Binaural Interaction Component, Binaural Fusion Test and Masking Level Difference in Children at Risk of Central Auditory Processing Disorder

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Abstract

To obtain the relationship between electrophysiological and behavioral test for assessing binaural interaction abilities in children at risk for CAPD.Objective: To assess binaural interaction abilities using electrophysiological test i.e. binaural interaction component (BIC) and with behavioral tests i.e. binaural fusion test and Masking level difference test in children at risk for CAPD. To find the correlation between subjective and objective tests used. A total of 30 children participated in the study, in which 15 participants in the clinical group who were at risk of CAPD and other 15 in the control group consists of typically developing children who were not identified as at risk for CAPD.Objective and subjective tests for assessing were carried out. The objective evaluation of binaural interaction were assessed by finding Binaural interaction component (BIC) using click evoked ABR. For the subjective evaluation of binaural interaction binaural fusion teat and making level difference test was carried out. There was a statistically significant difference between the results of children who were at risk for CAPD and age matched typically developing normal children in both subjective and objective tests. The results showed children who were at risk of CAPD performed poorer compared to the results of children who were not at risk for CAPD expect in MLD test , results were similar for both the group. The results showed that there is a strong negative correlation between BIC latency and binaural fusion test ($r = -0.63$, $p<0.05$). The finding indicates as latency of the BIC was prolonged (poorer), the BFT scores was also lesser (poorer) and vice versa. Electrophysiological test can be used to understand the behavioural problems in children at risk for CAPD along with other behavioral test. Use of electrophysiological tests along with behavioural measures should be encouraged while assessing these children so as to ascertain and confirm the diagnosis. 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.

Key words: *Digital hearing aid, Wireless, Synchronization, Older adults*

Introduction

Central auditory processing refers to the perceptual processing of auditory information in the central nervous system. It includes auditory mechanisms like 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).

There are several behavioral and/or electrophysiological test exists in the literature which can help in assessing central auditory processing disorder. Behavioral test and electrophysiological test helps in uncovering the important aspects of neural basis of central auditory dysfunction. However, there is no single test considered as gold standard for assessing CAPD and hence clinicians mainly rely on test battery approach. Test battery approach should include both electrophysiological and behavioral test to ensure all the mechanism which help in central auditory processing is tested. Both behavioral and objective test has their own advantages and disadvantages, there are still controversies about findings of behavioral tests of central auditory processing disorder. This may be due to reduced sensitivity and specificity of the behavioral tests which could be because of some variables like electronic recording and playback techniques (Shea & Raffin,1989), variability inherent in the tests (keith, Ruby, Donahue & Katbamma,1989). However, it has an advantage of being acceptable widely and less expensive. Compared to behavioral tests electrophysiological tests are less affected by extraneous variable but it has disadvantage of being expensive, time consuming and not available widely. Thus combination of both of these i.e. behavioral and electrophysiological tests will help clinician/ professionals to access different domains of auditory system more accurately. Present study focus on accessing binaural interaction abilities in children at risk of CAPD using electrophysiological test i.e. Binaural interaction component (BIC) and behavioral CAPD test like binaural fusion test (BFT) and Masking level difference (MLD) Test.

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Binaural fusion test is a 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 are results in unintelligible stimuli monaurally. However, when these filtered stimuli are presented together in both ears results in fusion of these information and helps in recognition of stimuli (Wilson, Arcos & Jones, 1984). Masking level difference (MLD) is another behavioral test helps in assessing binaural interaction abilities using pure tone signal. The MLD, which is a binaural phenomenon, is a release from masking that 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). Study done by Kumar, Singh and Ghosh (2013) studied 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.

The Binaural interaction component (BIC), is the residual ABR obtained after subtracting the sum of monaurally evoked responses from binaurally evoked ABRs. There are several studies explored measuring 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 Sebastain in 2013 tried to explore 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 observed significant difference for latency of BIC between normal and asymmetrical hearing impaired individuals. However, other parameters did not show any significant differences between groups. 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.

In clinical populations, BIC measurement has been employed to evaluate the integrity of binaural processing (Gordon, Solloum, Toor, Hoesel & Papsin, 2012). Deficits in binaural processing can lead to different degrees of auditory processing disorders. Accessing binaural interaction is having diagnostic importance especially in children with suspected APD. Further investigations conducted by Gopal and Pierel (1999) have shown the BIC to be reduced in amplitude in subjects who are diagnosed with an auditory processing disorder. Thus these authors concluded that with better characterization, the BIC may reflect auditory processing abilities and may be used as an index of binaural processing (Gopal & Pierel, 1999).

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. The main objectives were 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

METHOD

1. Participants

The Study will consist of two groups i.e. an experimental group and a control group in the age range of 8 to 14 years. The experimental group is defined as those children who are at risk of CAPD based on a questionnaire as screening checklist for auditory processing (SCAP) and audiological screening test for auditory processing (STAP) test. The control groups include those children who are not identified as at risk for CAPD. There will be minimum 15 participants in experimental group and 15 age matched typically developing children as control group. Informed consent will be obtained from all the participants. Prior to the experiment they will be explained about the test procedure in detail. Further, detail case history will be taken for all the participants.

Participant inclusion and exclusion criteria

In experimental and control group, those participants will be included who have normal hearing sensitivity (within 15 dBHL) at octave frequencies between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction. Immittance evaluation should reveal 'A' type tympanogram with ipsilateral and contralateral reflexes should be present. They should have normal or average IQ. They should be studying in English medium school from at least 2 to 3 years. Further, experimental group participants should be failed in the SCAP and STAP to be considered as at risk for CAPD group. However, control group participants should pass in the SCAP and STAP to be considered as not at risk for CAPD. In both group, those participants who will be having any past history of otological /neurological problems, and illness at the day of testing will be excluded from the study.

2. Instrumentation:

Calibrated two channel Piano Inventis diagnostic audiometer will be used for pure tone threshold estimation, BFT and MLD. Calibrated GSI TYMPSTAR Immittance meter will be used for tympanometry, ipsilateral and contralateral reflexometry. Calibrated ILO 292 DPEcho port system (otodynamics Inc., UK) will be used to assess transient evoked otoacoustic emissions. Biologic Navigator Pro EP 7.2.1 will be used for recording of the click evoked auditory brainstem responses and to obtain binaural interaction components.

3. Test Environment:

Both electrophysiological and behavioral test will be done in acoustically treated rooms with the permissible noise level as per ANSI 3.1(1999) standards. The experimental evaluation will be done in a quiet room.

4. Procedure:

Pure tone audiometry will be carried out based on Modified Hughson-Westlake procedure for octave frequencies. Thresholds will be obtained for the range of 250 to 8000 Hz for air conduction and 250 to 4000 Hz for bone conduction testing. In both the groups, the pure tone threshold should be within ? 15 dBHL in both ears.

Immittance evaluation will be carried out for both the ears using GSI-TS tympanometer with probe tone frequency of 226Hz. Ipsilateral and contralateral reflex threshold will be measured for 500, 1k, 2k and 4 k Hz. In both the groups, tympanogram should be 'A/As' type with ipsilateral and contralateral reflex presents at all the frequencies between 500 Hz to 4000 Hz.

Screening checklist for auditory processing developed by Yathiraj and Mascarenhas (2004) will be administered in all children to rule out auditory processing disorder. This checklist consists of 12 questions. The checklist is scored on a 2 point rating scale as "Yes" or "No". Each answer marked yes scores one and each no will be scored zero and children who scored more than 50% is considered to be at risk for CAPD. Pass criteria of SCAP is children who scored less than 50% (6/12).

Screening Test for Auditory Processing (STAP) developed by Yathiraj & Maggu (2012) will also be administered on all children to check 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 criteria defined by the developer will be used for the pass and fail purposes.

Transient evoked otoacoustic emissions will be carried out to rule out retrocochlear pathology. TEOAE should be present in both the groups. A good probe fit will be ensured prior to the testing. Click stimuli of total 260 will be presented and response will be averaged. Reproducibility of more than 80% and signal-to-noise ratio (SNR) of 6 dB will be considered as responses present. TEOAE responses will be measured for 1000, 2000, 3000 and 4000 Hz.

For ABR testing the subject will be made to sit on a reclining chair. The skin surface at the higher forehead, lower forehead and mastoid of both the ears will be cleaned using skin abrasive to achieve an impedance of less than 5k ohms. The electrodes will be placed using conduction paste and surgical plaster for firm attachment. The subjects will be instructed to relax and minimize body movements to reduce the artifacts while recording. Click evoked auditory brainstem response will be 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 will be used.

Table 1:- Protocol for clicked evoked ABR and SOL 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 will be recorded monaurally for both the groups and binaurally for the same group as well. The binaural interaction component will be determined by subtracting the binaurally evoked auditory potentials from the sum of monaural auditory evoked potentials (Brantberg, Fransson, Hansson, & Rosenhall, 1999; Levine, 1981; Gardi & Berlin, 1981; Wrege & Starr, 1981; Dobie & Norton, 1980; Jewett, 1970; Sebastein, 2013).

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

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

Binaural fusion test developed by Shivaprasad and Yathiraj (2006) will be used in the present study which consists of 4 lists having 25 words in each and these words are low pass filtered (500 to 700Hz) and high pass filtered (1800 to 2000 Hz) and will be presented in such a way that low pass filtered to one ear and high pass filtered to another ear. The participant's task is to repeat the words what they had heard which will be presented at 40 dBSL and if the participant repeated the word corrected score one will be awarded and zero for wrong response. For MLD, binaural masked threshold is will be obtained for homophasic and antiphasic conditions. It will be administered at 500Hz for both the groups. The noise level will be kept constant i.e. 40 dBHL. The difference obtained between homophasic and antiphasic condition will gives the MLD magnitude and if it is around 10 to 15 is considered as normal's and if magnitude is less than 5 dB, then it significantly indicates APD.

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).

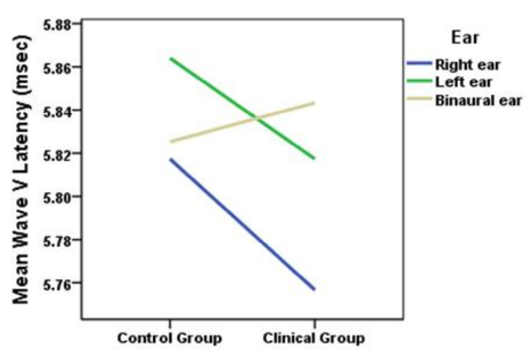

Figure 1: Wave V latency of monaural and binaural stimulation in both groups

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).

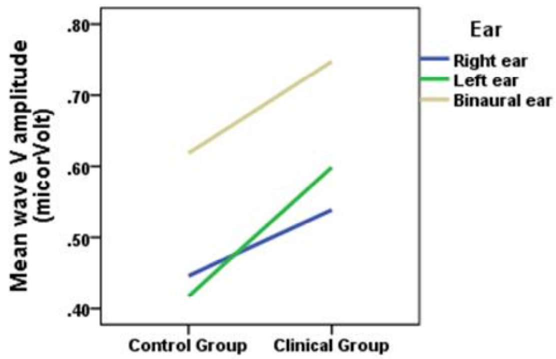

Figure 2: Wave V amplitude of monaural and binaural stimulation in both groups

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).

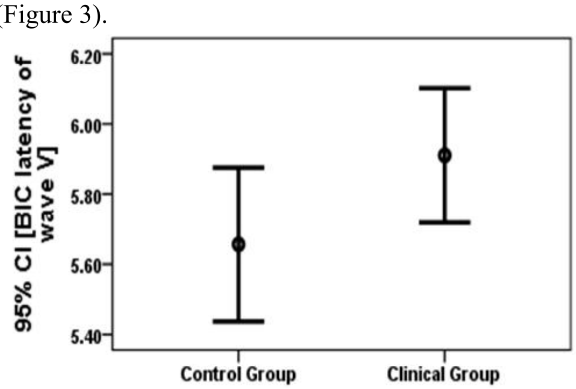

Figure 3: Error bar graph with 95% CI for BIC wave V latency measure for both groups

For latency 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).

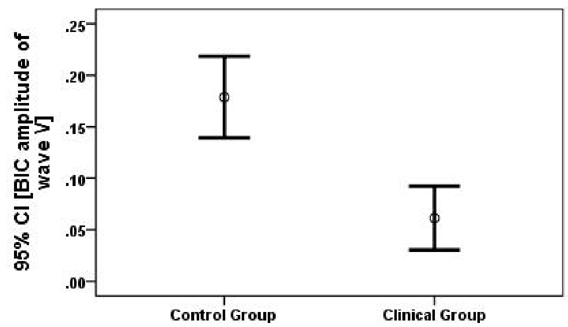

Figure 4: Error bar graph with 95% CI for BIC wave V amplitude measure for both groups

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).

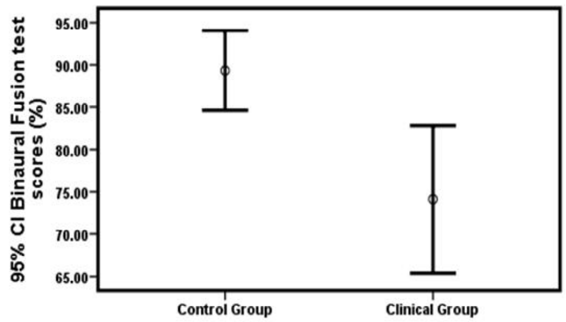

Figure 5: Error bar graph with 95% CI for Binaural fusion test scores for both groups

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).

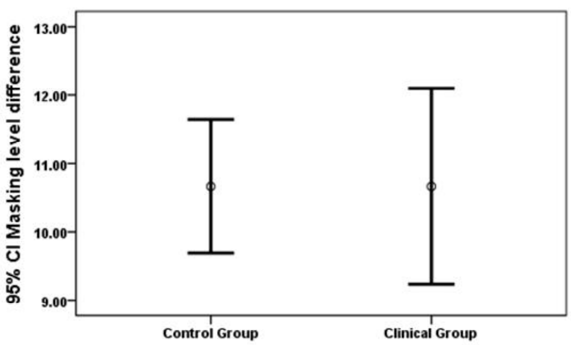

Figure 6: Error bar graph with 95% CI for masking level difference scores for both groups

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).

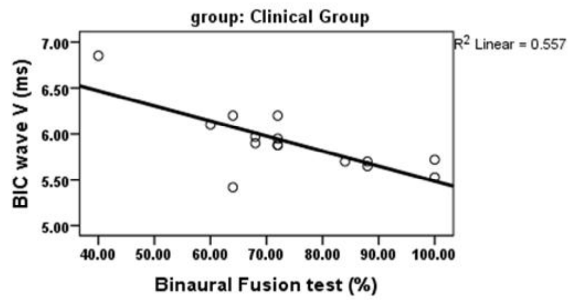

Figure 7: Scatter plot between BIC wave V latency (ms) and BFT scores (%) in clinical group

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.

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

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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