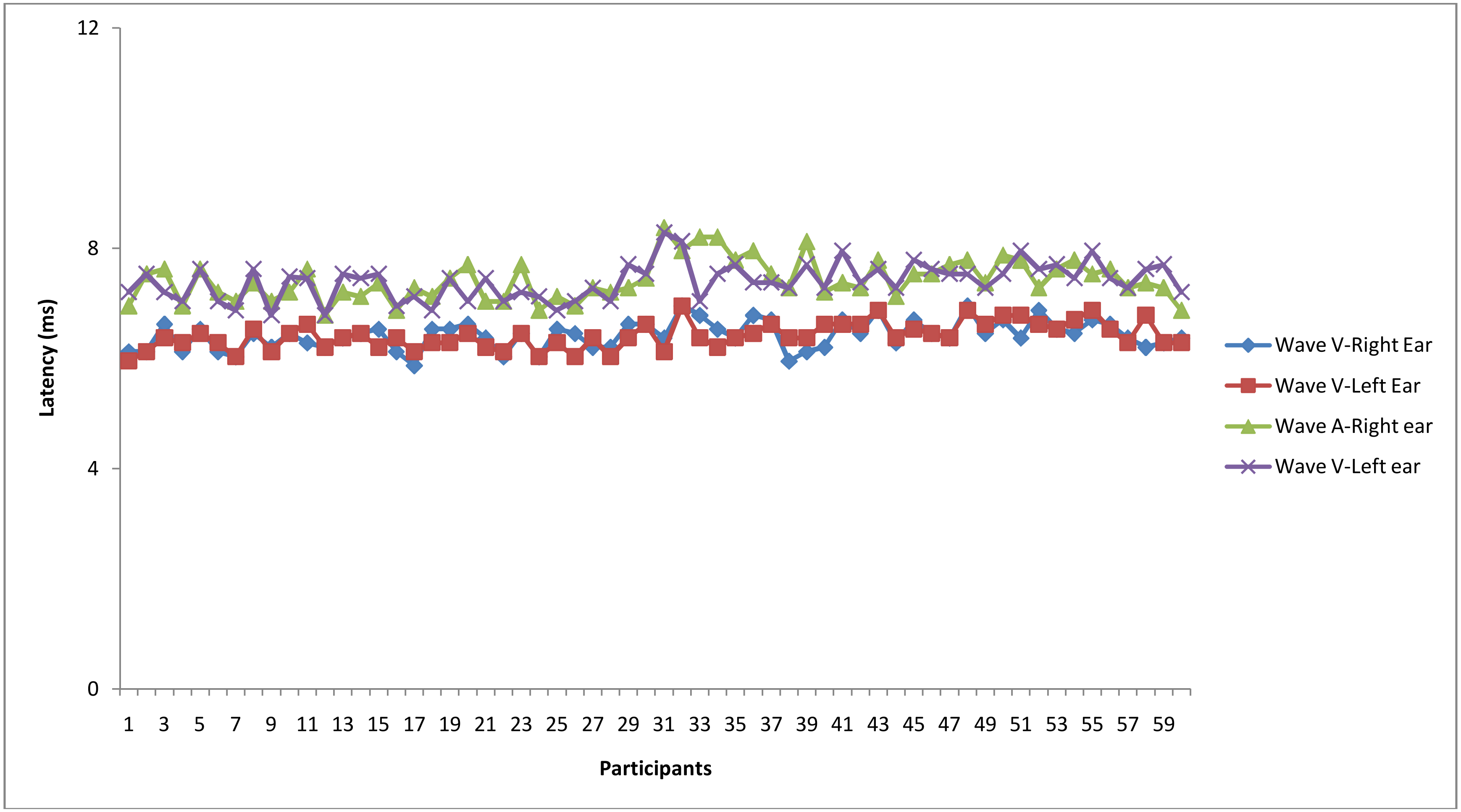

Figure 6: Individual raw scores of wave V and wave A of speech evoked ABR in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

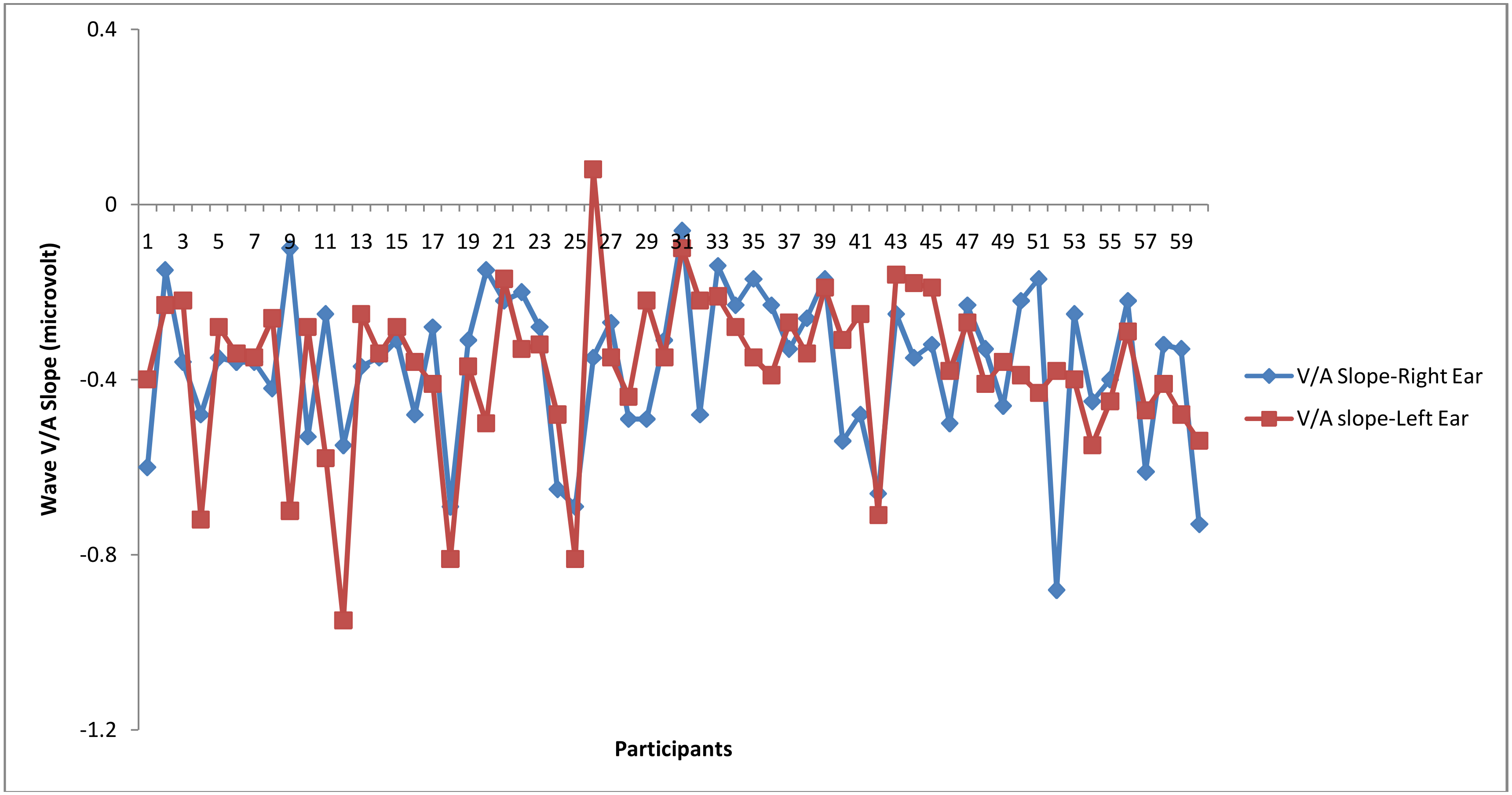

Figure 7: Individual raw scores of wave V/A slope of speech evoked ABR in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

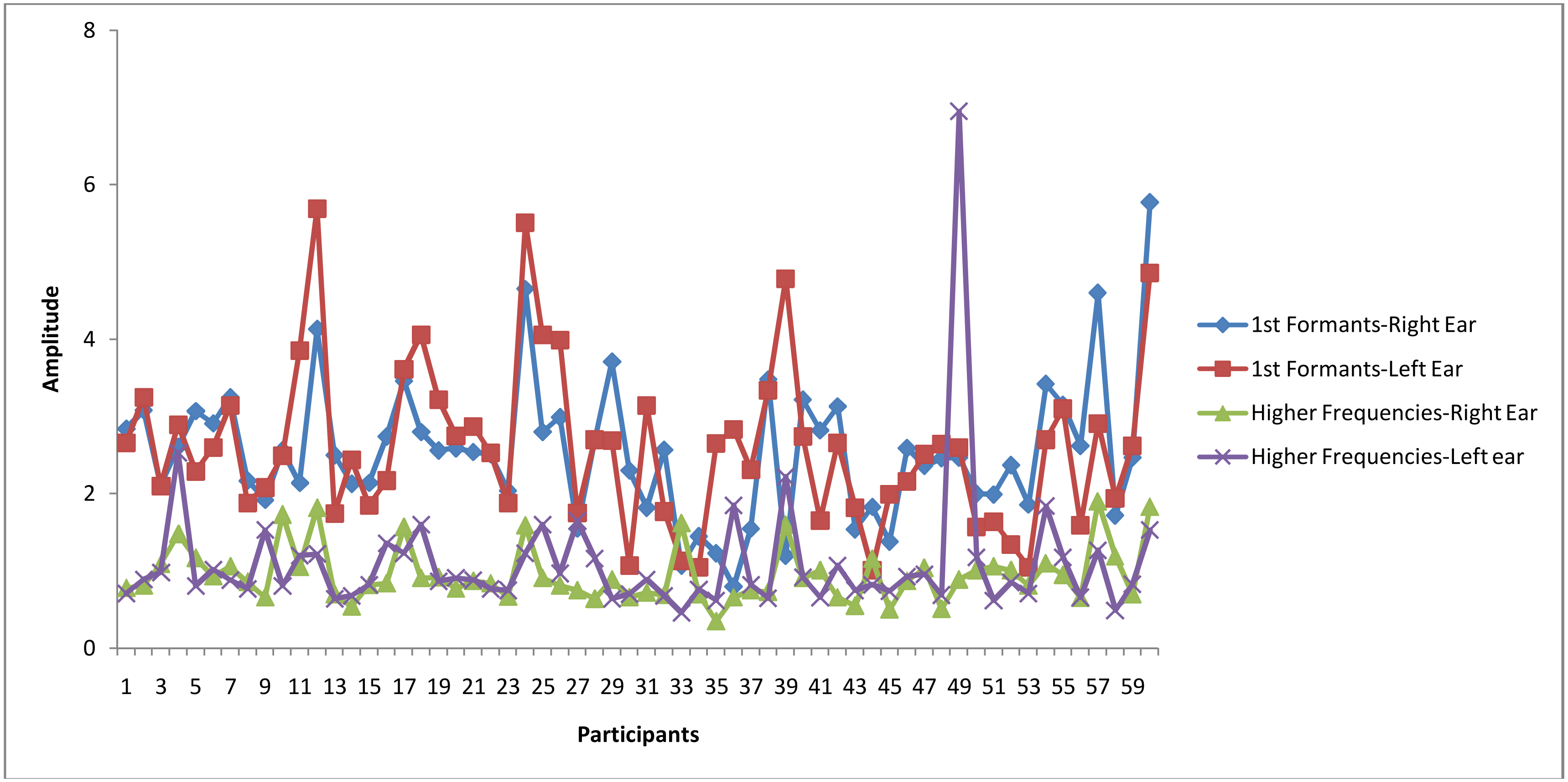

Figure 8: Individual raw scores of 1st formants and higher frequencies of speech evoked ABR in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

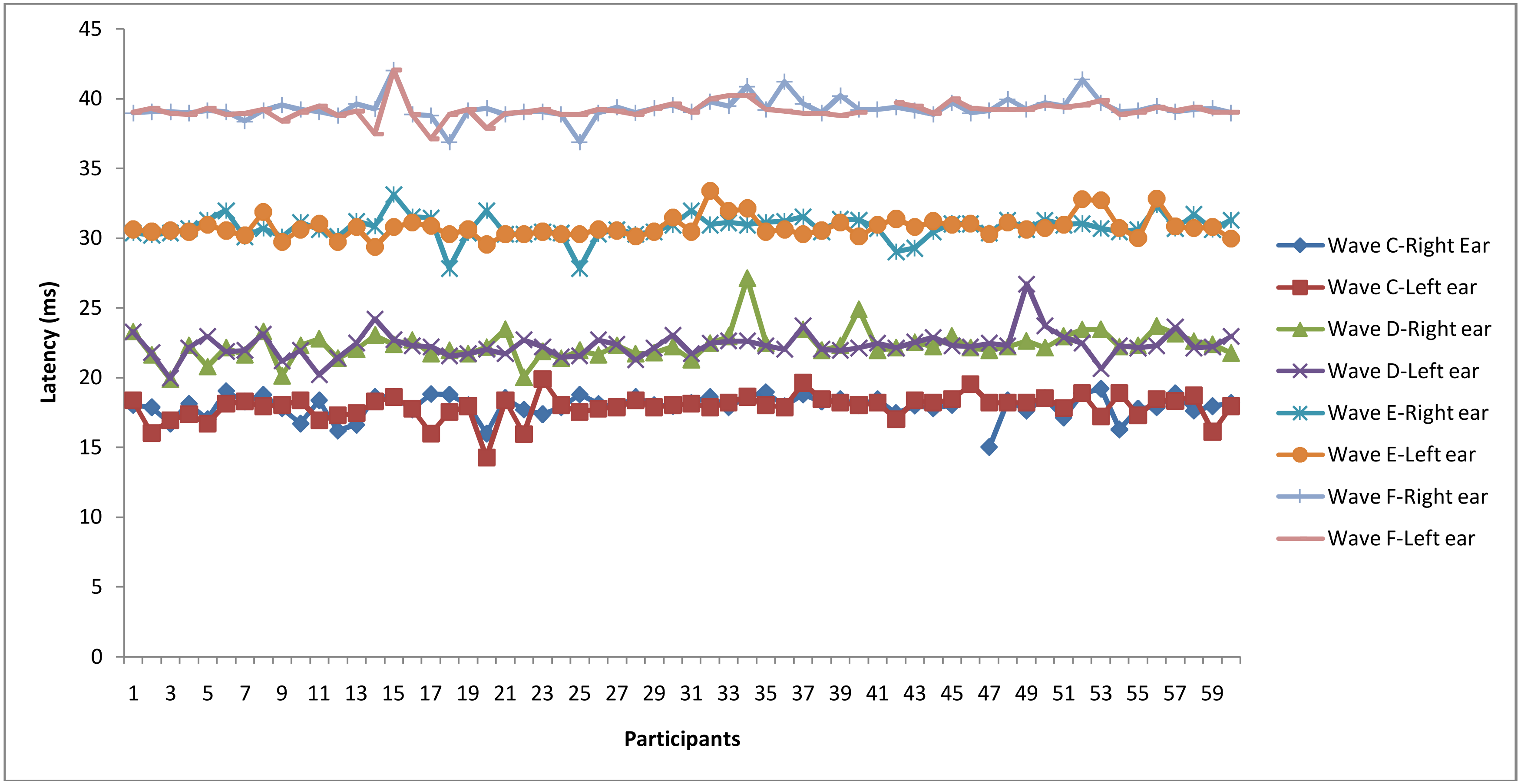

Figure 9: Individual raw scores of wave C, D, E and F of speech evoked ABR in both ears (Control group: 1 to 30; Experimental group: 31 to 60)

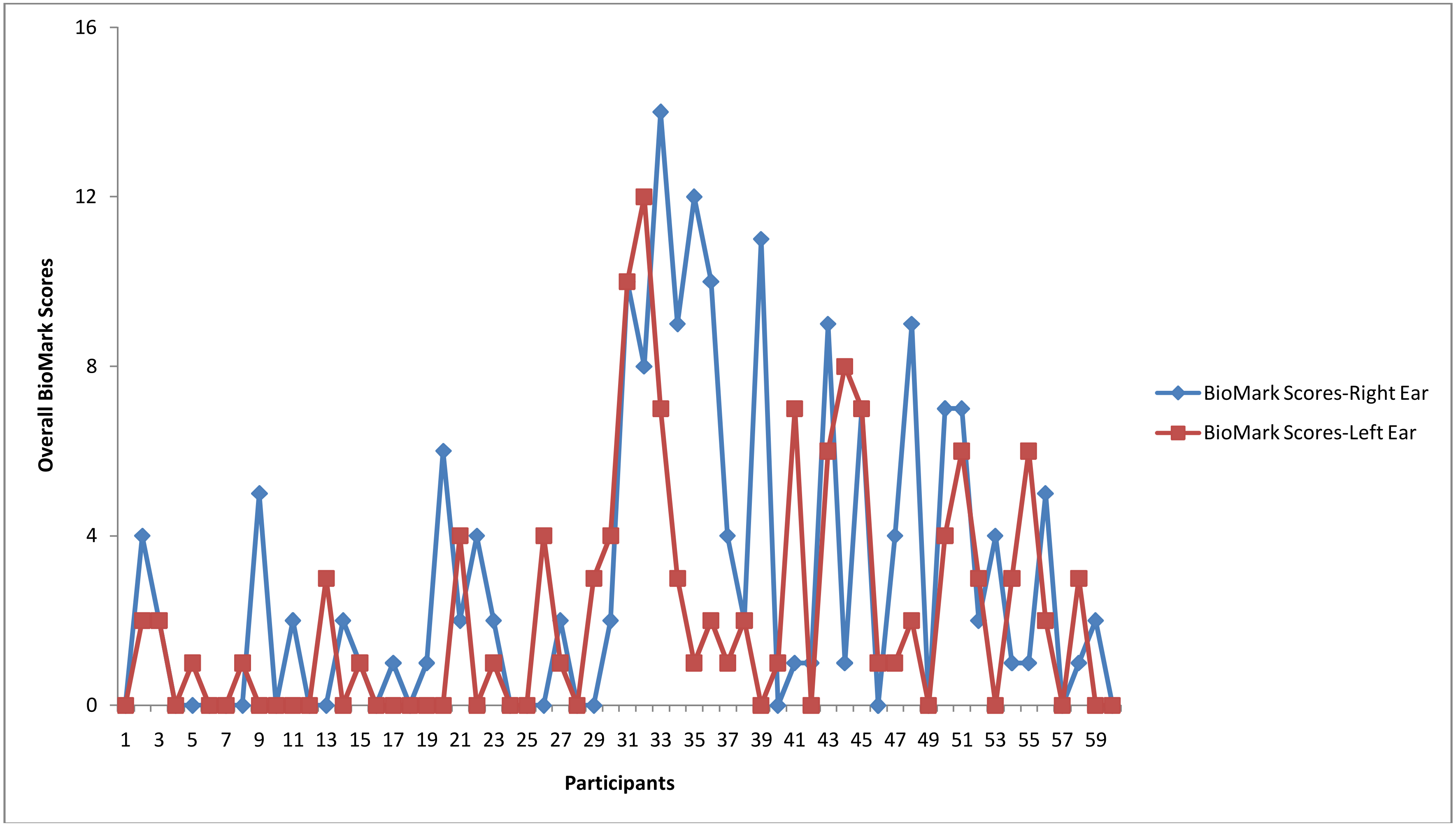

Figure 10: Individual raw scores of overall BioMark scores in both ears (Control group: 1 to 30; Experimental group: 31 to 60)