BINAURAL INTERACTION COMPONENT, BINAURAL FUSION TEST AND MASKING LEVEL DIFFERENCE IN CHILDREN AT RISK OF CENTRAL AUDITORY PROCESSING DISORDER

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CERTIFICATE

This is to certify that this dissertation entitled **"Binaural Interaction Component, Binaural Fusion test and Masking Level Difference in children at risk of Central Auditory Processing Disorder"** is a bonafide work submitted in part fulfillment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD007 This has been carried out under the guidance of faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore
May, 2017

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CERTIFICATE

This is to certify that this dissertation entitled **“Binaural Interaction Component, Binaural Fusion test and Masking Level Difference in children at risk of Central Auditory Processing Disorder”** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **“Binaural Interaction Component, Binaural Fusion test and Masking Level Difference in children at risk of Central Auditory Processing Disorder”** is the result of my own study under the guidance of Dr. Prawin Kumar, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore **Registration No: 15AUD007**
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ABSTRACT

The present study aimed to check the relationship between binaural interaction components of click evoked ABR and behavioral tests that access binaural interaction in children at risk of central auditory processing disorder (CAPD). The study included 30 school going children in the age range of 8 to 14 years as participants. Fifteen children who were found to be at risk of CAPD and 15 age-matched typically developing children were included as clinical and control group respectively. The participants of both the groups underwent behavioral test of binaural interaction namely masking level difference and binaural fusion test. They also assessed for binaural interaction component using auditory evoked brainstem response with click stimulus. Descriptive statistics shows poorer scores for children at risk for CAPD for binaural fusion test compared to typically developing children. However, masking level difference test shows alike performance between two groups. Further, binaural interaction components of wave V of click evoked ABR showed longer latency and shorter amplitude for children at risk for CAPD compared to typically developing children. Nonparametric Mann-Whitney test showed statistical difference between two groups for binaural fusion test and amplitude of the BIC of click evoked ABR. Behavioral 500 Hz masking level difference test and latency of the binaural interaction component of wave V click evoked ABR did not show significant differences between two groups. In addition, the correlation between behavioral tests and binaural interaction component was done. The result revealed significant negative correlation between latency of binaural interaction component and binaural fusion test. However, masking level difference did not showed any significant correlation with binaural interaction component. Reduction in the binaural interaction component in ABR and poor binaural fusion scores in

children at risk for CAPD could be attributed to the fact that there occurs a reduced activity or functional properties of neurons at the level of the brainstem. The significant correlation between the two tests provides the understanding that both the procedures investigate same processes but in a different way. The results from the study clearly signify that children at risk for CAPD have difficulty in behavioral perceptual processing as well as neurobiological functioning and there exists a significant dependency of one over the other. Thus the use of electrophysiological tests along with behavioral investigation should be encouraged while assessing these children so as to ascertain and confirm the diagnosis. Also in children with whom behavioral assessment becomes difficult the electrophysiological testing can be used to make an estimate of their problem in real life scenario.

Chapter 1

INTRODUCTION

Central auditory processing refers to the perceptual processing of auditory information in the central nervous system. It involves auditory mechanisms such as 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). Central auditory processing disorder (CAPD) is defined as poorer performance in one or more of the skills mentioned above i.e. auditory attention, discrimination, and auditory memory and temporal processing. Later, ASHA in 2005 redefined CAPD as a deficit in the perceptual i.e. neural processing of auditory stimuli and the neurobiological activity underlying that processing (ASHA, 2005).

According to the literature there are numerous behavioral and/or electrophysiological tests which can aid in the assessment of central auditory processing disorder. Behavioral as well as electrophysiological test helps in discovering the important aspects of neural basis of central auditory dysfunction. However, there is no single test available that can be considered as gold standard for assessing CAPD and therefore clinicians mainly rely on test battery approach. Test battery approach should include both electrophysiological and behavioral test to ensure that all mechanisms involved in central auditory processing is evaluated. Both behavioral and electrophysiological tests has their own pros and cons, still now there are controversies regarding the findings of behavioral tests of central auditory processing disorder. This may be attributed to reduced sensitivity and specificity of the behavioral tests which could be due to variables like electronic recording and playback techniques (Shea & Raffin, 1989), variability in here in the tests (Keith, Ruby, Donahue & Katbamma, 1989). Nevertheless, it has an advantage of being accepted widely and less expensive. Unlike behavioral tests electrophysiological tests are less affected by extraneous factors but it has disadvantages of being expensive, time consuming and not widely available. Thus incorporation of both behavioral and electrophysiological tests will help assist clinicians/professionals to measure different domains of auditory system more precisely accurately.

Several behavioral tests intended to assess different auditory functions of the brain can be used to measure APD. However, each person being tested should undergo a routine audiological testing before the assessment of APD begins (Chermak & Musiek, 1997). The special behavioral tests for the APD assessment involves dichotic listening tests (Musiek & Pinheiro, 1985), Monaural low redundancy speech test (Jerger & Jerger, 1971), Temporal Processing Tests (Pinheiro, 1977), Binaural Interaction Tests (Matzker, 1959).

Binaural fusion test helps in assessing binaural interaction abilities in which low pass and high pass filtered speech stimuli presented in both ears together. Filtering of the speech stimuli using low and high pass filter results in unintelligible speech when presented monaurally. However, presenting the filtered stimuli together in both ears did show fusion of this information thereby helping in recognition of stimuli (Wilson, Arcos & Jones, 1984).

Roush & Tait, (1984) examined the performance of 18 normal and 18 children with language learning disabilities in the age range of 6 to 12 years using a battery of tests like binaural fusion test, masking level difference and auditory brainstem responses. Band pass filtered speeches were presented in dichotic and diotic mode to evaluate binaural fusion. The stimuli used for measuring MLD were tonal and for ABR was click. For the binaural fusion tasks results revealed poorer scores in clinical group. Although for diotic condition performance of both groups was relatively higher. Their study suggests the efficiency of binaural fusion measures in the assessment of auditory processing abilities in children.

Penaloza-Lopez et al 2009 assessed central auditory processes in children with dyslexia and controls using binaural fusion test and filtered word test in 40 children with dyslexia and 40 children without dyslexia in the age range of 8 to 12 years. The results revealed that correct scores of binaural fusion test for dyslexic group is less (poorer) compared to children without dyslexia also, filtered word test scores shows less scores (poorer) in dyslexic group of children compared to children without dyslexia. These results shows auditory processing is also affected in children with dyslexia, which in turn help to expand the rehabilitative plan in these children.

Stollman et al (2003) compared the performance of a group of 20 children of 6-years of age with specific language impairment (SLI) and 20 age matched control children on several behavioral auditory tests. The behavioral auditory test battery they used consisted of following tests: a speech-in-noise test, a filtered speech test, a binaural fusion test, a frequency pattern test, a duration pattern test, a temporal integration test, an auditory word discrimination test, an auditory synthesis test, an auditory closure test and a number recall test. The results reported that in almost all tests the SLI children obtained significantly lower (poorer) scores than those of the control group. Significant positive correlation was found between behavioral tests which are basic auditory processing measures and receptive language scores. This in turn suggests a relationship between auditory processing and language proficiency.

Masking level difference (MLD) is another behavioral test that aids in assessing binaural interaction abilities using pure tone signal. MLD, which is a binaural phenomenon, is a release from masking which occurs when the phase of a signal (S) or noise (N) in one ear is reversed with respect to the phase of the signal or noise in the other ear (Hirsh, 1948; Webster, 1951). The phenomenon of masking level difference (MLD) for pure tones was originally described by Hirsh(1948),which is known to be a psychoacoustic phenomenon which compares masked thresholds in a number of signal and noise phase condition that is threshold difference occurs for a SoNo(signals and noise in phase at the two ears) or SπNπ (signal and noise out of phase at the two ears)or signals in SπNo (signals π radians out of phase and noise in phase at the two ears) and signals in So Nπ (Signals in phase and noise out of phase at the two ears) (Hirsh,1948; Licklider, 1948). Thresholds for the SπNo /SoNπ conditions are lower than thresholds for the SoNo or SπNπ condition, and difference between the thresholds is termed the MLD. Theoretically, the phenomenon associates to the ability of the binaural system to separate target signals from a background noise. Clinically, the MLD is used to identify eighth nerve and /or auditory brainstem lesion (Quaranta & Cevellera, 1977). Psychophysically, masking level difference is the elevation of detection threshold when the sound is masked by noise only in the same ear than when it is masked by noise in both ears. In other words the effect of noise paradoxically decreases with binaural presentation of noise compares to ipsilateral masking .Masking level difference involves the simultaneous presentation of sound and noise to both ears; sound and noise, mask each other less if, one is in phase and other is out of phase across ears. However, if the interaural phases are the same for both tones and noise (i.e. both are in or both are out of phase), mutual masking is increased by between 0 and 15 dB depending on the frequency spectra of the signals involved.

Zurek (1990) proposed a model to predict the binaural advantages and directional effects on speech intelligibility in normal listeners and suggested that binaural MLD may improve speech intelligibility. In normal listeners binaural advantages may enhance speech intelligibility resulting in much clearer, louder and less contaminated perception of speech in the presence of background noise and/or reverberation. The phenomenon of the binaural MLD may be related to the “cocktail party effect”, in which the discrimination of individual sounds in a complex acoustic environment is made easier if the sound sources are separated in space (Yost, 1994).The two phenomenon may be related because in real situations, the interaural phase and level differences contributing to the Binaural MLD only occur when the signal and masker are spatially separated (Moore, 1997)

The binaural MLD is suggested to be one of the best indicators of early or subclinical auditory brainstem dysfunction which is not reflected by hearing thresholds (Hannley et al, 1983; Musiek &Lamb, 1994).The MLD has been demonstrated to be useful to study the central auditory function of multiple sclerosis patients, especially for the assessment of the auditory function of lower brainstem integrity (Musiek & Lamb, 1994).

The assessment of the binaural MLD may be included in the test battery for auditory processing disorder experienced by some school age children and adolescents. These students have normal hearing thresholds to pure tones but experience difficulty understanding speech in noisy, but not in quiet situations (Chermak, Somers, & Seikel, 1998).The assessment of the MLD may be used to assess the binaural processing ability of APD children and to investigate whether their auditory system is capable to integrate binaural cues normally (Lynn, Gilroy, Taylor, & Leiser, 1981). However, Study done by Kumar, Singh and Ghosh (2013) using behavioral CAPD assessment of children at risk of central auditory processing disorder without reading difficulties in the age range of 8 to 12 years. Study noticed no significant differences in MLD test between at risk of CAPD children and typically developing children. Similarly study done by Roush & Tait (1984) shows performance of Masking level differences were not significantly different for both normal children and children with language learning disabilities.

Behavioral measures require the subject to pay attention and respond to the task, which may not be ideal for difficult to test population. However binaural interaction component can be measured electrophysiologically estimating BIC using click evoked ABR. This is used to assess the binaural interaction abilities at the level of brainstem. The Binaural interaction component (BIC) is the residual ABR obtained after subtracting the sum of monaurally evoked responses from binaurally evoked ABRs. This concept is expressed as binaural difference waveform i.e. (L+R)-BI, where, L+R is the sum of the left and right evoked potentials obtained with monaural stimulation and BI is the response acquired from binaural stimulation.

There are several studies in literature that are several studies in literature that measured binaural interaction components in children and adults with and without hearing impairment (Kumar & Sinha, 2011; Sebastian, 2013; Uppunda, Bhat, D'costa, Raj, and Kumar, 2015; VanYper, Vermeire, DeVel, Beynon, Dhooge, 2016). Study done by Sebastian in year 2013 studied the presence or absence of binaural interaction component in individuals with symmetrical and asymmetrical hearing impairment within the age group of 18 to 55 years. They reported a significant difference for latency of BIC between normal and asymmetrical hearing impaired individuals. However, there was no significant differences between groups with respect to other parameters .Another Study reported binaurally evoked wave V responses are smaller than the sum of monaurally evoked responses (Riedel & Kollmeier, 2002; VanYper et al, 2016). The two main cues relevant for binaural hearing are interaural time difference (ITD) and interaural level difference (ILD) being processed in medial and lateral superior olivary complex (Grothe, Pecka & McAlpine, 2010). These cues can affect negative component of the BIC recorded using auditory brainstem responses. Wong (2002) studied the presence of binaural interaction component using the auditory brainstem response (ABR) among 47 normal hearing adults in the age range of 20 and 41 years. They found BIC with better morphology at slower rate in majority of young individuals with normal hearing when compared with faster rate. Kumar and Sinha in 2011 recorded BIC in children in the age range of 6 to 12 years using click and speech evoked ABR. They studied maturation of BIC using presence of click and speech evoked ABR in children with normal hearing. They reported difference in the latency of the click and speech evoked ABR across different age groups. However, significant differences were not observed for amplitude of the click and speech evoked ABR. Study done by Uppunda et al in 2015 measuring BIC using speech evoked ABR in individuals with normal hearing. They used speech stimulus /da/ of 40 ms to elicit the ABR for both monaural and binaural stimulation. They found that using speech evoked ABR, first BIC (BIC-SP1) and second BIC (BIC-SP2) could be noticed near 6 ms and 8 ms respectively. Similarly, third (BIC-SP3) and fourth BIC (BIC-SP4) could be traced at 36 ms and 46 ms respectively. However, they reported first and second BIC more consistent compared to third and fourth BIC using speech evoked ABR in young adults.

BIC measurement has been employed to evaluate the integrity of binaural processing in clinical populations (Gordon, Solloum, Toor, Hoesel & Papsin, 2012). Deficits in binaural processing can lead to different degrees of auditory processing disorders. Therefore assessment of binaural interaction has a crucial diagnostic importance especially in children with suspected APD.. Further study done by Gopal and Pierel (1999) reported that a subject diagnosed with auditory processing disorder has reduced amplitude of BIC. Similarly Delb, Struss, Honhenberg and Plinkert (2003) investigated the sensitivity and specificity of BIC between normal and children at risk for CAPD. BIC were performed on 17 children at risk for CAPD. Sensitivity and specificity of 76% was reported for the study. Their results revealed that BIC has diagnostic value in assessment of CAPD. Thus these authors concluded that with better characterization, BIC may reflect auditory processing abilities and may be used as an index of binaural processing (Gopal & Pierel, 1999).

In summary tests of binaural interaction generally access the ability of the central auditory nervous system to process interaction abilities between two ears. Binaural interaction tests are thought to be sensitive to brainstem pathology. However the majority of these tests may also be affected by pathology at peripheral as well as central system.

Binaural interaction can be measured through both behavioural as well as electrophysiological tests. According to existing literature shows behavioural test like MLD is the good indicator of early or subclinical auditory brainstem dysfunction. Studies also suggest that MLD has been useful to study the central auditory function of the multiple sclerosis patients, to assess binaural processing ability in CAPD children, especially for the assessment of auditory function of the lower brainstem integrity. Whereas behavioral test like binaural fusion test studies in literature suggests the potential usefulness of binaural fusion measures in the assessment of auditory processing abilities in children with specific language impairment, language related learning disability and specific language impairment. Behavioural measures require subject to pay attention and respond to the task which may not be ideal for difficult to test population. However binaural interaction component can be measured electrophysically by using click and speech evoked ABR. This is also used to access binaural interaction at the level of brainstem. Studies in literature suggest the use of binaural interaction component in assessment of the children with auditory processing disorder. Amplitude and latency parameters are taken into consideration while assessing binaural interaction component electrophysiogically.

Need for the study

Studies existing in literature show binaural interaction component are present in 100% individuals with normal hearing (Uppunda et al., 2015; Wong, 2002; Sebastain, 2013) . In another study done by Delb et al (2003) tried to explore up to what extend binaural interaction component using click evoked ABR are capable of differentiating between children with normal hearing and children at risk for CAPD. Binaural interaction component were estimated on 60 children at risk for CAPD and results shown that the beta component of the BIC can be observed more often in patients at risk for CAPD. They also reported that the judgment on whether (or not) a given child is at risk for CAPD is based on the presence or absence of a beta peak in the BIC waveform. Further, they reported sensitivity and specificity of BIC measures were 76% in children at risk for CAPD. Thus BIC has diagnostic value in identifying of children at risk for CAPD. In addition, the advantages of using ABRs for BIC because it is not affected by sleep and mature early. Hence, this tool can be used in identifying binaural interaction in younger and difficult-to-test populations (Uppunda et al., 2015). On the other hand, behavioral measures such as binaural fusion test in normal hearing individuals shows sensitivity of 78% while in individual at risk of CAPD is 66.5% (Delb, Strauss, Hohenberg, & Plinkert, 2003).

In addition, MLD is another clinical test to assess binaural interaction abilities which has shown sensitive to lower brainstem region (Lynn et al., 1981). However, study done by Kumar, Singh, and Ghosh (2013) performed MLD at 500 Hz and reported alike performance between children at risk for central auditory processing disorders and typically developing children. Hence they concluded that MLD is not sensitive in assessing children who are at risk of CAPD (Kumar, Singh & Ghosh, 2013).

However, existing literature do support the use of MLD in assessing binaural interaction abilities in children with CAPD (Lynn et al., 1981; Somers, et al., 1998). Based on the existing literature it appears that there is a discrepancy towards the utility of electrophysiological or behavioral test alone in identifying the children at risk of CAPD with binaural interaction deficit. Due to the above inconsistency, present study aimed to assess the binaural interaction abilities in children at risk for CAPD using electrophysiological and behavioral measures. Further, present study is also aimed to see the relationship between Electrophysiological (i.e. BIC) and behavioral test (i.e. BFT and MLD) in children at risk of CAPD to tap binaural interaction deficit.

Aim of the study

The aim of the study is to obtain the relationship between electrophysiological and behavioral test for assessing binaural interaction abilities in children at risk for CAPD.

Objective of the study

- To assess binaural interaction abilities using electrophysiological test i.e. binaural interaction component (BIC) using click evoked ABR in children at risk of CAPD.
- To assess binaural interaction abilities using behavioral tests i.e. binaural fusion test and Masking level difference test in children at risk for CAPD.
- To check whether any relationship exists between electrophysiological and behavioral tests among children at risk of CAPD.

Hypothesis of the study

- There is no significant difference between children's with normal hearing and children at risk of CAPD in BIC component of ABR.
- There is no significant difference between children's with normal hearing and children at risk of CAPD in BFT and MLD test.
- There is no relationship exists between electrophysiological and behavioral test in measurement of binaural interaction in children at risk of CAPD.

Chapter 2

METHOD

The study was carried out with the aim to check the relationship between electrophysiological and behavioral test for assessing binaural interaction abilities in children at risk for CAPD.

Participants

The study consisted of two groups i.e. a clinical group and a control group in the age range of 8 to 14 years. The clinical group includes children who were at risk of CAPD based on a questionnaire as screening checklist for auditory processing (SCAP) and audiological screening test for auditory processing (STAP). The control group consists of typically developing children who were not identified as at risk for CAPD. There were 15 participants in clinical group and 15 age matched typically developing children in control group. Informed consent was obtained from all the participants. Prior to the experiment they were explained about the test procedure in detail. Further, detail structured case history was taken from all the participants.

Participant inclusion and exclusion criteria

In clinical and control group, those participants were included who had normal hearing sensitivity (within 15 dB HL) at octave frequencies between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction. Immittance evaluation revealed 'A/As' type tympanogram with ipsilateral and contralateral reflexes present at 500 Hz, 1k Hz, 2k Hz and 4k Hz. All the participants in both the groups had normal or average Intelligent Quiescent (IQ). They were studying in English medium school from at least 2 to 3 years. Further, clinical group participants were considered at risk for CAPD based on SCAP and STAP test. The control group included those participants who passed in SCAP and STAP test of auditory processing. In both groups, those participants who were having any past history of otological /neurological problems, and illness at the day of testing were excluded from the study.

Instrumentation

Calibrated two channel Piano Inventis diagnostic audiometer with TDH-39 headphone coupled with MX-41/AR ear cushions and a bone vibrator radio ear B-71 was used for air conduction and bone conduction threshold estimation respectively. Same audiometer was used for binaural fusion test (BFT) and masking level difference (MLD) test. Calibrated GSI TYMPSTAR Immittance meter was used for tympanometry, ipsilateral and contralateral reflexometry. Calibrated ILO 292 otoacoustic emission system (otodynamics Inc., UK) was used to record transient evoked otoacoustic emissions. Biologic Navigator Pro EP 7.2.1 was used for recording click evoked auditory brainstem responses and to obtain binaural interaction component (BIC).

Test Environment

Both electrophysiological and behavioral test were carried out in an acoustically treated rooms with the permissible noise level as per ANSI 3.1(1999) standards. The experimental evaluation was done in a quiet and distraction free environment.

Procedure:

Pure tone audiometry was carried out based on Modified Hughson-Westlake procedure (Carhart & Jerger, 1959) for octave frequencies from 250 Hz to 8k Hz. A Radio ear B-71 bone vibrator was used to estimate bone conduction thresholds for frequencies between 250 to 4000 Hz. In both the groups, the pure tone threshold was within ≤ 15 dBHL in both ears. Along with pure tone audiometry, speech audiometry was carried out to find speech recognition threshold and speech identification scores for both the group. The speech recognition scores for both the groups were in the range of 90 to 100% in quiet condition.

Immittance evaluation was carried out for both the ears using GSI-TS tympanometer with probe tone frequency of 226 Hz. Ipsilateral and contralateral reflex threshold were measured for 500, 1k, 2k and 4 kHz. In both the groups, tympanogram revealed ‘A/As’ type with ipsilateral and contralateral reflex present at all the frequencies between 500 Hz to 4000 Hz were considered for the study.

Screening checklist for auditory processing (SCAP) developed by Yathiraj and Mascarenhas (2004) was administered on both the groups. This checklist consisted of 12 questions. Each question is scored on a 2 point rating scale as ‘Yes’ or ‘No’. Each answer marked as ‘yes’ given a score of ‘one’ and each wrong answer was scored as ’zero’. Based on the above questionnaire, those children who scored more than 50% is referred for audiological CAPD screening test. The above pass/refer criteria of SCAP was recommended by the developer of the screening test.

Screening Test for Auditory Processing (STAP) developed by Yathiraj & Maggu (2012) was administered on children referred based on SCAP, to check for at risk of central auditory processing disorder. The STAP audiological test contains four subsections i.e. speech-in-noise test, dichotic consonant vowel test, gap detection test and auditory memory test. The pass/fail criteria was considered as per normative developed by Yathiraj & Maggu (2012).

A transient evoked otoacoustic emission was carried out to assess the functioning of outer hair cells. A good probe fit was ensured prior to the testing. Click stimuli of total 260 was presented and response is averaged. Reproducibility of more than 80% and signal-to-noise ratio (SNR) of 6 dB was considered as responses present. TEOAE responses were measured for 1000, 2000, 3000 and 4000 Hz. TEOAE was present in both the groups.

For ABR testing the subject was made to sit on a reclining chair. The skin surfaces at the vertex, forehead and mastoid of both the ears was cleaned by using skin abrasive to achieve an impedance of less than 5k ohms. The electrodes was placed using conduction paste and surgical plaster for firm attachment. The subjects were instructed to relax and minimize body movements to reduce the artifacts while recording. Click evoked auditory brainstem response was measured with the repetition rates of 11.1/s at the intensity level of 60 dBnHL and rarefaction as the stimulus polarity with the band pass filter of 100-3000 Hz for both the ears. Conventional electrode montage of non-inverting at vertex, inverting at mastoid of both the ears, and ground at forehead was used. The protocol used for the click evoked ABR is mentioned in Table 1.

Table 1:

Protocol for clicked evoked ABR and Site-of- lesion testing

	Click evoked ABR	Site of Lesion test
Transducer	ER 3A insert ear phones	ER 3A insert ear phones
Filter band	100 to 3000 Hz	100 to 3000 Hz
No of sweeps	1500	1500
Stimulus, duration	Clicks,0.1µs	Clicks,0.1µs
Intensity	60 dBnHL	90 dBnHL
Polarity	Rarefaction	Rarefaction
Repetition rate	11.1/sec	11.1/sec and 90.1
Time window	12 ms	12 ms
Electrode placement	Inverting electrode(-): Mastoid Non inverting electrode(+): Vertex Ground: Forehead	Inverting electrode(-): Mastoid Non inverting electrode(+): Vertex Ground: Forehead

Click evoked ABR was recorded binaurally as well as monaurally for both the groups. The binaural interaction component was determined by subtracting the binaurally evoked auditory potentials from the sum of monaural auditory evoked potentials.

BIC= {(left monaural + right monaural) - Binaural}

The amplitude and latency of click evoked ABR was estimated for monaural and binaural recordings. Amplitude and latency of V peak of binaural component was estimated. For click evoked ABR, the peak which comes under 5 to 6 ms was determined for obtaining the latency of the V peak. Finally the amplitude and latency of BIC were obtained for all the participants in both the groups.

Binaural fusion test developed by Shivaprasad and Yathiraj (2006) was used in the present study which consists of 4 lists having 25 words in each list. These words are low pass filtered (500 to 700Hz) and high pass filtered (1800 to 2000 Hz) and was presented in such a way that low pass filtered to one ear and high pass filtered to another ear. The participant's task was to repeat the words what they had heard which was presented at 40 dBSL (Ref SRT). Those who repeated the word correctly score 'one' was awarded and 'zero' for wrong response.

For MLD, the signal and noise were given in both homophasic and antiphasic conditions. The test was administered at 500 Hz for both the groups. The noise level was kept constant i.e. 40 dB SL (Ref. SRT). The difference between homophasic and antiphasic condition was calculated to obtain the MLD magnitude and If difference is around 10 to 15 dB considered as normal's and those whose magnitude less than 5 dB was considered as having binaural interaction deficit.

Statistical analysis

Descriptive statistics was applied to find out mean and standard deviation for each group. The tabulated data were analyzed for normal distribution using Shiparo-Wilk test, which shows non-normal distribution of the data. Hence, non-parametric test (Mann Whitney U test) was administered to compare between two groups. Paired‘t’ test was done to compare the difference between left and right ear recording of wave V component of ABR in each group. Further, to check the relationship between electrophysiological and behavioral measures, spearman correlation analysis was done.

Chapter 3

RESULTS

The current study included two groups of participants. Group 1 comprised of 15 normal hearing individuals without CAPD and group 2 consist of 15 children at risk for CAPD. Across group, comparison was done between group 1 and 2. All the subjects were assessed for both electrophysiological (click evoked ABR) measures to obtain BIC and behavioral measures for Masking level difference test and binaural fusion test.

Electrophysiological measure:

Click evoked ABR was done using monaural stimulation (left and right ear alone) as well as binaural stimulation in both the groups. The waveforms of both monaural stimulation and binaural stimulation showed good morphology in both the groups. The mean of wave V latency in left ear was higher (more) in comparison to right ear in both control and clinical group (Figure 1). However, pair‘t’ test did not show statistical difference between two ears in both control (t (14) = -0.582; p>0.05) and clinical group (t (14) = -0.514; p>0.05). It means the wave V responses were symmetrical in both ears in each group. While binaural stimulation, the mean latency of wave V was in between both right and left ear in control group but higher (more) in clinical group (Figure 1).

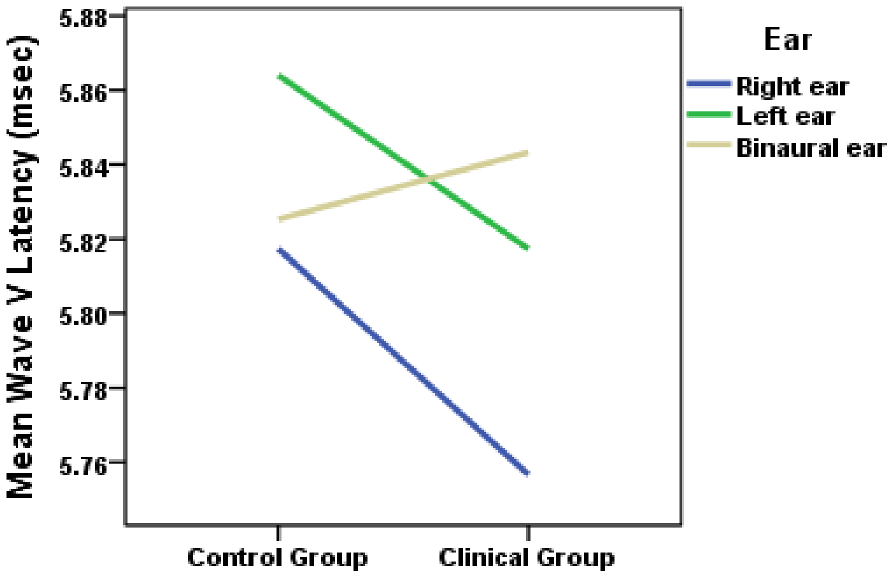

Figure 1: Wave V latency of monaural and binaural stimulation in both groups

The amplitude of wave V click evoked ABR for both monaural and binaural ear stimulation were shown in figure 2. The mean amplitude of left ear was lesser than the right ear in control group. However, in clinical group the mean amplitude of the right ear was lesser compared to left ear. When paired‘t’ test was performed both control (t (14) = 0.612; p>0.05) and clinical (t (14) = -0.789; p>0.05) group did not show statistically significant difference between two ears. Further, when comparison were made with the mean amplitude for binaural stimulation which showed higher (more) compared to either left or right ear stimulation in both the groups (Figure 2).

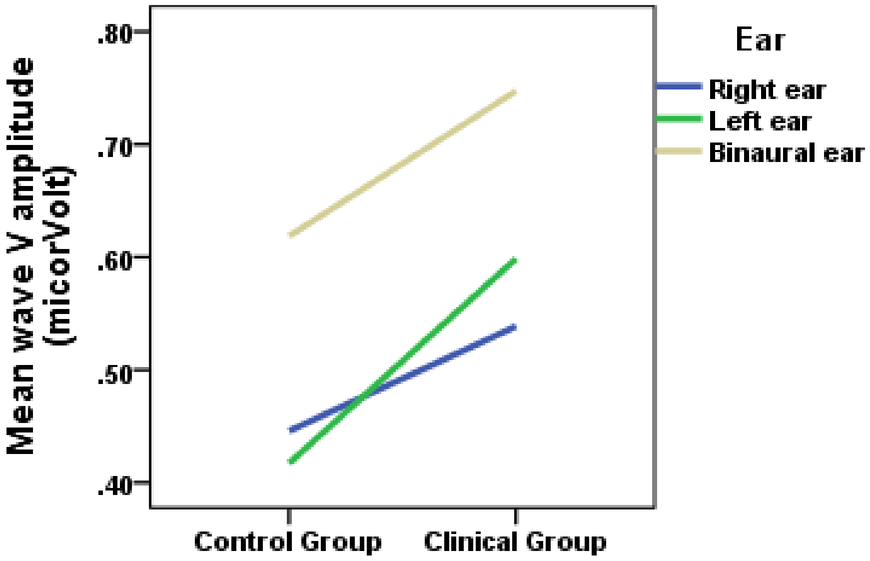

Figure 2: Wave V Amplitude of monaural and binaural stimulation in both groups

Descriptive statistics were done to obtain mean and standard deviation of both latency and amplitude measure of binaural interaction component using wave V of click evoked ABR. The mean wave V latency of BIC for children with normal hearing was 5.66 ms (0.39) where as among children at risk for CAPD, it was 5.91 ms (0.35). The mean latency of BIC was prolonged (poorer) in children at risk for CAPD compared to children without CAPD. Further, Mann Whitney U test was done to compare the statistical significance between two groups i.e. clinical and control group. Results showed statistically no significant difference between two groups (Z= = -1.722, p>0.05). The above finding indicates that mean latency of wave V of binaural interaction component is comparable between two groups, though children at risk for CAPD showed higher mean compared to control group. The figure 3 shows error bar graph of mean latency of BIC in both groups (*Figure 3).*

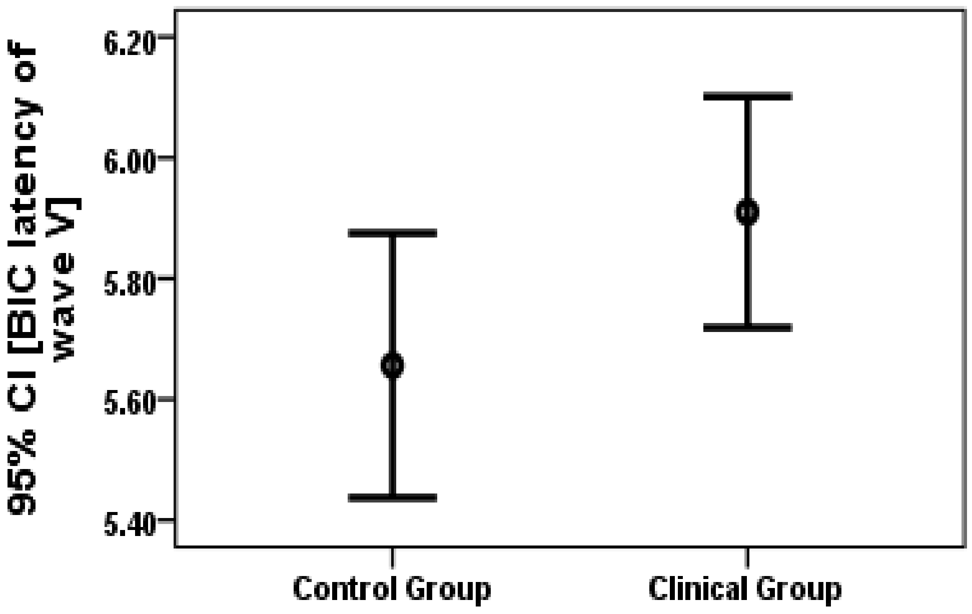

Figure 3: Error bar graph with 95% CI for BIC wave V latency measure for both groups

For amplitude measure of click evoked ABR. mean amplitude of BIC for children with normal hearing was 0.17 microvolt (0.07) where as among children at risk for CAPD, it was 0.06 microvolt (0.55). The mean amplitude of BIC was shorter (poorer) in children at risk for CAPD compared to children without CAPD. Further, Mann Whitney U test was done to compare the statistical significance between two groups i.e. clinical and control group. Results showed statistically significant difference between two groups ($Z = -3.76$, $p<0.05$). The above finding indicates that mean amplitude of wave V of binaural interaction component is reduced (poorer) significantly for children at risk for CAPD compared to typically developing children. The figure 4 shows error bar graph of mean amplitude of BIC in both groups (Figure 4).

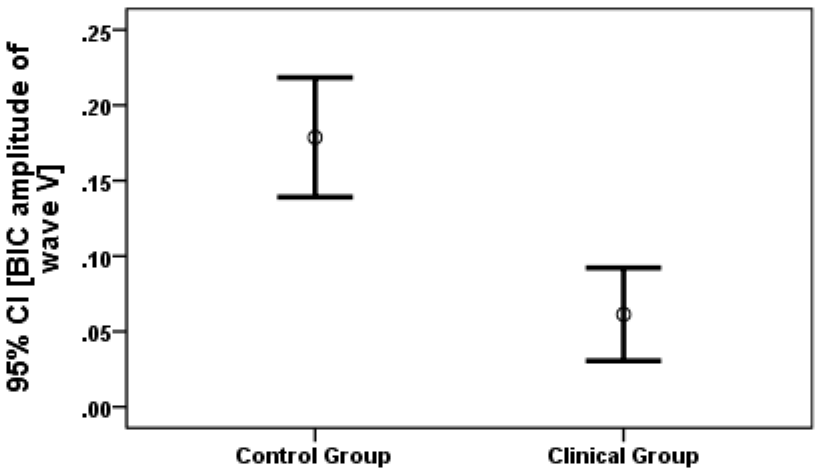

Figure 4: Error bar graph with 95% CI for BIC wave V amplitude measure for both groups

Behavioral Measures

Along with the electrophysiological measures, behavioral tests were performed to assess binaural interaction abilities in children at risk for CAPD and compared with those children without CAPD. Binaural fusion test and masking level difference test were chosen since these two tests are commonly used for assessing binaural interaction abilities.

Descriptive statistics were done to obtain mean and standard deviation of BFT. The mean (SD) BFT scores for children with normal hearing were 89.33% (8.50) where as among children at risk for CAPD, it was 74.13 % (15.78). The mean scores for BFT were reduced (poorer) in children at risk for CAPD compared to children without CAPD. Further, Mann Whitney U test was done to compare between two groups. Results showed statistically significant difference between two groups ($Z= -2.69$, $p < 0.05$). The above finding indicates that mean scores of BFT reduced (poorer) significantly for children at risk for CAPD compared to typically developing children. Figure 5 shows mean with 95% confidence interval (CI) binaural fusion test scores in both groups (Figure 5).

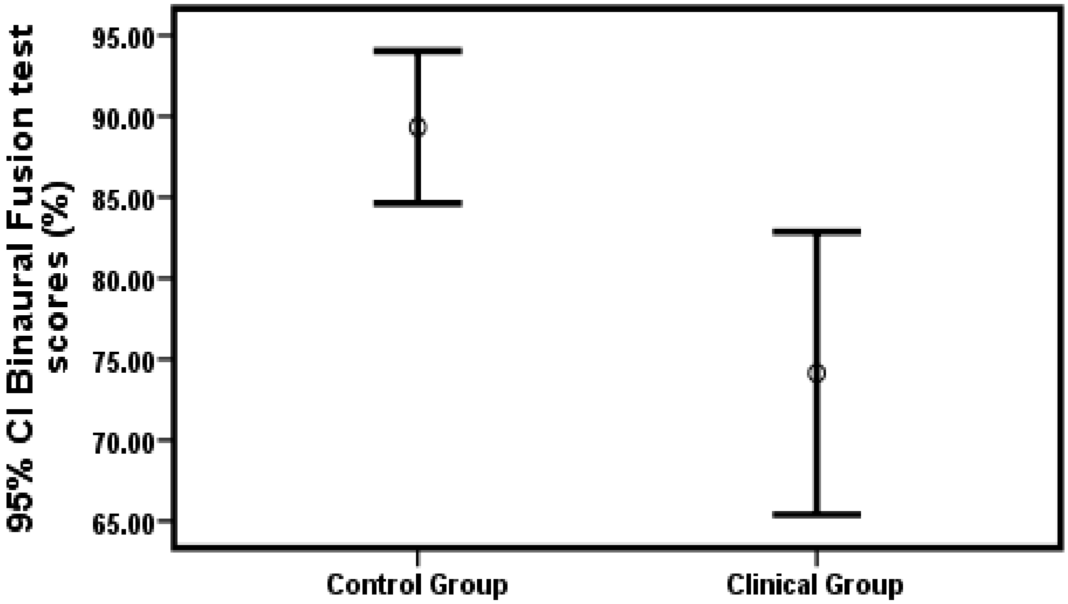

Figure 5: Error bar graph with 95% CI for Binaural fusion test scores for both groups

Descriptive statistics were done to obtain mean and standard deviation (SD) for MLD. The mean (SD) MLD for children with normal hearing without CAPD was 10.67 dB (1.76) and among children at risk for CAPD was 10.67 dB (2.59). The mean value of MLD is showing similar in children at risk of CAPD and children without CAPD. Further, Mann Whitney U test was done to compare between two groups i.e. clinical and control group. Results showed no significant difference between two groups (Z= -.060, $p > 0.05$). The above finding indicates that mean value of MLD is comparable between two groups. Figure 6 shows mean with 95% confidence interval (CI) masking level difference test scores in both groups (Figure 6).

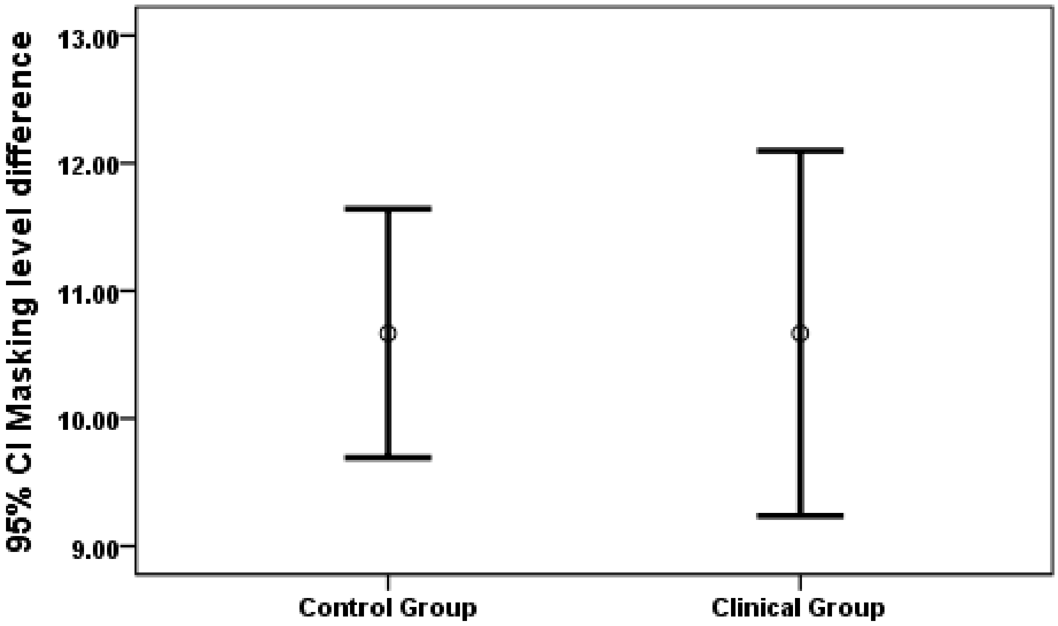

Figure 6: Error bar graph with 95% CI for masking level difference scores for both groups

Relationship between Electrophysiological and behavioral measures

To check the relationship between electrophysiological and behavioral measures, spearman correlation analysis was done. Spearman correlation analysis showed strong negative correlation between BIC latency and binaural fusion test (r = -0.63, p<0.05) which was statistically significant. The above finding indicates as latency of the BIC was prolonged (poorer), the BFT scores was also lesser (poorer) and vice versa. However, the BIC amplitude and BFT scores also showed negative but weak correlation (r = -0.05, p > 0.05) and not statistically significant. However, correlation analysis showed weak negative correlation between BIC amplitude and MLD (r= -2.53, p> 0.05) as well as between BIC latency and MLD (r= -0.09, p> 0.05), though it was not statistically significant. Figure 7 shows the scatter plot between wave V latency of BIC and binaural fusion test in children at risk for CAPD (Figure 7).

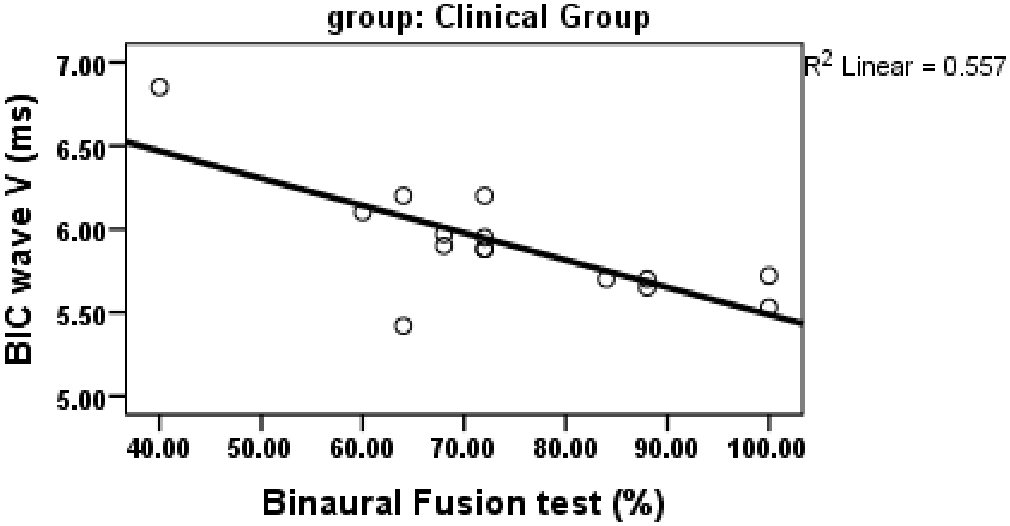

Figure 7: Scatter plot between BIC wave V latency (ms) and BFT scores (%) in clinical group

Chapter 4

DISCUSSION

The performance of children who are at risk of CAPD and typically developing children were assessed using behavioral tests (BFT and MLD) and click evoked ABR (Binaural interaction component) in the present study. Further, these findings were studied to identify the existence of correlation between behavioral test (BFT and MLD) and that with the wave V of click evoked ABR (binaural interaction component).

Electrophysiological measures of binaural interaction component

Latency and amplitude of BIC for click evoked ABR

The result of the present study shows that the wave V amplitude of binaural interaction component was statistically significant between two groups whereas wave V latency of BIC did not shows statistically significant difference. Finding indicates that mean amplitude of wave V in children at risk for CAPD were shorter (poorer) compared to children with normal hearing. However, mean latency of wave V of binaural interaction component is comparable between two groups, though children at risk for CAPD is having higher mean compared to control group. These findings of the present study are in congruence with those reported previously in related clinical group (Gopal & Pierel, 1999). They reported significant difference in the amplitude of the binaural interaction component in the CAPD group of children. They also reported no significant difference in latency measures between CAPD group and typically developing children. They hypothesized that this may reflect insufficient binaural inhibitory interactions at the higher level of the auditory brainstem. Although the underlying mechanism for the reduced inhibition is exploratory, it is more than likely that the deficit lies in the functional properties of neurons stimulated binaurally (Gopal & Pierel, 1999). Similarly, Delb, Strauss, Hohenberg, Plinkert, & Delb, (2003) suggests the use of beta-wave as an objective measure of binaural interaction and has been shown to be of diagnostic value in the CAPD diagnosis. However, a reliable and automated detection of the beta-wave capable of clinical use still remains a challenge.

In contrary, studies in existing literature shows that BIC latency is a better parameter to evaluate the binaural interaction compared to the amplitude, as amplitude of the BIC shows a very large standard deviation (Sebastian, 2013; Kumar & Sinha, 2011). However, present study noticed amplitude as better measures instead of Latency of ABR. The above difference could be because of differences in the population they assessed for obtaining binaural interaction component. Study done by Sebastian in 2013 were estimated BIC in individuals with symmetrical and asymmetrical sensorineural hearing impairment. However Kumar and Sinha in 2011 estimated BIC using speech stimuli in individuals with normal hearing. Present study used click as stimuli which differs when compared with speech stimuli in terms of frequency characteristics of the stimuli. Similarly, Sebastein (2013) explored sensorineural hearing impaired individuals to estimate BIC whereas present study targeted children at risk for CAPD. Due to the differences in populations and type of stimuli, the results of previous two studies might differ from the present study finding.

Based largely on the latencies of BIC, investigators have also suggested that the generators are the inferior colliculus (McAlpine, Jiang, & Palmer, 1996; Wrege & Starr, 1981), third order neurons of Superior olivary colliculus (McPherson & Starr, 1993) or afferents from the Superior olivary colliculus to the Lateral leminiscus (Kelly, Liscum, van Adel, & Ito, 1998; Jones & Van der Poel, 1990; Riedel & Kollmeier, 2002). Thus, BIC latency does not provide clear evidence regarding the source of the BIC. These studies are in congruence with the result of the present study where results are not showing any significant difference in latency measures where as amplitude measure is showing significant difference while comparing both the groups.

Further stimulus used also can affect binaural interaction component even in normal as age increases. Study done by Van Yper et al found that binaural interaction component decline with age for 500 Hz tone burst, but for the click stimulus it doesn't decline with age. They postulated that MSO is involved in the processing of low frequency whereas LSO for high frequency. Studies in existing literature and in present study it was found that even in case of children with CAPD, binaural interaction component is reduced for click stimuli. This might be due to reduced processing ability of the LSO in the CAPD children.

Behavioral measures of binaural interaction abilities

The comparison of binaural fusion test between both groups showed statistically significant difference and the findings indicates that mean scores of BFT reduced (poorer) significantly for children at risk for CAPD compared to typically developing children. The findings of the present study are in congruence with those reported previously in related clinical group (Roush & Tait, 1984; Singer, Hurley, & Preece, 1998; Musiek & Geurkink, 1980) Roush and Tait (1984) reported overall scores of binaural fusion test for clinical group is lower (poorer) children with learning disabilities than typically developing peers. Their findings also suggest the potential usefulness of binaural fusion measures in the assessment of auditory processing abilities in children.

Singer, Hurley, & Preece, (1998) investigated the individual test efficiency in identifying targeted group of children. The study included 91 children with normal learning and 147 children with classroom learning disability (CLD) and presumed CAP disorders in the age range of 7 to 13 years. The results showed that binaural fusion test separated the two groups most effectively than any other tests. Likewise, the effect of central auditory tests in assessing binaural interaction abilities on children with auditory processing problems was evaluated by Musiek & Geurnik (1980). They assessed 5 children with auditory processing problems and reported that out of 5 children, 3 children got lesser (poorer) scores in binaural fusion test. Similarly reduced BFT scores has been shown among children with specific-language impairment (Stollman, Velzen, Simkens, Snik, & Van den Broek, 2003), children with deviant language development (Quaranta & Cervellera, 1977) and also in children with dyslexia (Peñaloza-López et al., 2009).

Comparison between the groups for MLD tests revealed that MLD scores at 500 Hz were similar between the groups. The findings of the present study are in congruence with those reported previously in related clinical group (Kumar et al., 2013; Roush & Tait, 1984). 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 MLD test has been shown among children with dyslexia (Hill, Bailey, Griffiths, & Snowling, 1999) and in adults with reading disabilities (Amitay, Ahissar, & Nelken, 2002). Study done by Kumar, Singh and Ghosh (2013) on CAPD children reported lack of sensitivity of MLD at 500 Hz to differentiate clinical population with typically developing children. The poor sensitivity of MLD observed in present study could be due to use of 5 dB step size while estimating threshold in different condition. In a similar line, study done by Kumar et al in year 2013 used 5 dB step size while estimating the MLD score. However, study done by Roush and Tait in year 1984 used 2 dB step size to estimate the MLD scores in different phase condition. Comparing both behavioral tests which assess similar process i.e. binaural interaction, it is interesting that the two groups differed only on binaural fusion of filtered speech task while performance on the other test i.e. MLD employing nonlinguistic stimuli did not differentiate the two groups. It appears from these data that children at risk for CAPD described here might be more detrimentally affected by reduced redundancy in the speech signal than normal children.

Relationship between electrophysiological and behavioral measures

Correlation analysis of various behavioral test results with click evoked ABR (binaural interaction component was carried out in both control and clinical group. The results revealed that strong negative correlation between BIC latency and binaural fusion test which was statistically significant. Findings also shows that as latency of the BIC was prolonged (poorer), the BFT scores was also lesser (poorer) and vice versa. However, the BIC amplitude and BFT scores also showed negative but weak correlation and not statistically significant. Similarly, correlation analysis showed weak negative correlation between BIC amplitude and MLD as well as between BIC latency and MLD though it was not statistically significant. Strong correlation of BIC latency and BFT may be because both tests are accessing same process i.e. binaural interaction. In the present study MLD results are showing comparable performance in both control and clinical group .Which shows MLD is not a sensitive test in accessing binaural interaction in children at risk for CAPD. This may be the reason that MLD test is not showing any correlation with other tests which access binaural interaction. Similarly, Kelly-Ballweber and Dobie in year 1984 evaluated binaural interaction behaviorally and electrophysiologically in young and older adults i.e. 12 young men in the mean age range of 39.1 years and 12 older men in the mean age range of 69.4 years. However, their work supports suggestions that there is no significant found between electrophysiological and behavioral measures of binaural interaction. Even though these tests assess same process3 i.e. binaural interaction they don’t show any significant correlation. As per our knowledge there are very limited studies available in literature to discuss the correlation finding. Hence, the present study reinforces the needed of using test battery approach in CAPD rather than a single gold standard test.

Chapter 5

SUMMARY AND CONCLUSION

The present study aimed to check the relationship between electrophysiological and behavioural tests of binaural interaction of central auditory function in children who are at risk for CAPD. The study consists of 15 school going children who are at risk for CAPD in the age range of 8 to 14 years which constituted clinical group and 15 age matched typically developing children constituted the control group. All the participants underwent detailed audiological evaluation they had normal hearing and normal middle ear function. This was followed by behavioural tests for binaural interaction and click evoked ABR (binaural interaction component).

Electrophysiological measure

- Descriptive statistics were done to obtain mean and standard deviation of both latency and amplitude measure of binaural interaction component using click evoked ABR.
- The latency of BIC for children with normal hearing was 5.66 ms (0.39) where as among children at risk for CAPD, it was 5.91 ms (0.35). The mean latency of BIC was prolonged (poorer) in children at risk for CAPD compared to children without CAPD.
- For amplitude measure of BIC for children with normal hearing was 0.17 microvolt (0.) where as among children at risk for CAPD, it was 0.06 microvolt (0.55). The mean amplitude of BIC was shorter (poorer) in children at risk for CAPD compared to children without CAPD.
- Further, Mann Whitney U test was done to compare the statistical significance between two groups i.e. clinical and control group.

- Results showed statistically no significant difference between two groups in latency of binaural interaction component whereas significant difference in amplitude was seen between two groups.

Behavioural measure

- Descriptive statistics were done to obtain mean and standard deviation (SD) for MLD and BFT. The mean (SD) MLD for children with normal hearing without CAPD was 10.67 dB (1.76) and among children at risk for CAPD was 10.67 dB (2.59). The mean value of MLD is showing similar in children at risk of CAPD and children without CAPD.
- The mean (SD) BFT scores for children with normal hearing were 89.33% (8.50) where as among children at risk for CAPD, it was 74.13 % (15.78). The mean scores for BFT were reduced (poorer) in children at risk for CAPD compared to children without CAPD.
- Further, Mann Whitney U test was done to compare the statistical difference between two groups.
- The results of these evaluations revealed that the children who are at risk for CAPD poorly performed poorly in behavioural test i.e. binaural fusion test, where as MLD test result was comparable for both group.

Correlation between electrophysiological behavioral measures

- To check the relationship between electrophysiological and behavioural measures, spearman correlation analysis was done.
- Spearman correlation analysis showed strong negative correlation between BIC latency and binaural fusion test ($r = -0.63$, $p<0.05$) which was statistically significant.

- The above finding indicates as latency of the BIC was prolonged (poorer), the BFT scores was also lesser (poorer) and vice versa. Whereas no significant correlation was found between MLD and electrophysiological test.

Implications of the study

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1. Electrophysiological test can be used to understand the behavioural problems in children at risk for CAPD along with other behavioral test.
2. Use of electrophysiological tests along with behavioural measures should be encouraged while assessing these children so as to ascertain and confirm the diagnosis.
3. Children with CAPD whom behavioural assessment becomes difficult, the electrophysiological testing can be used to make an estimate of their problem in real life scenario.
4. Add information to the existing literature.

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