Relationship between Speech Evoked ALLR and Dichotic CV Scores in Children with Dyslexia

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Abstract

Children with dyslexia may be associated with (central) auditory processing disorders. These processing disorders of an individual can be assessed either through behavioural tests and/or electrophysiological tests. Behavioural and electrophysiological tests are useful in uncovering the important aspects of neural basis of central auditory dysfunction in children with dyslexia. The present study evaluated the performance of children with dyslexia in comparison to typically developing children on speech evoked ALLR and Dichotic CV test. It was also aimed to see if any correlation exists between speech evoked ALLR and in Dichotic CV test in children with dyslexia. A total number of 30 children in the age range of 10 to 12 years were taken for the study. Out of 30 children, there were 15 typically developing children and 15 children with dyslexia. The results revealed that overall for speech evoked ALLR, latencies were significantly prolonged and amplitude was reduced in dyslexic children as compared to typically developing children. Similarly, Dichotic CV scores were also significantly reduced in dyslexic children. Further, it was observed that there were positive correlation between double corrected score and speech evoked ALLR but statistically non-significant. Hence, it is concluded that children with dyslexia performed poorly in dichotic listening test. It is also concluded that there is abnormal encoding of speech signal at cortical level in these children.

Keywords: *Dyslexia, Speech evoked ALLR, Dichotic listening, Dichotic CV test.*

Introduction

Dyslexia is a specific learning disability that is neurological in origin. It is characterized by difficulties with accurate or fluent word recognition and by poor spelling and decoding abilities. Learning problem is one of the common educational problems seen in a number of school going children. This learning problem negatively affects a variety of behaviours, so early intervention is one of the most important steps in this regard. In India, the occurrence of dyslexia ranges from 3% to 7.5% of children (Ramma, 2000). The prevalence estimate of this disability has been found to be 3 to 10 % (Snowling, 2000). Children with dyslexia may have auditory processing disorder and have been experimentally investigated by many researchers (Bellis, 1996; Billiet & Bellis, 2011; Johnson, Nicol & Kraus, 2005; Kraus et al., 1996; Rosen & Manganari, 2001). Studies on incidence of auditory processing deficits in children with dyslexics are estimated to be of 40% (Ramus, 2003).

Studies have shown abnormal processing of speech stimuli and normal processing for tonal stimuli in dyslexic children (Serniclaes, Sprenger-Charolles, Carre & Demonet, 2001). Tallal (1980) reported that there is deficit in processing of brief, rapidly changing auditory stimulus in dyslexics. Study has suggested that such children have difficulty in processing of complex stimuli especially to process through auditory mode (Estes & Huizinga, 1974; Manson & Mellor, 1984).

The auditory processing of an individual can be assessed through behavioural tests or either by electrophysiological tests. Behavioural and electrophysiological tests have also been useful in uncovering the important aspects of neural basis of central auditory dysfunction. Behavioural tests mainly cut down the external redundancy and assess processing of auditory signal. These behavioural tests includes Dichotic tests, Competing sentence test, Staggered spondaic word test, Pitch pattern test, Duration pattern test, and Gap detection test. These tests are clinically useful to assess one or more auditory processes like auditory integration, sequencing, attention etc.

Dichotic listening test has been frequently used to evaluate the binaural separation and binaural integration abilities. Dichotic CV test has been used to evaluate the normal and impaired auditory process at the cortical level. Dichotic speech test includes variety of stimuli such as nonsense syllables, digits, monosyllabic words, spondaic words or sentences. Studies have shown that children with dyslexia exhibit poorer dichotic listening abilities (Moncrieff & Musiek, 2002; Purdy, Kelly & Davies, 2002).

On the other hand, electrophysiological tests assess the underlying physiology of the auditory system. Auditory evoked potentials provide strong objective methods to assess the neural integrity of the auditory pathway from auditory nerve to cortex (Hood, 1998). Majority of electrophysiological tests has been carried out in individuals with learning disability to assess the auditory processing at the cortical level. The Auditory long latency response (ALLR) is the most frequently used test among

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the cortical potentials to assess cortical region. Most of the studies have reported a prolonged latency (Arehole, 1995; Guruprasad, 1999; Jirsa & Clontz, 1990; Radhika, 1997) and reduced amplitude in these populations (Jirsa & Clontz, 1990; Mason & Mellor, 1984; Radhika, 1998). David and Ghosh (1984) recorded P1, N1, P2 and N2 peaks in individuals with reading problem and results reveal an increased latency of P1 and P2 peaks when compared with normal average readers. Arehole (1995) studied the relationship between long latency responses and learning disorders in individuals with dyslexia. Results revealed an increased P2-P1 inter-peak latency in individuals with dyslexia in comparison to normal children.

Johnson et al. (2005) described that the synthetic /da/ syllable has been used to study the processing of complex stimuli like speech, at the level of brainstem as well as at the level of cortex and further to study deviancies if any, in clinical population like learning disability. The response manifests as a series of brief neural events that are time-locked to the onset, offset, and the sustained information of the stimulus /da/. This tool has been used to assess binaural listening processing in children with learning disability including dyslexia. Therefore it has been suggested that the use of speech evoked ALLR in assessing such kind of processing deficits is promising to be a valid and reliable tool in such clinical population.

Though behavioural tests have been widely accepted to be the test of choice, however processing deficits may be co-morbid with a number of the pathologies that prevent the administration of behavioural tests. Hence, an attempt is required to check the equivalency of electrophysiological tests in the assessment of (central) auditory processing disorders in children with dyslexia. Cortical potentials have been widely used to understand the neurophysiological basis for speech perception, which would give information of speech processing abilities of the individuals. One such potential may be speech evoked ALLR.

Speech evoked ALLR helps in assessing the capacity of auditory cortex to detect changes within the speech stimuli (Martin & Boothroyd, 1999). There are different types of speech signals which are quite useful in eliciting ALLR includes natural or synthetic vowels, syllables and words (Ceponieni et al., 2001; Sharma, Marsh & Dorman, 2000; Tremblay Friesen, Martin & Wright, 2003). Hence, the recording of ALLR using speech stimuli can probe how the brain processes the signals that underlie auditory detection and discrimination. Majority of the studies have focused on recording of ALLR on click stimulus or more frequency specific tone bursts. But recording of ALLR using tone burst does not give much information about the processing or perception of speech. The P1-N1-P2 evoked neural response is heavily influenced by acoustic content of evoking signal. Hence it is important to know more about how the speech signal is processed in children with dyslexia. Therefore, the speech stimuli /da/ was used in the present study.

Most of the studies have evaluated children with dyslexia, and they observed clinically significant reductions in dichotic listening performance (Maerlender, Wallis & Peter, 2004; Moncrieff & Black, 2008). However, research done in dichotic listening test is very limited in clinical population such as dyslexia, where it can be used as a tool to identify the individuals with dyslexia. Hence, the aim of the present study was to evaluate the efficacy of speech evoked ALLR and dichotic CV test in individuals with dyslexia in comparison to typically developing children. It was also aimed to find out if any correlation exists between speech evoked ALLR and Dichotic CV tests in children with dyslexia.

Method

Participants

Two groups of participants were included in the study: control and experimental group. Thirty participants (60 ears) from both the groups in the age range of 10 to 12 years participated in the study. Control and experimental group consisted of 30 ears from 15 typically developing children (13 males & 3 females) and 15 children with dyslexia (11 males & 4 females) respectively. The diagnosis for the experimental group was made by speech language pathologists / Psychologists at AIISH, Mysore. All the participants had hearing sensitivity within normal limits (hearing threshold less than 15 dB HL at octave intervals between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction), normal middle ear functions as per immittance evaluation, and average or above average intelligence, based on Raven's progressive matrices were selected for the study. However, those participants who were diagnosed as dyslexia with any additional associated problems such as attention deficit disorder with/without hyperactivity, chronic psychological disorder, or with any other neurological disorder were excluded from the study.

Instrumentation

A calibrated two channel diagnostic audiometer (Orbiter-922) with TDH-39 headphones and MX-14/AR ear cushion was used for air conduction thresholds. Radio ear B-71 bone vibrator was used for estimating bone conduction thresholds. The same audiometer was used for presenting dichotic CV test stimuli coupled with personal computer. A calibrated middle ear analyzer (GSI-Tympstar, version 2) was used to rule out middle ear pathology. ILO version 6 was used to record the TEOAEs. Bio-logic Navigator pro (ver-

Table 1: Protocol for recording click evoked ABR and speech evoked ALLR

Parameters	Click evoked ABR	Speech evoked ALLR
Stimulus	Click (100 μs duration)	Natural /da/ stimulus (185 ms)
Electrode Placement	Non-inverting-Fpz Common-A1/A2 Inverting-A2/A1	Non-inverting-Fpz Common-A1/A2 Inverting-A2/A1
Intensity	90 dBnHL	80 dBnHL
Polarity	Rarefaction	Alternating
Filter setting	100 - 3000 Hz.	1 - 30 Hz.
Repetition rate	30.1/sec	1.1/sec
Time window	10-12 ms	500 ms
No. of channel	Single	Single
No. of sweeps	1500	200
Impedance	< 5kΩ	< 5kΩ
No. of replication	2	2

sion 7.0) evoked potential system was used for recording click evoked auditory brainstem response (ABR) and speech evoked ALLR.

Test Materials

For speech evoked ALLR, a natural /da/ stimulus was recorded by an adult male speaker with clear articulation. The recording was done using unidirectional microphone connected to the computer in the sound treated room. Adobe Audition (version 2) software with a sampling rate of 48000 Hz and 16 bit resolution was used. The stimulus duration was approximately 185 ms. Recorded stimulus was then converted into wave file and loaded into the Biologic navigator pro evoked potential system for speech evoked ALLR recording.

For dichotic CV test, the material used was dichotic Consonant-Vowel (CV) word lists (Yathiraj, 1999) consisting of 30 standardized pairs of syllables /pa/, /ta/, /ka/, /ba/, /da/ and /ga/.

Test Environment

The testing was carried out in an acoustically sound treated room with ambient noise levels within permissible limits as per ANSI S3.1 (1991).

Test Procedure

Screening Checklist for Auditory Processing (SCAP) was administered on control group developed by Yathiraj and Mascarenhas (2003), to rule out symptoms of auditory processing disorders. It consists of twelve questions having the symptoms of deficits in auditory processing. The scoring was done on a two point rating scale (Yes/No). Children who scored less than 50% were considered for the study.

Pure tone thresholds were obtained at octave intervals between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction (mastoid placement), using modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Tympanometry was carried out using 226 Hz probe tone at 85 dBSPL to rule out any middle ear pathology. For reflexometry, acoustic reflex measurement was performed using reflex eliciting tone of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz ipsilaterally and contralaterally. Transient evoked otoacoustic emissions (TEOAE) were measured using click stimuli at 85 dBSPL in both ear to assess the outer hair cells functioning.

Click evoked ABR and speech evoked ALLR were recorded in both ears for all the participants using the test protocol mentioned in Table 1. Participants were made to sit comfortably in order to ensure a relax posture and minimum rejection rate. Gold cup electrodes were placed after cleaning the electrode placement sites with preparing gel. Conduction paste was used to improve the conductivity of the recording signal from the generator sites. The electrodes were secured to the place by using plasters. The electrode placement was kept and followed as per the test protocol.

Dichotic CV test: The dichotic consonant-vowel test material was played through personal computer connected to the calibrated double channel diagnostic audiometer. The dichotic CV word lists were presented to both the ears using zero (0) ms lag at 40 dB SL (re: SRT). The children were instructed as "*You will be hearing two words one to each ear at the same time. You should repeat both the words that you hear*". Task understanding was ensured using five practice items before proceeding to the dichotic consonant-vowel test.

Table 2: Mean and standard deviation of latency and amplitude measure for control and experimental groups

Waves	Latency Measures (ms)				Amplitude measures(μV)			
	Control group (N = 29)		Experimental group (N = 26)		Control group (N = 29)		Experimental group (N = 26)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P1	91.26	15.52	113.35	31.57	2.88	1.23	1.41	0.82
N1	134.48	23.67	175.14	37.15	-2.15	1.51	-3.88	1.96
P2	192.43	42.57	242.65	43.95	1.99	0.81	0.71	0.52
N2	235.68	46.09	303.20	39.19	-1.48	1.41	-2.81	1.40

N = number of ears; SD= Standard deviation; ms = millisecond; μV = microvolt.

The responses of all the participants were scored in terms of single correct score and double correct scores. The right ear score (RES), left ear score (LES), and double correct score (DCS) were scored. A single correct score was calculated when the participants reported the syllable presented to any one ear correctly. A double correct response was calculated when the participants reported the syllable presented to both ears correctly.

Statistical Analysis

Descriptive statistical analysis of the scores in terms of mean, standard deviation and other tests (parametric and non-parametric) such as Multivariate analysis of variance (MANOVA), Paired t-test and Karl Pearson correlation test performed using Statistical package Social Science (SPSS 16.0) software for both speech evoked ALLR and Dichotic CV tests. The results obtained are presented and discussed in the subsequent section.

Results and Discussion

Descriptive statistics was done to find out the mean and standard deviation (SD) for all the parameters for both control and experimental groups. MANOVA was administered to compare between experimental as well as control group for latency and amplitude of speech evoked ALLR and behavioural tests (dichotic CV) scores. In order to find out ear advantage Paired t-test was used to compare between the two groups. Karl Pearson's Correlation was done to check whether any relationship exists between speech evoked ALLR and DCS of dichotic CV scores.

Speech Evoked ALLR

In typically developing children all the peaks of speech evoked ALLR was present in all participants. However, in children with dyslexia, all peaks of speech evoked ALLR was present in all participants expect wave N2, which was absent in two participants. Hence, the percentage of recorded waveform for P1, N1, and P2 was 100% whereas for N2 it was only 86.6%. The mean and standard deviation of speech evoked ALLR latency and amplitude measures are mentioned in Table 2.

P1 wave: From Table 2, it can be observed that the mean latency of P1 was significantly prolonged and amplitude was reduced in dyslexic children as compared to typically developing children ($p < 0.05$). This is in agreement with the findings of Satterfield et al. (1984) and Byring and Jaryilehto (1985). They also reported that P1 latency was delayed and amplitude was reduced in children with learning disability. They attributed it could be probably due to delayed maturation in children with learning disability.

N1 wave: From the visual inspection it was observed that wave N1 present in all dyslexic children. This finding was consistent with the findings obtained by Radhika (1998). They found that N1 was present in all children with learning disability. Moreover, the results of MANOVA (Table 3) revealed that latency of N1 was significantly prolonged in children with dyslexia as compared to typically developing children. ($p < 0.05$). The amplitude of N1 was also found to be significantly reduced in dyslexic children as compared to typically developing children. These findings are consistent with the finding of other's researchers (David & Ghosh., 1984; Kibble et al., 1986; Pinkerton et al., 1989). They reported that the latency was increased and amplitude was reduced in children with learning disability. This could be related to short attention span in children with dyslexia (Picton et al., 1978). This suggests that children with learning problem take longer time to initiate the negativity.

Wave P2: As reflected from Table 2, latency of wave P2 was significantly prolonged and amplitude was reduced in children with dyslexia as compared to typically developing children. ($p < 0.05$). The similar results of increased latency and reduced amplitude of waves P2 was reported by David and Ghosh (1984), Byring and Jaryilehto (1985). They found that the latency of wave P2 was prolonged and amplitude was reduced in children with learning disability as compared to children without learning problem.

Wave N2: From the visual inspection it was observed that out of 15 dyslexic children wave N2 was absent in two participants. In rest of the children with dyslexia the wave N2 was quite visible. This finding was con-

Table 3: F-value for latency and amplitude measure between control and experimental groups

Waves	Latency measures		Amplitude measures	
	F-value	p-value	F-value	p-value
P1	F (1,53) = 11.42	0.001**	F (1,53) = 13.04	0.001***
N1	F (1,53) = 23.92	0.000***	F (1,53) = 6.59	0.017*
P2	F (1,53) = 18.50	0.000***	F ((1,53) =23.19	0.000***
N2	F (1,53) = 33.83	0.000***	F ((1,53) = 5.99	0.022*

*p<0.05; **p<0.01; ***p<0.001

sistent with the findings obtained by Radhika (1998). They found that N2 was absent in 8 children out of 12 children with learning disability. Moreover, the results of MANOVA (Table 3) reveled that latency of N2 was significantly prolonged in children with dyslexia as compared to typically developing children. ($p < 0.05$). There are few studies have been reported in literature on latency of N2 because of wide range of latency variation observed in normal individuals. In the present study these deviancy in N2 latency could be because of the deficits in auditory processing of temporal aspects of the stimuli, which required more controlled attention (David et al., 1984; Byring & Jaryilehto, 1985).

To conclude, present study finding suggests that children with dyslexia performed poorly in comparison to typically developing children. This outcome is based on the differences observed in latency and amplitude measures between two groups in speech evoked ALLR.

Dichotic Consonant-Vowel (CV) Test

Descriptive statistics was done to obtained mean and standard deviation (SD) of dichotic CV score in terms of single correct scores (SCS) of right and left ear and double correct scores (DCS) for children with dyslexia and a typically developing children. *MANOVA* results showed thatthere were statistically differences between two groups on behavioural dichotic CV scores (Table 4 & 5). Mean scores of typically developing children were much poorer in comparison to dyslexic children. This difference in performance for left ear and right ear single correct score between the two groups were statistically significantly ($p < 0.05$). Similarly double corrected scores (DCS) between the two groups was also statistically significant ($p < 0.05$).

These findings suggest that children with dyslexia shows binaural integration deficit in comparison to typically developing children. The present finding is in agreement with other studies on dichotic listening test which assessed binaural integration processes (Ayers, 1972; Billiet & Bellis, 2011; Cermak & Koomar, 1981; Helland, Asbjornsen, Hushovd & Hugdahl, 2008; Moncrieff & Black, 2008; Mortan & Siegel, 1991). These studies reported that children with learning disability scored significantly poorer in comparison with typically developing children. In a similar line, Ganguly, Rajagopal and Yathiraj (1994) also found reduced scores in children with learning disability on the dichotic CV test in comparison to typically developing children.

Moreover in order to find out the ear advantage the *paired t-test* was used to compare right and left ear of control as well as experimental group. These differences between the ear scores were statistically significant ($p < 0.05$), which showed right ear advantage in typically developing children.

On the other hand, experimental group shows significantly higher scores for left ear ($p < 0.05$), which pointed towards left ear advantage in children with dyslexia. These finding in children with dyslexia in comparison to typically developing children revealed the differences in performance between two ears (ear advantage) and heterogeneity among dyslexic groups. These discrepancies probably are because of differences in degree of reading and writing impairment (Helland et al., 2008; Hugdahl et al., 1995; Iliadou, Kaprinis, Kandylis & Kaprinis, 2010; Moncrieff & Black, 2008). The lack of right ear advantage (REA) in children with dyslexia observed in present study may also be explained by a tendency seen in dyslexics to switch attention between the ears rather than splitting their attention (Dickstein & Tallal, 1987). In the another study Iliadou et al. (2010) found that the purely dyslexic children shows an almost equally distributed right and left hemispheric dominance as well as no dominance of the two hemispheres. This shows heterogeneity of dyslexic group in comparison to typically developing children.

To conclude, behavioural dichotic CV tests results in present study revealed poorer performance for children with dyslexia in comparison to typically developing children. The poorer performance was observed for single correct scores as well as for double correct scores between two groups. It was also observed that typically developed children show REA whereas children with dyslexia exhibit left ear advantage (LEA). Hence, the outcome of present study indicates there is binaural integration deficit in children with dyslexia in comparison to typically developing children.

Table 4: Mean and standard deviation values of Dichotic CV scores in control and experimental group

Scores	Control group (N = 15)		Experimental group (N = 15)	
	Mean*	SD	Mean*	SD
LCS	16.93	1.71	14.07	2.31
RCS	22.80	1.56	11.93	2.25
DCS	10.93	2.37	4.93	1.38

**Maximum scores=30; LCS=left correct scores; RCS=right correct scores; DCS=double correct scores; N = number of participants*

Table 5: F values for Dichotic CV scores between control and experimental group

Scores	F-value	p- value
LCS	F (1,28) = 14.89	0.001***
RCS	F (1,28) = 235.42	0.000***
DCS	F (1,28) = 71.41	0.000***

p<0.05; **p<0.01;*p<0.001*

Relationship between Speech-evoked ALLR and Dichotic CV Test

Karl Pearson's correlation was used to check whether there were any relationship between different components of speech evoked ALLR (latency & amplitude) and double corrected scores of dichotic CV tests in typically developing children as well as dyslexic children.

From the Table 6 it can be inferred that there is a positive correlation between dichotic listening and speech evoked ALLR. This suggest that dichotic listening tends to be poorer when there is an increase (prolong) in latency and reduction in amplitude of ALLR and vice versa. Though, there was the relationship between speech evoked ALLR and dichotic listening, it was not statistically significant. This suggests that the speech evoked ALLR could be taken as alternative tool to assess dichotic listening. Moreover, we did not find any study in this regard to support the findings of present study. Probably larger sample size may be required to validate the present findings.

Table 6: Correlation between Speech evoked ALLR and Dichotic CV test

	Double correct scores			
	Latency Measures		Amplitude measures	
Parameters	correlation coefficient (r)	p-value	correlation coefficient (r)	p-value
P1	0.23	0.39	0.41	0.60
N1	0.06	0.80	0.10	0.71
P2	0.00	0.99	0.02	0.92
N2	0.32	0.28	0.47	0.10

However, there are some studies which indirectly support the present findings. Banai et al. (2009) studied the relationship between sub-cortical auditory encoding and literacy-related skills in children with learning problems. They observed statistically significant correlation between the measures of timing components (transition) of sub-cortical auditory encoding and reading skills. Moreover, the relationship was less significant between the harmonic components (formants) of sub-cortical auditory encoding and reading skills. Based on these findings they concluded that good readers show more temporally precise encoding and more robust representation of speech harmonics in comparison to poor readers who represent poor timing of sub-cortical auditory encoding and impoverished representation of signal harmonics. To conclude, there is a relationship between dichotic listening and speech evoked ALLR. However it was not statistically significant in children with dyslexia.

Conclusions

Speech evoked ALLR is easily traceable in all children with dyslexia as well as typically developing children. The results of speech evoked ALLR indicates abnormal encoding of speech signal at the cortical level in children with dyslexia. Further, Dichotic CV test showed poorer dichotic listening ability for dyslexic children in comparison to typically developing children. In addition, correlation analysis suggest that dichotic listening tends to be poorer when there is increase in latencies or reduction in amplitude of speech evoked ALLR in dyslexic children. Hence, from the above findings present study highlights the importance of speech evoked ALLR as tool to assess dichotic listening along with dichotic test.

References

American National Standards Institute (1991). "American national standard maximum permissible ambient noise levels for audiometric test rooms." ANSI S3.1. (1991). New York: *American National Standards Institute*.

Arehole, S., (1995). A Preliminary Study of Relationship between Long Latency Response and Learning Disorder. *British Journal of Audiol-*

ogy, 29, 295-298.

Ayers, A. (1972). *Sensory Integration and Learning Disorders*. Los Angeles: Western Psychological Services.

Banai, K., Hornickel, J., Skoe, E., Nicol, T., Zecker, S., & Kraus, N. (2009). Reading and subcortical auditory function. *Cerebral Cortex, 19*, 2699-2707.

Bellis, T. J. (1996). *Assessment and Management of Central Auditory Processing Disorders in Educational Settings: From Science to Practice*: Singular Publishing Group, Inc: San Diego.

Billiet, C. R., & Bellis, T. J. (2011). The Relationship between Brainstem Temporal Processing and Performance on Tests of Central Auditory Function in Children with Reading Disorders. *Journal of Speech, Language, and Hearing Research, 54*, 228-242.

Byring, R., & Jaryilehto, T. (1985). Auditory and Visual Evoked Potential of Schoolboys with Spelling Disabilities. *Developmental Medicine and Child Neurology, 27*, 141-148.

Carhart, R., & Jerger, J. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders, 24*, 350-345.

Ceponiene, R., Shestakova, A., Balan, P., Alku, P., Yiaguchi, K., & Näätänen, R. (2001). Children's auditory event-related potentials index sound complexity and "speechness". *The International Journal of Neuroscience, 109*, 245-260.

Cermak, S. A., & Koomar, J. A. (1981). Reliability of dichotic listening using two stimulus formats with normal and learning-disabled children. *The American Journal of Occupational Therapy, 35*,456-463.

David, J., & Ghosh, M. (1984). Late Latency Response in Poor Readers. *Electroencephalography and Clinical Neurophysiology, 70*, 232-237.

Dickstein, P., & Tallal, P. (1987). Attentional capabilities of reading impaired children during dichotic presentation of phonetic and complex nonphonetic sounds. *Cortex, 23*, 237-249.

Estes, R. E., & Huizinga, R. J. (1974). A Comparison of Visual and Auditory Presentation of a Paired-Associate Learning Tests with Learning Disabled Children. *Journal of Learning Disabilities, 7*, 44-51.

Ganguly, L., Rajagopal, L., & Yathiraj, A. (1994). Perception of Dichotic CV Syllables in Normal and Learning Disabled Children. *Journal of Indian Speech and Hearing Association, 13*, 56-59.

Guruprasad, A. (1999). Evaluation of central auditory processing disorder in children with learning disability. *Unpublished Masters Dissertation*, University of Mysore, Mysore.

Helland, T., Asbjornsen, A. E., Hushovd, A. E., & Hugdahl, K. (2008). Dichotic Listening and School Performance in Dyslexia. *Dyslexia, 14*, 42-53.

Hood, L. J. (1998). *Clinical applications of auditory brainstem responses*. Singular publishing group, San Diego Inc.

Hugdahl, K., Helland, T., Farevaag, M. K., Lyssand, E. T., & Asbjornsen, A. (1995). Absence of ear advantage on the consonant-vowel dichotic listening test in adolescent and adult dyslexics: Specific auditory-phonetic dysfunction. *Journal of Clinical and Experimental Neuropsychology, 17*, 833-840.

Iliadou, V., Kaprinis, S., Kandylis, D., & Kaprinis, J. S. (2010). Hemispheric laterality assessment with dichotic digits testing in dyslexia and auditory processing disorder. *International Journal of Audiology, 49*, 247-252.

Jirsa, R. E. & Clontz, K. B. (1990). Long Latency Auditory Event Related Potentials from Children with Auditory Processing Disorders. *Ear and Hearing, 11*, 222-232.

Johnson, K. L., Nicol, T. G., & Kraus, N. (2005). Brainstem response to speech: A biological marker of auditory processing. *Ear and Hearing, 26*, 424-434.

Katz, J., Burkard, R. F., & Medwetsky, L. (2002). *Handbook of Clinical Audiology* (5^{th} Ed.), Lippincott Willliams & Wilkins.

Kibble, K., Michael, M. A., Suzanne, B., Verkert, M. A., Karen, M. G., & Frank, E. M. (1986). Late Latency Potentials and P300. *Hearing Instruments, 37*, 22-24.

Kraus, N., McGee, T., Carell, T. D., Zecker, S. G., Nicol, T. G., & Koch, D. B. (1996). Auditory Nerophysilogical Responses and Discrimination Deficits in Children with Learning Problems. *Science, 273*, 971-973.

Maerlender, C., Wallis,D. J. & Peter, K. (2004). Psychometric and Behavioral Measures of Central Auditory Function: The Relationship between Dichotic Listening and Digit Span tasks. *Child Neuropsychology, 10*, 318-327.

Manson, S. M., & Mellor, D. H. (1984). Brainstem, middle latency and late cortical evoked potentials in children with speech and language disorders. *Electroencephalography and Clinical Neurophysiology, 59*, 297-309.

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

Moncrieff, D. W., & Black, J. R. (2008). Dichotic Listening Deficits in Children with Dyslexia.

Dyslexia, 14, 54-75.

Moncrieff, D. W., & Musiek, F. E. (2002). Interaural asymmetries revealed by dichotic listening tests in normal and dyslexic children. *Journal of the American Academy of Audiology, 13,* 428-437.

Morton, L. L., & Siegel, L. S. (1991). Left ear dichotic listening performance on consonant vowel combinations and digits in subtypes of reading-disabled children. *Brain and Language, 40,* 162-180.

Picton, T. W., Woods, D. L., & Proulx, G. B., (1978). Human auditory sustained potentials. II. Stimulus relationships. *Electroencephalography and Clinical Neurophysiology, 45,* 198-210.

Pinkerton, F., Watson, D. R. & McClelland, R. J. (1989). A Neurophysiological Study of Children with Reading, Writing and Spelling Difficulties. *Developmental Medicine and Child Neurology, 31,* 569-581.

Purdy, S. C., Kelly, A. S., & Davies, M. G. (2002). Auditory brainstem response, middle latency response, and late cortical evoked potentials in children with learning disabilities. *Journal of the American academy of audiology, 13,* 367-82.

Radhika, A. (1998). Auditory Late Latency Potentials in Learning Disabled Children. *An Unpublished Independent Project, University of Mysore,* Mysore.

Ramma, S. (2000). Two decades of research on learning disabilities in India. *Dyslexia, 6,* 268-283.

Ramus, F. (2003). Developmental Dyslexia: Specific phonologic deficit or general sensorimotor dysfunction? *Current opinion in Neurobiology, 13,* 212-218.

Rosen, S., & Manganari, E. (2001). Is There a Relationship Between Speech and Nonspeech Auditory Processing in Children with Dyslexia? *Journal of Speech, Language and Hearing Research, 44,* 720-736.

Satterfield, J. H., Schell, A. M., Backs, R. W., & Hidaka, K. C. (1984). Cross sectional and Longitudinal Study of Age Effects of Electrophysiological Measures in Hyperactive and Normal Children. *Biological Psychiatry, 19,* 973-990.

Serniclaes, W., Sprenger-Charolles L., Carre R., & Demonet, J. F. (2001). Perceptual Discrimination of Speech Sounds in Developmental Dyslexia. *Journal of Speech, Language and Hearing Research, 44,* 384-389.

Sharma, A., Marsh, C. M., & Dorman, M. D. (2000). Relationship between N1 evoked potential morphology and the perception of voicing. *Journal of the Acoustical Society of America, 108,* 3030-3035.

Snowling, M. J. (2000). *Dyslexia (2nd Ed.),* Oxford: Blackwell Publishers Ltd.

Tallal, P. (1980). Auditory temporal perception, phonics and reading children. *Brain and Language, 9,* 182-198.

Tremblay, K. L., Friesen, L., Martin, B. A., & Wright, R. (2003). Test retest reliability of cortical evoked potentials using naturally produced speech sounds. *Ear and Hearing, 24,* 225-232.

Yathiraj, A. (1999). *Dichotic CV test- revised.* Developed at Department of Audiology, All India Institute of Speech and Hearing, Mysore.

Yathiraj, A., & Mascarenhas, K. E. (2003). Effect of auditory stimulation in central auditory processing disorder. *AIISH Research Fund Project,* All India Institute of Speech and Hearing, Mysore.