EVALUATION OF CENTRAL AUDITORY PROCESSING DISORDERS IN CHILDREN WITH LEARNING DISABILITY

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DEDICATED TO

To all those people who have spread their
knowledge to me:
Teachers, Family and Friends

Certificate

This is to certify that this Dissertation entitled : *'EVALUATION OF* ***CENTRAL AUDITORY PROCESSING DISORDERS IN CHILDREN WITH LEARNING DISABILITY'*** is the bonafide work in part fulfillment for the degree of Master of Science (Speech & Hearing) of the student with Register No. M9807.

Mysore
Mysore
May, 2000

Director,
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Certificate

This is to certify that this Dissertation entitled : ***'EVALUATION OF CENTRAL AUDITORY PROCESSING DISORDERS IN CHILDREN WITH LEARNING DISABILITY'*** has been prepared under my supervision and guidance.

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Declaration

This Dissertation entitled: *'EVALUATION* ***OF*** *CENTRAL* ***AUDITORY PROCESSING DISORDERS IN CHILDREN WITH LEARNING DISABILITY'*** is the result of my own study under the guidance of Ms. Vanaja. C.S., Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

Mysore,
May, 2000.

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INTRODUCTION

The National Advisory Committee on Handicapped children, (1967) defined specific Learning Disability as follows:

"Children with Specific Learning Disabilities exhibit a disorder in one or more of the basic psychological processes involved in understanding or in using spoken or written language. These may be manifested in disorders of listening, thinking, talking, reading, writing, spelling, or arithmetic. They include conditions which have been referred to as perceptual handicaps, brain injury, minimal brain dysfunction, dyslexia, developmental aphasia etc. They do not include learning problems which are primarily due to visual, hearing, or motor handicaps, to mental retardation, emotional disturbance, or to environmental disadvantage."

A review of literature shows that children with learning disability (LD) may have auditory and / or visual processing problems (Estes and Huizinga, 1974; Larsen, Rogers and Sowell, 1976; Mason and Mellor, 1984). However, whether Central Auditory Processing problems are cause or effect is a controversial issue (Jerger, 1998).

Central Auditory Processing involves various processes such as auditory closure, binaural integration, binaural separation, temporal pattering, binaural interaction and neuromaturation (Bellis, 1996). ASHA Task Force (1996) defines Central Auditory Processing Disorders (CAPD) as a deficiency in one or more of the following processes:

1. Sound localization.
2. Auditory discrimination.

3. Auditory pattern recognition
4. Temporal aspects of audition.
5. Problems with competing signals and
6. Problems with degraded signals.

Ferre (1987) has described four kinds of Central Auditory Processing Disorders. They are

1. Auditory Decoding Deficit which involves difficulty in sound recognition, blending and auditory closure abilities. Poor scores are obtained on monaural low redundancy speech tests and lesion lies in the primary auditory cortex.
2. Integration Deficit which involves difficulty in multimodality tasks, and music skills. Deficits on dichotic speech and temporal pattering tests are observed and the lesion lies in the corpus callosum.
3. Associative Deficits which includes deficits in receptive language and dichotic speech test. Site of dysfunction being primary and associative cortical region.
4. Output - Organisation Deficit which includes deficits in sequencing abilities, reversals and poor recalls. The site of lesion being efferent system. Deficits may be observed in any task requiring report of more then two critical elements.

These are the kind of deficits seen but, how are they assessed? Jerger (1998) classifies the approaches that have been used to diagnosis of CAPD into four parts:

1. Diagnosis by observation
2. Diagnosis by exclusion
3. Diagnosis by behavioral tests
4. Diagnosis by electrophysiological tests.

Most often, a combination of these approaches is essential to detect CAPD in children with learning disability (LD) (Welsh, Welsh and Healy, 1996). Observation in natural situation and exclusion of other problem is the first step in diagnosis. Studies have been carried out on LD children using behavioral as well as electrophysiological tests (Jerger, 1998). Some of the tests that have been used by various investigators include Binaural fusion (Ferre and Wilber, 1986), Rapid Alternating Speech Perception (Windham, 1985), Masking Level Differences (Grant 1980a), Pitch Pattern Sequence Test (Pinheiro, 1977), Low Pass Filtered Speech (Willeford, 1977) Speech Perception in Noise (Jerger, Martin and Jerger, 1987) and Compressed Speech Test (Manning, Johnston and Beasly, 1977). Dichotic studies shown controversial findings of children with LD having right ear or left ear advantage (Obrzut et al, 1985; Thomson, 1975). Dichotic tests which have been used are dichotic digits (Zurif and Carson, 1970), Dichotic CVs (Bowen and Hynd, 1988), Dichotic words (Gomez and Condon, 1999), Staggered Spondiac words (Berrick et al, 1984) and Competing Sentence tests (Windham, 1985).

Electrophysiological tests that have been used to study are Auditory Brainstem Responses (Shomer and Student, 1977), Auditory Middle Latency Responses. (Kraus et al, 1985), Auditory Late Latency Responses, (Pinkerton et al, 1989), P300 (Duncun et al, 1994) and Mismatch Negativity (Kemmer et al, 1995).

The results of these various studies highlight the heterogeneity in children with LD. As each test evaluates auditory processing from the different perspective, a battery of tests is necessary for identifying CAPD in children with learning disability. Of course, a number of factors such as age, speech and language ability of the subject, test facilities and norms available will determine the choice of tests.

NEED FOR THE STUDY

Review of literature shows that though a number of investigators have studied auditory processing in learning disabled children, the results are inconclusive. Very few studies have used a battery of behavioral, physiological and electrophysiological tests in evaluating CAPD in children with learning disabled children. A combination of these tests would definitely help in better understanding of the problems of an LD child and hence device better management strategies. The present investigation aimed at studying CAPD from various perspectives in children with LD. The tests chosen for assessment included behavioral, both pure tone and speech test, physiological and electrophysiological tests.

Aims of the Present Study

To study the central auditory processing in LD children using the following behavioral, physiological and electrophysiological tests:

A) Behavioral tests

1. Speech Perception in Noise (SPIN)
2. Masking Level Difference (MLD)
3. Pitch Pattern Sequence Test (PPST)
4. Time compressed speech Test
5. DichoticCV test

B) Physiological Test

1. Acoustic Reflex Thresholds (ART)

C) Electrophysiological Tests

1. Auditory Brainstem Response (ABR)

(at 11.1/s, 65.1/s and 90.1/s rates)

2. Auditory Late Latency Responses (ALLR)
3. P300
4. Mismatched Negativity (MMN).

REVIEW OF LITERATURE

Behavioral tests and electrophysiological tests have been useful in uncovering the important aspects of neural basis of many central auditory dysfunction. One such group, who show Central Auditory Processing Disorders (CAPD) are the Learning Disabled (LD) children or Dyslexics. Various studies using behavioral test and electrophysiological tests or a battery of tests have shown central auditory defects in these children.

Some of the behavioral tests used for evaluating central auditory processing in children with learning disability include :

1. Monaural low redundancy speech tests : PI-PB, Filtered Speech, Interrupted Speech, Time Altered (compressed or expanded) Speech, SSI-ICM and Speech Perception in Noise.
2. Binaural interaction tests : Binaural Fusion, Rapidly Alternating Speech Perception, Masking Level Difference, Simultaneous Balanced Medial Plane Lateralization, Speech With Alternating Masking Index and Segment Altered CVC Word test.
3. Sequencing and temporal ordering tests : Pitch Pattern Sequence Test, Duration Pattern Test, and Psychoacoustic Pattern Discrimination Test.
4. Dichotic speech tests : Dichotic Words, Dichotic Digits, Dichotic CV, Staggered Spondiac Word Test, Dichotic Rhyme Test, Dichotic Sentence Identification, SSI-CCM, Competing Sentence Test and IC-CS tests.
5. Physiological and Electrophysiological tests: Acoustic Reflex Thresholds, Otoacoustic Emissions, Short, Long and Middle Latency Responses, both exogeneous and endogenous components.

/. *CONVENTIONAL AUDIOLOGICAL TEST BATTERY*

1. Pure tone audiometry

A review of literature shows that majority of the children with learning disability have normal hearing (Musiek & Geurkink, 1980; Welsh, Welsh and Healy, 1980, 1996). However there are sporadic reports of presence of mild hearing loss in such children. One such report was by Sprunt and Finger (1949) who studied 692 students with academic problems. 6.6% of the children had mild hearing loss. 65% of this 6.6% children showed left ear deficit.

2. Speech Identification

Learning disabled children show poor speech identification scores. Haggerty and Stamm (1978) found that children with learning disability were impaired in the ability to discriminate between consonant sounds embedded in minimally different pairs of nonsense syllables or words.

Poor scores have also been found in non audiological tests. Mathew and Seymour (1981) studied 47 learning disability children and found poor auditory discrimination in a non audiological test. Blalock (1982) studied 80 adults with learning disability on auditory discrimination test and found persistent problems in auditory tests.

3. Tympanometry and Acoustic Reflex Thresholds

Children with learning disability have often a history of middle ear pathology during their infancy or childhood. Masters and Marsh (1978) studied 108 children with learning disability and found 25% had middle ear pathology.

Measurement of acoustic reflexes is useful in evaluation of Ventral Cochlear Nucleus (VCN), Medial Superior Olivary (MSO) and motor nucleus of the facial nerve (N-VII). It is sensitive to intra axial and extra axial brainstem lesions (Hall, 1985). Lenhardt (1981) reported bilaterally absent acoustic reflexes in a subject with CAPD and associated learning problems. However Greenblatt et al. (1983) observed acoustic reflexes in both ears from 500 Hz to 2000 Hz but absent reflexes at 4000 Hz. However absence of reflex at 4000 Hz does not have diagnostic significance as it may be absent even in a normal subject (Jerger, Jerger and Mauldin, 1972).

Jerger, Martin and Jerger (1987) found absent or elevated cross reflex thresholds on both ears. Increased thresholds at 1000 Hz were elevated on left ear and normal on right ear. Averaged reflex "waveforms were degraded in both ears. Uncrossed reflex amplitude were severely reduced in both ears in a child with learning disability.

Reviewing these studies it can be said that acoustic reflex thresholds can be used for assessing CAPD in children with learning disability.

//. TESTS FOR DETECTION OF CAPD

A) BEHAVIOURAL TESTS

1. MONAURAL LOW REDUNDANCY SPEECH TESTS :

"Auditory Closure" refers to the ability of the normal listener to utilize intrinsic and extrinsic redundancy to fill in missing or distorted portions of the auditory signal and recognise the whole message. (Rintelmann, 1985). Due to redundancy both within the auditory system (intrinsic redundancy) as well as in spoken language (extrinsic redundancy), the normal listener typically is able to achieve closure and make auditory discrimination even when a portion of the auditory signal is missing or distorted in the monaural low redundancy speech tests.

These tests are sensitive to brainstem and cortical lesions. They may also be sensitive to diffuse pathology involving the primary auditory cortex (Bellis, 1996). Low Pass Filtered Speech (LPFS), Interrupted Speech, Time Compressed Speech, Speech Perception in Noise (SPIN) and SSI-ICM are some of the monaural low redundancy speech tests used for assessing central auditory processing in learning disabled children (Rintelmann, 1985).

a) Low Pass Filtered Speech (LPFS)

Results of the various studies carried out using LPFS are controversial Investigations have been carried out using CNC monosyllables passed through a filter or with cut off frequency of 500 Hz with slope of 18 dB/octave. (Willeford, 1976; Pinheiro, 1977 ; Musiek and Geurkink, 1980; Welsh, Welsh and Healy, 1980, 1996; Farrer and Kieth, 1981; Musiek, Geurkink and Kietel, 1982: Welsh et al, 1982) Cut off frequency as low as 100 Hz (Farre & Kieth, 1981) and as high as 1000 Hz (Ferre and Wilber, 1986;Musiek & Geurkink, 1980) has also been used.

A majority of the investigators have reported that the learning disabled group yield poorer means scores than normals. (Willeford, 1976; Willeford, 1977; Welsh, Welsh and Healy, 1980; Farre and Kieth 1981; Musiek, Geurkink and Kietel, 1982; Welsh et al; 1982; Windham, 1985; Ferre and Wilber, 1986; Welsh, Welsh and Healy, 1996). The mean scores obtained for children with learning disability in these studies ranged from less than 40% (Welsh et al, 1982), to 75% (Welsh, Welsh & Healy, 1980). In these studies 92.3% (Ferre and Wilber, 1986) to 100% (Welsh, Welsh &

Healy, 1980; Welsh et al 1982; Welsh, Welsh and Healy , 1996) of subjects with learning disability have shown poor performance.

On the other hand, a few investigators have reported that **LPFS** could not differentiate the children with learning disability from the normal group. No significant differences between the two groups have been observed. (Pinheiro, 1977; Musiek & Geurkink, 1980). Few studies show **that** learning disabled children have obtained normal scores (Harris, 1963; Hodgson, 1966; Greenblatt **et** al, 1983).

b) Speech Perception in Noise (SPIN)

Studies carried out on children with learning disability show that they perform poorer than normals in the presence of noise. Speech identification in the presence of noise has been evaluated using monosyllables at + 10 SNR (Greenblatt et al, 1983), + 12.5 dB SNR (Chermak, Vanhof & Bendel, 1989).

Results indicate that poorer scores are obtained in noisy condition than quiet condition on word identification and discrimination tasks when compared to normals. (Greenblatt et al, 1983; Rupp et al, 1986; Jerger, Martin & Jerger, 1987; Chermak, Vanhof and Bendel, 1989). Scores obtained by children with learning disability varied from 77% and 86% (Greenblatt et al, 1983; Jerger, Martin & Jerger, 1987). Wright et al (1997) found that they also had difficulty in detecting tone in noise.

c) Time (Altered) Speech

It has been reported in literature that children with learning disability obtain poorer scores for time compressed speech as compared to normals. Studies show that children with learning disability score poorer than normal for 60% compressed speech (McCorsky and Thompson, 1973; Tallal, 1976; Manning, Johnston and Beasly, 1977; Freeman and Beasly, 1978; McNutt and Chia-Yenki, 1980; Welsh et al, 1982; Ferre and Wilber, 1986). Scores obtained by children on this test has varied from 50% (McNutt & Chia - Yenki, 1980) to 80% (Freeman and Beasly, 1978; Ferre and Wilber, 1986).

Similar results was seen with 50% compressed speech (Wattson and Rostatter, 1985) and 30% compressed speech (McNutt and Chia-Yenki, 1980, Welsh, Welsh and Healy, 1996). Wattson and Rostatter (1985) reported a score of 70% in younger and 80% in older group for 50% compressed speech. Scores obtained for 30% compressed speech varied from 65% (McNutt and Chia-Yenki, 1980) to 80% (Manning, Johnston and Beasly, 1977).

Speech intelligibility of normals improve as the compression ratio decreases (Manning, Johnston and Beasly, 1977). An attempt has been made to study whether this is true for learning disabled children also. Manning, Johnston and Beasly (1977) and McNutt and Chia-Yenki, (1980) observed that performance of learning disabled children also improved with decrease in compression ratio but the learning disabled children scored poorer than normals for both 60% and 30% compressed speech. Greater deficit was observed for 60% compressed speech.

Compressed speech have yielded poorer scores than expanded speech (McCorsky and Thompson, 1973; Tallal, 1976). A comparison of performance on 140% to 180% expanded speech showed that 140% expansion had poorer scores than normals but better scores than 60% and 80% compression (McCorsky and Thompson, 1973). Tallal (1976) also supports these findings.

Age of the child also affect the performance. The younger group with learning disability perform poorer than that of older group (Wattson and Rostatter, 1985; Welsh et al, 1982; Ferre and Wilber, 1986; Welsh, Welsh and Healy, 1996). Dermody et al (1975) has reported normal scores in children with learning disability, which contradicts the other studies.

Thus, a review of literature shows that children with learning disability perform poorer as the compression rate as increased from 30% to 60%.

2) BINAURAL INTERACTION TASKS

The term 'binaural interaction or integration' refers simply to the way in which the two ears work together. Binaural interaction include not only lateralization and localization of auditory stimuli, but also binaural release from masking, detection of signals in noise, binaural fusion and rapidly alternating speech. (Durlach, Thompson, Colburn, 1981).

The level of the superior olivary complex in the pons in the most caudal structure in CANS to receive binaural input which implicates the low brainstem as being particularly critical to binaural processing (Bellis, 1996). The various binaural interaction tasks are Binaural Fusion, Rapidly Alternating Speech Perception (RASP), Interaural Intensity Differences (IID), Masking Level Differences (MLD). These are generally sensitive to low brainstem lesions (Tobin, 1985).

a) Binaural Fusion Test

Various investigators have studied the performance of learning disabled children on Binaural Fusion tasks. The most commonly used filter in these studies are low band pass filter of 500-700 Hz and high band pass filter of 1900-2100 Hz (Willeford, 1976; Pinheiro, 1977; Willeford and Billiger, 1978; Welsh, Welsh and Healy 1980 Musiek, Geurkink and Kietel, 1982; Welsh et al, 1982; Windham, 1985; Welsh, Welsh and Healy, 1996). Other low pass and high pass filters have been used, i.e., 420-750 Hz and 1950-2100 Hz (Roush and Tait, 1984); 380-1850 Hz and 650-2150 Hz (Ferre and Wilber, 1986). Stimuli used were spondees presented at 35-40 dB SL. Roush and Tait (1984) had presented the stimuli dichotically, diotically and reversed dichotically.

There are controversial reports of results and this test. Majority of the studies show poor scores for learning disabled children on binaural fusion test (Willeford, 1976, Martin and Clarke, 1977; Pinheiro, 1977; Devens et al, 1978; Haggerty and Stamm, 1978; Willeford and Billger, 1978; McCorsky and Kidder; 1980; Welsh, Welsh and Healy, 1980; Musiek, Geurkink and Kietel, 1982; Welsh et al, 1982; Roush and Tait, 1984, Windham, 1985; Ferre and Wilber, 1986; Welsh, Welsh and Healy, 1996). A few investigators have reported normal scores (Greenblatt et al, 1983) or no significant differences between performance of normals and children with learning disability (Musiek and Geurkink, 1980; Harris, 1963).

Scores obtained by children with learning disability were 0% (Willeford, 1976), 35%-50% (Willeford, 1976; Welsh et al, 1982; Roush and Tait, 1984) and 50-70% (Pinheiro, 1977; Windham, 1985). Very few of these studies reviewed here showed learning disabled children scoring above 70% (Welsh et al, 1982).

The sensitivity of this test to CAPD in children with learning disability is still questionable as the performance of learning disabled has varied across studies. Correct identification has been as low as 30% (Musiek, Geurkink and Kietel, 1982) and as high as 85% (Welsh et al, 1982).

a) Rapidly Alternating Speech Perception (RASP)

A review of literature indicates that the performance of learning disabled children on this test is similar to that of normals. Poor scores on RASP has been reported in one study by Willeford (1976). However, other investigators have reported no significant difference between the scores obtained for learning disabled and normal children for speech alternating at every 300 ms. (Pinheiro, 1977; Musiek and Geurkink, 1980; Welsh, Welsh and Healy, 1980; Musiek, Geurkink and Kietel, 1982; Greenblatt et al, 1983; Windham, 1985). Atypical lateralization of scores was found by Dalby and Gibson (1981).

Thus, this test is not sensitive in identifying CAPD in children with learning disability. Welsh, Welsh and Healy (1980) reported that CAPD could be identified in only 10% of learning disabled children using this test.

b) Masking Level Difference (MLD)

Very few studies have investigated MLD in children with learning disability. Results of the studies show controversial findings. MLD in learning disabled children has been established for a 500 Hz pure tone in the presence of narrow band noise centered at 500 Hz at 40 dB HL (Grant, 1980a, 1980b; Roush and Tait, 1984).

Grant (1980a) in his study on learning disabled found significantly reduced MLD scores in these children. Grant (1980b) again reported reduced MLD scores in children with learning disability. On the contrary, Roush and Tait (1984) found that MLD scores ranged from 9 to 14 dB in both normal and learning disabled children. The two groups could not be separated based on MLD.

3) TEMPORAL ORDERING AND SEQUENCING TESTS

The term 'temporal' refers to time related aspects of the acoustic signal. The various processes that contribute to this ability of temporal ordering and sequencing are discrimination of differences in auditory stimuli, sequencing of auditory stimuli, gestalt pattern perception and trace memory. (Musiek, Pinheiro and Wilson, 1980).

Analysis of temporal order takes place primarily in the dominant hemisphere, specifically in the temporal lobe, extending posteriorly to the Wernicke's area and the angular gyrus (Pinheiro and Musiek, 1985). Right temporal lobe lesion shows contralateral deficits on two tone ordering or gap detection, and bilateral deficits on temporal patterning tasks involving more than two stimuli. Left temporal lobe deficits show significant contralateral and or bilateral effects. Corpus callosum lesion show bilateral deficits on temporal patterning tasks involving more than two stimuli (Bellis, 1996). Some of the temporal ordering and sequencing tasks are Pitch Pattern Sequencing Test (PPST), Duration Pattern Test (DPT) and Psychoacoustic Pattern Discrimination Test (PPDT) (Pinheiro and Musiek, 1985).

A review of literature shows that pitch pattern sequencing in affected in a majority of children with learning disability. Pinheiro (1977) found poor performance in children with learning disability. They scored as low as 25.5% and 23.1% (normals : 75%) when the response was manual and 88% to 93% (normals : 90%) when hummed responses were used. Later, Pinheiro (1978) compared the performance of 6-7 year old learning disabled children and 8-14 year old learning disabled children with that of normals. Both the groups performed poorly. The younger group scored 17.5% (normals : 56.6%) and older group scored 33.3% (normals : 86%).

Results of an investigation by Musiek and Geurkink (1980) which showed poor scores in four out of five of this subjects support these findings. Musiek, Geurkink and Kietel (1982) identified 72.7% of the subjects with CAPD and associated learning problems using PPST. They had better right ear scores than left ear scores.

Lincon et al (1992) studied these children on discrimination of various sequences of tones of two frequencies. They produced more errors as the number of tones per sequence increased. They had more difficulty on faster rates than on slower rates.

Thus, it can be concluded from these studies that temporal ordering is affected in children with learning disability. However, there is a dearth for studies investigating learning disabled children using DPT and PPDT.

4) DICHOTIC SPEECH TESTS

Dichotic tests evaluate the binaural separation with the binaural integration ability. Dichotic tests mainly show contralateral deficits (Musiek and Pinheiro, 1985). Dichotic tests are sensitive to lesions affecting either the auditory areas of the left temporal lobe or corpus callosum. Right temporal lobe lesion shows left ear suppression and left temporal lobe lesion shows contralateral or bilateral suppression. Posterior corpus callosal lesion shows marked left ear deficit and there is no effect in anteriorcorpus callosal lesions (Bellis, 1996).

The various dichotic tests used in assessment of central auditory processing are Dichotic Digits, Dichotic CV, Staggered Spondiac Word Test (SSW), Competing Sentences Test (CST), SSI-CCM, Dichotic Sentence Identification (DSI) and Dichotic Rhyme Test (DRT). A number of studies have been carried out on learning disabled children using dichotic digit pairs given by Musiek (1983), Dichotic CV given by Berlin et al (1972), SSW given by Katz (1962) and CST by Willeford (1968).

Results of various studies evaluating ear advantage have shown equivocal results. A majority of the investigators report Right Ear Advantage (REA) in learning disabled children whereas a few studies report Left Ear Advantage (LEA) or no hemispheric dominance.

Right Ear Advantage (REA) has been reported on dichotic digits test (McKeever and VanDeventer, 1975; Obrzut, 1979; Musiek and Geurkink, 1980; Musiek, Geurkink and Kietel, 1982), Dichotic Animal Naming Test (Pettit and Helms, 1979), SSW (Pinheiro, 1977; Musiek and Geurkink, 1980; Welsh, Welsh and Healy, 1980; Windham, 1985), CST (Pinheiro, 1977; Musiek and Geurkink, 1980; Welsh, Welsh and Healy, 1980) and Dichotic CV tests (Hynd et al, 1983; Roeser and Millay and Marrow, 1983; Bowen and Hynd, 1988; Obrzut et al, 1985; Ganguly, Rajagopal and Yathiraj, 1994).

Scores obtained by learning disabled children have been variable across various studies. In the studies reporting REA means scores were like 78.3% in right and 61.5% in left ear for dichotic digits (Obrzut, 1979). SSW showed a difference of 7% - 18% (Welsh, Welsh and Helay, 1980). Non competing condition in SSW showed 97% in right and 84.1% in left ear and in competing condition, 86.7% in right and 76.3% in left ear

(Pinheiro, 1977). CST mean scores mere 94.5% in right and 71.2% in left (Pinheiro, 1977). Dichotic CVs showed mean error scores varying from 48% to 57% (Hynd et al, 1983; Roeser, Millay and Marrow, 1983). Right ear mean scores more above 38% and left ear mean scores were 34% (Hynd et al; 1983; Obrzut et al, 1985). At 90 ms lag mean scores were 58% for right and 53% in left and 0 ms mean scores were 50% in right and 57% in left ear for dichotic CV test (Roeser, Millay and Marrow, 1983). Ganguly, Rajagopal and Yathiraj (1994) reported 33.3% mean scores in right, 53.3% in lelft ear on Dichotic CV at 0ms lag.

Left Ear Advantage (LEA) has been reported in a few studies on dichotic digits (Zurif and Carson, 1970; Pettit and Helms, 1979; Obrzut and Belick, 1986), CST (Willeford, 1976), on words presented dichotically (Thomson, 1975; Bowen and Hynd, 1988) and competing environmental sounds (Johnson et al, 1981). Dichotic CVs also showed LEA on free recall (Obrzut et al, 1985; Kershner and Micaleef, 1992) and also an directed left condition (Hynd et al, 1983; Obrzut et al, 1985; Bowen and Hynd, 1988). The mean scores in these studies were 38.33% in left and 32.1% in right and dichotic CV (Obrzut et al, 1985) in directed left condition. CST means score showed 0-30% in weaker ear and less than 80% in stronger ear (Welsh et al, 1982).

Bryden (1970) reported crossed dominance on dichotic digits. No hemisphere dominance was also found in a few studies using dichotic digits (Witelson and Rabinovich, 1972; Thomson, 1975) and on words. (Thomson, 1975) Dichotic advantage in dichotic listening task were also reported (Martin and Clarke, 1977).

Reduced double correct responses (7.4%) was reported by Ganguly, Rajagopal and Yathiraj (1994). Reversal errors, and order effect mere observed when SSW test was used on learning disabled children. (Stubblefield and Young, 1975; Johnson et al, 1981; Greenblatt et al, 1983; Berrick et al, 1984). Poorer scores than normals were obtained in children with learning disability on dichotic word test (Ferre and Wilber, 1986), CST (Welsh et al, 1982; Windham, 1985; Welsh, Welsh and Healy, 1996), SSW (Berrick et al, 1984; Riccio et al, 1996) and Dichotic CV (Swanson and Cochran, 1991). Total recall scores were impaired in these children with learning disability (Zurif and Carson, 1970; Obrzut, 1979; Windham, 1985). Testing done in presence of noise also yielded poorer scores on CST with S/CM ratio of 0 to +10 dB (Lasky and Tobin, 1973) and 12.5 dB MCR (Chermack, Vanlof and Bendel, 1989) and tn Dichotic CV (Hynd et al, 1983). Longer interval temporal effect between CV pairs was seen on Dichotic CVs (Tobey et al, 1979) and dichotic digits (Obrzut, 1979).

Thus, tests on dichotic listening were helpful in identifying CAPD in children with learning disability. Dichotic digits could identify 63.6%, SSW could identify 50% and CST could identify 86.4% (Musiek, Geurkink and Kietel, 1982) of children with learning disability. The differences in results obtained was probablly due to heterogenity and learning disabled children.

5. AUDITORY CUES USED IN PERCEPTION OF SPEECH BY LEARNING DISABLED CHILDREN

Lasky, Jay and Hanz-Ehrman (1975) studied 20 learning disabled children on differences in the delayed recall performance of linguistic meaningful and non meaningful and non linguistic meaningful and non meaningful auditory stimuli. These children scored poorer than normals on all tasks. Brandt and Rosen (1980) showed that dyslexics perceived, synthetic speech syllables with varied VOT or direction of formant transitions, categorically. They also relied more on phonemic labels in discriminating speech sounds. Tallal (1980) studied 20 reading disabled on various auditory perceptual tests using non verbal auditory stimuli. 45% of them showed significant errors. Tobey and Cullen (1984) studied temporal auditory integration for short duration frequency varying signals. At higher levels, learning disabled children showed an inability to assemble acoustic cues into a phonetic percept efficiently. Liebermann et al (1985) studied 18 adult dyslexics on the identification of vowels when the sole acoustic cue was steady state formant frequency patterns. The vowel error rate was 29% and consonantal error rate was 22%. Tallal, Stark and Mellits (1985) showed that all the 26 learning impaired children performed poorer than the normals in a temporal perception task on a discrimination of syllables. Elliott, Hemmer and Schell (1989) studied 294 children with language - learning problems on a set of fine grained auditory discrimination task that required responding to small acoustic differences among CV syllables. 87% showed poor scores on this task.

Steffens et al (1992) studied 18 adult dyslexics on perception of 3 synthetic speech continua. They were able to discriminate and label the synthetic speech continua, but they did not necessarily use the acoustic cues in the same manner as normal readers.

Thus it can be concluded that children with learning disability do show deficits on behavioral tests. This in turn indicates that these children do have central auditory processing disorder.

B) ELECTROPHYSIOLOGICAL TESTS

1) AUDITORY BRAINSTEM RESPONSE (ABR)

Reports of ABR in learning disabled children are equivocal. Normal ABR was obtained in a majority of the investigations (Lenhardt, 1981; Tait, Roush and Johns, 1982; Welsh et al, 1982; Greenblatt et al, 1983; Tait, Roush and Johns, 1983; Roush and Tait, 1984; Mason and Mellor, 1984; Jerger, Martin and Jerger, 1987; Pinkerton et al, 1989). The repetition rates that has been used for these studies are 5/sec (Lenhardt, 1981), 10/sec (Lenhardt, 1981; Greenblatt et al, 1983; Mason and Mellor, 1984), 11/sec (Tait, Roush and Johns, 1982; 1983), 20/sec (Lenhardt, 1981; Welsh et al, 1982; Jerger, Martin and Jerger, 1987), 33.3/sec (Lenhardt, 1981), 41/sec (Tait, Roush and Johns, 1983), 50/sec and 99.9/sec (Lenhardt, 1981).

However, a few investigators have reported abnormal ABR in children with learning disability. The abnormalities observed in these children include delayed waves (Sohmer and Student, 1978; Lenhardt, 1981; Welsh et al, 1982) and absent waves (Greenblatt etal, 1983). ABR waves appeared at earlier latencies in a few subjects (Pinkerton et al, 1989; Gopal and Kowalski, 1999).

Attempts have also been made to study the binaural interaction in children with learning disability. Gopal and Kowalski (1999) have observed BIC in the range of 5.2 - 6 ms in these children. A delay in BIC by 0.2 ms was found by Welsh et al (1982). In another study Gopal and Pierel (1999) found negative BIC for wave V. Controversial findings have been reported for amplitudes of binaural interaction tests. Reduced amplitude to binaural than summed monaural responses has been observed in a few studies (Mason and Mellor, 1984; Gopal and Kowalski, 1999) whereas increased amplitude for binaural stimulation have been reported by Gopal and Pierel (1999).

2) AUDITORY MIDDLE LATENCY RESPONSES (AMLR)

AMLR have been recorded in learning disabled children using tone pips (Mason and Mellor, 1984) and clicks (Kraus et al, 1985; Jerger, Martin and Jerger, 1987; Arehole, Augustine and Simhadri, 1995). In all these studies stimulus was presented at high intensity (60 dB nHL to 80 dB nHL). Various rates that have been used are 3/sec (Mason and Mellor, 1984), 7.7/sec (Arehole, Augustine and Simhadri, 1995), 8.8/sec (Jerger, Martin and Jerger, 1987) and 11/sec (Kraus et al, 1993). AMLRs in learning disabled children have been reported to be normal in latency and reduced in amplitudes by a majority of the investigators.

Arehole, Augustine and Simhadri (1995) reported prolonged latencies of Pa at 32 ms as compared to normals especially for contralateral recording. On the other hand, Mason and Mellor (1984) reported normal latencies for Po, Pa and Pb. Other studies which report no significant difference in latencies between learning disabled children and normals support this finding (Kraus et a, 1985; Arehole, Augustine, Simhadri, 1995).

Decrease in absolute amplitudes have been recorded for Na and Pa (Kraus et al, 1985). Jerger, Martin and Jerger (1987) have recorded reduced relative amplitudes for NaPa and PaNb. On the contrary, increased amplitudes has been observed for PoNa and for NaPa (Mason and Mellor, 1984). Normal amplitudes for PaNb, NbPb and PbNc have also been recorded in learning disabled (Mason and Mellor, 1984). Poor morphology and poor replicability has been reported by Jerger, Martin and Jerger (1987).

3) AUDITORY LATE LATENCY RESPONSES (ALLRS)

A majority of investigators have reported that ALLR components show increased latencies and reduced amplitudes in children with learning disability. ALLR studies have been carried out at moderate intensities and low repetition rates (below 2/sec) stimuli used have been 1000 Hz tone burst (Satterfield et al, 1984; Mason and Mellor, 1984; Byrnig and Jaryilehto, 1985; Duncan et al, 1994, Radhika, 1997) and 2000 Hz tone bursts (Pinkerton et al, 1989). Other stimuli used are speech (Fried et al, 1981; Dawson et al, 1989;Wood et al, 1991; Brunswick and Rippon, 1994), musical cord (Dawson et al, 1989; Fried et al, 1981), pure tones (Tonnquist-Uhlen, 1996), clicks (Satterfield et al 1984; Dawson et al, 1989; Arehole, 1995) and tone pairs (Shucard, Cummigs and McGee, 1984).

P_1 Wave

P_1 wave is reported to be delayed in latency (Satterfield et al, 1984; Byring and Jaryilehto, 1985; Leppamann and Lytinen, 1997). Latency has been reported to be 88.72 ms in a study by Satterfield et al (1^84). A significant increase in latency when compared to normals was found in another study by Byring and Jaryilehto (1985). On the contrary, Korpihahti and Lang (1994) reported normal P_1 latencies. Radhika (1997) observed that in 5 out of 7 learning disabled children in whom P_1 could be recorded, latency was normal.

Reduced P_1 amplitude ranging from -3.0 to -4.9 (µV have been reported in literature (Pinkerton et al, 1989; Jirsa and Clontz, 1990; Korpihahti and Blang, 1994; Leppamenn and Lyytinen, 1994). Reduced P_1

N_1 amplitudes have also been reported (Mason and Mellor, 1984; Satterfield et al, 1984; Byring ad Jaryilehto, 1985). In an investigation by Radhika (1997), P_1 wave was absent in seven out of twelve children with tearing disability.

N_1 wave

Increase in latency of N_1 component has been reported in a majority of the studies (Satterfied et al, 1984; Dawson et al, 1989; Jirsa and Clontz, 1990; Neville et al, 1993; Arehole, 1995; Tonnquist - Uhlen et al, 1996; Radhika, 1997). The mean latency values has ranged from 113-123ms (Satterfield et al, 1984; Dawson et al, 1989; Jirsa and Clontz, 1990; Arehole, 1995; Radhika, 1997) and 125-153 ms (Radhika, 1997). However, Arehole (1995) observed an increase in latency but the increase was not statistically significant. This supports the results of an earlier study by Duncan et al (1994) who observed that the latency was within normal limits. Reduced latency of N_1 was also reported by Mason and Mellor (1984).

Reduced absolute amplitude of N_1 has been reported in many studies (Mason and Mellor, 1984; Dawson et al, 1989; Pinkerton et al, 1989; Jirsa and Clontz, 1990; Neville et al, 1993; Brunswick and Rippon, 1994; Duncan et al, 1994; Kemmer et al, 1995; Radhika, 1997). Amplitude has ranged from -0.1 [TV to 1.93 µ.V (Dawson et al, 1989; Brunswick and Rippon, 1994; Kemmer et al, 1995; Radhika, 1997) and from 5.7µV,to 6.5 µ*V* (Pinkerton et al, 1989; Jirsa and Clontz, 1990). Refuting these studies Lincoln et al (1995) observed increased absolute amplitude whereas Jirsa (1992) reported normal absolute amplitudes ranging from -3.7µV to -3.9

Reduced N)P_2 amplitude have also been reported in literature (Mason and Mellor, 1984; Satterfield et al, 1984; Arehole, 1995; Radhika, 1997) N_1 was not identifiable in 8 out of 12 subjects studied by Radhika (1997).

P_2 Wave

An increase in P_2 latency has been reported in children with learning disability (Satterfield et al, 1984; Byring and Jaryilehto, 1985; Jirsa and Clontz, 1990; Arehole, 1995; Tonnquist - Uhlen et al, 1996; Leppamann and Lyytinen, 1997; Radhika, 1997). Latencies reported ranged from 160ms to 188 ms (Satterfield et al, 1984; Arehole, 1995; Tonnquist - Uhlen etal, 1996; Radhika, 1997).

Jirsa and Clontz (1990) observed P_2 at a latency of 220 ms. However, a few studies refute these findings. Arehole (1995) reported that there was no significant differences between normals and learning disabled children. Normal latencies observed in some of the investigations (Duncan et al, 1994; Radhika, 1997) support the above finding. Increased P_rP_2 latency have been reported by Arehole, (1995).

Absolute amplitude of P_2 has also been reported to be reduced in children with learning disability (Satterfield et al, 1984; Brunswick and Rippon, 1994; Duncan et al, 1994; Tonnquist-Uhlen et al, 1996; Leppamann and Lyytinen, 1997). Amplitude reported in literature varied from -0.07 (iV to 7.83 µV (Satterfield et al, 1984; Brunswick and Rippon, 1994; Tonnquist - Uhlen et al, 1996), Mason and Mellor. (1984) and Satterfield et al (1984) reported a reduction in P_2N_2 relative amplitude ranging from 6.3 µV to 13.4µ.V. Report by Jirsa (1992) which stated that P_2 amplitude was normal in children with learning disability contradicts the above findings. P2 wave was not identifiable in a few studies (Pinkerton et al, 1989; Jirsa and Clontz, 1990; Radhika, 1997).

N_2 wave

An increase in the N_2 latency has been reported in a majority of the studies on learning disabled children (Satterfield et al, 1984; Mason and Mellor, 1984; Korpihahti and Lang, 1994; Tonnquist-Uhlen et al, 1996). Latencies reported in these studies ranged from 263 ms to 267 ms (Satterfield et al, 1984; Korpihahti and Lang, 1994) and 294 to 310 ms (Mason and Mellor, 1984; Tonnquist - Uhlen et al, 1996). However, Duncan et al (1994) reported that the latency of N_2 was normal, ranging from 177 to 230 ms. Results of a investigation by Radhika (1997) showed that N_2 was absent in 2 of the 12 children with learning disability. 10 children in whom N_2 could be recorded had normal latency.

Controversial findings about N_2 amplitudes have been reported in learning disabled with a majority of investigation indicating decreased absolute amplitudes (Satterfield et al, 1984; Korpihahti and Lang, 1994; Tonnquist-Uhlen, 1997 Leppamenn and Lyytinen, 1997). The amplitude of N_2 ranged from -4.5 µV to -5.6 µV (Satterfield et al, 1994; Tonnquist-Uhlen et al, 1996). Mason and Mellor (1984) observed that there was a decrease in N_2P_3 amplitude.

Other studies have reported absence of N2 waves (Pinkerton et al, 1989; Jirsa and Clontz, 1990; Duncan et al, 1994; Radhika, 1997) increased N_2 absolute amplitude has been recorded in some of the investigations (Mason and Mellor, 1984; Byring and Jaryilehto, 1985). However Tonnquist - Uhlen et al (1996) identified 80% of learning disabled children using ALLRs. However normal amplitudes was reported by Holcomb, Ackerman and Dykman (1985).

N_3 waves

There is not much literature on presence of N_3 waves in children with learning disability. Mason and Mellor (1984) recorded N_3 at a latency of 465 ms. P_3N_3 amplitude was increased at 4.2 µV. It was reported to be abnormal in bearing disabled children.

Hemispheric asymmetries

Auditory evoked potential recording has indicated hemispheric asymmetry in learning disabled children (Rosenthal et al, 1982; Fried et al, 1981; Wood et al, 1991). Differences in the waveform recorded from left and right hemisphere were seen in al these studies. Poorer right ear performance has been reported in many studies. (Rosenthal et al, 1982; Mason and Mellor, 1984; Shuchard, Cummings and McGee, 1984;Neville et al, 1993; Brunswick and Rippon, 1994).

4) P **300 WAVE**

An increase in P300 latency and decrease in amplitude has been observed in learning disabled children. P300 has been elicited using pure tones (Holcomb et al, 1986; Jirsa and Clontz, 1990; Jirsa, 1992, Segalowitz et al, 1992; Erez and Pratt, 1992; Mazzotta and Gallai, 1992; Neville et al, 1993; Radhika, 1997) or nonsense syllables (Holcomb, Ackerman and Dykeman, 1985; Erez and Pratt, 1992).

Investigators have reported an increase in the P300 latency in children with learning disability (Byring and Jaryilehto, 1985; Holcomb, Ackerman and Dykman, 1985; Holcomb et al, 1986; Erez and Pratt, 1992;

Jirsa, 1992; Mazzotta and Gallai, 1992; Duncan et al, 1995; Leppamann and Lyytinn, 1997). Latencies reported in literature vary from 335 ms to 580 ms (Byring and Jaryilehto, 1985; Duncan et al, 1994). Holcomb et al (1986) observed P300 at a latency of 900-1150 ms in these children. Increased P_2-P_3 interpeak latency have been documented by some investigators (Jirsa and Clontz, 1990; Erez and Pratt, 1992).

Normal P300 latency values have also been reported by Segalowitz et al, (1992). Radhika (1997) observed bifid P300 wave at normal latency in three learning disabled subjects and absent P300 waves in nine learning disabled subjects. Normal P2-P3 interpeak latency has been recorded by Dawsonetal(1989).

A significant decrease in P300 amplitude have been reported in learning disabled children (Byring and Jaryilehto, 1985; Holcomb, Ackerman and Dykman, 1985; Jirsa and Clontz, 1990; Jirsa, 1992; Duncan et al, 1994; Kemmer et al, 1995; Leppamann and Lyytinne, 1997; Radhika, 1997). Absolute amplitude varied from 1.55 |iV to 1.5 ^iV (Jirsa and Clontz, 1990; Jirsa, 1992; Duncan et al, 1994; Radhika, 1997; Holcomb, Ackermann and Dykman, 1985; Kemmer et al, 1995).

However, increase P300 absolute amplitudes have been reported by Courchesne et al (1989) and Mazzotta and Gallai (1992). Segalowitz et al (1986) found normal P300 amplitudes. In an exclusive study Jirsa (1992) compared pre-therapy and post-therapy P300 amplitudes and latencies. Latency decreased from 440 ms to 342 ms after therapy and amplitudes increased from 5.3 µV to 9.2 µV.

5) MISMATCH NEGATIVITY

Studies have shown a reduction in amplitude and duration of MMN in children with learning disability. But the reports on latency of MMN are equivocal. Various stimuli used to elicit an MMN include pure tones at different durations and frequencies (Korpihahti and Lang, 1994), tone bursts (Radhika, 1997) and speech stimuli (Kraus et al, 1996) at high intensities above 60 dB nHL.

Reduced amplitude of MMN was first reported by Korpihahti and Lang (1994) for MMN using duration deviance of 450 ms (50 ms and 500 ms) and for MMN using frequency deviance of 53 Hz (500 and 553 Hz). They did not find any amplitude difference when tones of 50 ms and 110 ms duration was used. This finding was supported by other studies which reported of reduced MMN amplitude (Kemmer et al, 1995; Leppamann and Lyytienn, 1997; Radhika, 1997). Amplitudes reported in literature has varied from -0.91 - 3.89 (Korpihahti and Lang, 1994; Radhika, 1997) and from -2.4 to 3.8 |iV (Korpihahti and Lang, 1994; Kemmer et al, 1995).

Korpihahti and Lang (1994) reported that the latency was prolonged for frequency MMN but the latency for duration MMN was dependent on the characteristics of the stimuli. Latency of MMN was normal when stimuli of 50 and 500 ms duration was used whereas shorter latency was observed for stimuli of 50 and 110 ms duration was used. The latency for stimuli of 500 and 553 Hz MMN was normal for 9 out of 12 learning disabled children investigated by Radhika (1997). No off time was recorded in 5 out of these children. She further reported that MMN was absent in 3 children.

Reduced area of MMN (Kraus et al, 1996) and reduced duration (Kraus et al, 1996; Radhika, 1997) and poor morphology of MMN (Radhika, 1997) have been reported in children with learning disability. Korpihahti and Lang (1994) reported right hemisphere dominance in 36% of the children.

Thus, there is a death for studies on MMN, which is reported to be abnormal in children with learning disability and more research needs to be carried out to support these findings.

To summarize, it has been reported in literature a subgroup of learning disabled children do have a central auditory processing disorder which is evident on both behavioral, physiological and electrophysiological tests. A few studies have compared the sensitivity of these different tests in identifying CAPD in children with learning disability.

Willeford (1976) found the most sensitive test as filtered speech followed by Binaural fusion and competing sentences. Pinheiro (1977) used 7 tests and found significantly poorer scores for left than right ear for competing sentences, SSW, simultaneous sentences and no differences for filtered speech, binaural fusion and RASP. He also found significant differences between hummed responses and manual responses for PPST when compared to normals. Musiek and Geurkink (1980) also found lower left than right ear scores for competing sentences, SSW, dichotic digits and bilaterally depressed scores for PPST. No significant difference was found for binaural fusion and RASP as compared to normals.

Welsh, Welsh and Healy (1980) found filtered speech most sensitive followed by binaural fusion, competing sentence and RASP. 50% of the subjects showed poor scores in these tests. Musiek Geurkink and Keitel (1982) found competing sentences the most sensitive test with 86.7% failure. This was followed by PPST with 72.7% failure, dichotic digits with 63.6% and SSW and 50% failures. On these tests left ear scores were poorer than right ear. Filtered speech showed bilaterally depressed scores. This was followed by binaural fusion and RASP also having poor scores.

Welsh et al (1982) found the most sensitive test as binaural fusion, to be followed by filtered speech, time compressed and then competing sentences. ABR amplitude also used had reduced amplitudes.Greenblatt et al (1983) found poor scores in SSW, binaural fusion and RASP. He found normal scores on filtered speech and competing sentences. Abnormal ABR findings were also seen.

Roush and Tait (1984) found poor scores on binaural fusion and abnormal ABRs but normal MLD scores. Windham (1985) found no difference between normal and LD children on RASP Test. Poor scores were found in competing sentences, filtered speech, binaural fusion and SSW. 92% failed in a battery of test studied by Ferre and Wilber (1986). Next sensitive was filtered speech with 92.3% failure and then dichotic CV. Poor scores was also found in binaural fusion and time compressed speech. Welsh, Welsh and Healy (1996) found poor scores in competing sentences, the compressed speech, filtered speech and binaural fusion.

Thus there is a heterogeniety in children with LD, therefore a test battery approach may be more useful in detecting CAPD. Different processing dysfunctions seen in LD children cannot be detected by a single test. In the present study, a battery of tests which included behavioral, physiological and electrophysiological test were chosen to identify CAPD in Learning Disabled children.

METHODOLOGY

The aim of the present study was to study the central auditory processing in children with learning disability (LD). Behavioral, physiological and electro physiological tests used for assessing central auditory processing were as follows:

Behavioral Tests:

1. Speech Perception In Noise (SPIN)
2. Masking Level Difference (MLD)
3. Pitch Pattern Sequence Test (PPST)
4. Dichotic CV Test
5. Time Compressed Speech Test.

Physiological Test:

1. Acoustic Reflex Thresholds (ART)

Electrophysiological Tests:

1. Auditory Brainstem Reponses (ABR)
2. Auditory Late Latency Responses (ALLR)
3. P 300
4. Mismatch Negativity (MMN)

Subjects:

Two groups of subjects, an experimental group and a control group were included for the study.

Experimental group (E):

A total of seven children, 4 males and 3 females who were diagnosed as learning disabled using Early Reading Skills - Informal Reading Diagnosis (Rae and Potter 1973) served as subjects. As shown in Table-1 the age of the children ranged from 8 to 13 years.

Table - 1: Age wise distribution of subjects.

Age	Number	
	Male	Female
8 Years	-	1
10 Years	3	2
13 years	1	-

Other criterias for subject selection were as follows:

1. Average intelligence
2. English as first or second language
3. Normal peripheral hearing

Control Group (C):

Seven children matched for age and gender for children in the experimental group served as control subjects. They had normal scores on the Early Reading Skills (Rae & Potter, 1973) and also met the above lying criterias.

Instrumentation:

1. A calibrated audiometer Madsen, O.B. 822 with TDH - 39 earphones lodged in MX-41 AR ear cushion and bone vibrator Radio ear B-71 were used for the pure tone audiometry, speech audiometry, speech in

noise test, time compressed speech test, pitch pattern sequence test and dichotic C.V. tests.

2. A calibrated middle ear analyzer GSI 33 Version II was used for tympanometry and reflexometry.
3. Calibrated GSI 10 audiometer with TDH 50P earphones lodged in MX - 41 - AR ear cushion was used for administering the masking level difference test.
4. The audio cassette consisting of the recorded test stimuli for time compressed speech, pitch pattern sequence and dichotic CV tests, were played on a calibrated Philips 160 W tape recorder. The signal from the tape recorder was fed to tape input of the calibrated Madsen OB 822 audiometer.
5. The electrophysiological test unit used was the Biologic Auditory Evoked Potential (Navigator System) with software EP 317. All the evoked potentials were recorded using silver chloride disc electrodes. TDH 39 earphone with MX 41 —AR cushion was used to present the stimuli.

MATERIALS USED

(1) Speech Reception Threshold:

The CID W22 spondee word list Ia in English for children standardized for Indian population (Swarnalatha, 1972) was used for estimating the speech reception threshold (Appendix - D).

(2) Speech Identification In Quite:

The monosyllables word list Ia in English (Rout, 1996) were used for speech identification in quiet condition (Appendix - A).

(3) Speech Perception in Noise:

25 monosyllabic words in English Form I (Rout, 1996) was delivered in the presence of speech noise (Appendix - A).

(4) Time Compressed Speech Test:

40% compressed speech in English developed by Yathiraj (1999) at AIISH, Mysore was used. The test stimuli consisted of 25 mono-syllablic words (Rout 1996) (Appendix-A).

5) Pitch Pattern Sequence Test:

This consisted of 30 test sequences of pitch pattern developed by Pinheiro (1974). Each sequence was made up of 3 tone bursts, two of one frequency and one of a second-frequency arranged in six possible combinations. The 'high' tone was 1122 Hz and the 'low' tone was 880 Hz. Duration of each tone was 200 ms and there was a silent interval of 150 ms between tones so that the total duration of each sequence in 900 ms. First 30 sequences presented in random order have been used in this study. Each combination was presented five times (Appendix-B).

6) DichoticCV:

Dichotic CV test developed by Yathiraj (1994) at CID, St, Louis was used. It consisted of 30 randomized pairs of stop consonant - vowel (CVs): Ipal, Ibal, Ital, Idal, Ikal and Igal in 30 possible combinations. The CVs were generated simultaneously and with a particular time lag as in the manner described below :

a) 0 ms lag - Both the ears were presented with stimulus simultaneously.

b) 90 ms left ear lag - Here the syllable in left ear was presented with a lag period of 90 ms when compared to the right ear.

c) 90 ms right ear lag - Here the syllable in right ear was presented with a lag period of 90 ms when compared to the left ear (Appendix C).

TEST PROCEDURE

Each child was evaluated in two sittings, one for behavioral evaluation and the other for electrophysiological and physiological evaluation. 2 to *2½* hours was required for each sitting.

1. BEHAVIORAL TESTS

(1) Pure Tone Audiometry

Pure tone thresholds for air conduction was assessed at octave frequencies between 250 Hz - 8000 Hz. Modified Hughson-West-lake procedure was used for estimation • of thresholds. Bone conduction thresholds were assessed at octave frequencies between 250 Hz to 4000 Hz.

(2) Speech Reception Thresholds (SRT)

The signal was presented at PTA (3 frequency 500, Ik, 2 kHz average) + 20 dB. If the subject responded at that intensity then the intensity was reduced in 10 dB steps till the level where the subject repeats two spondees. At that level, the intensity in raised in 5 dB steps until patient responds by repeating at least 3 out of 6 words. The intensity at which the subject responded by repeating 50% of the given words correctly and below which he/she could or could not repeat any of the given words and also above which he repeated all the given words, was bracketed as SRT.

(3) Speech Identification Test in Quiet

Speech identification scores were obtained at 40 dBSL using recorded monosyllables in English. The subject was asked to repeat the words. Scores were converted into percentage scores.

(4) Speech Perception in Noise (SPIN)

Subjects were presented English monosyllabic word list and speech noise in monotic presentation through the earphones. The speech stimuli was presented at 40 dBSL (re : SRT) with an S/N ratio of 10 dB (i.e., noise at 30 dBSL re : SRT). Subjects were asked to repeat the speech stimuli. Responses were scored in terms of percentage correct per ear.

(5) Time compressed speech test

The 40% compressed speech was presented monaurally at 70 dBHL. The subjects were asked to repeat the speech stimuli after each presentation. Responses were scored in terms of percentage correct per ear.

(6) Masking Level Difference (MLD)

Masking level difference was obtained by calculating the difference between binaural threshold in homophasic (SoNo) condition and antiphasic (SoNπ and SπNo) condition. A 500 Hz pure tone signal was presented in presence of a 45 dBHL narrow band noise centered at 500 Hz. The level of the noise was kept constant and intensity of signal was raised in 2.5 dB steps to estimate the threshold. Subjects were instructed to respond to pure tone ignoring the presence of noise.

(7) Pitch Pattern Sequence Test

Subject were presented monaurally 30 test pattern sequences in each ear at 50 dBSL (re : 1 kHz threshold). Prior to this, series of sequences were given for practice to make them familiar to the test. The subjects were instructed to a) hum the response b) tell verbally the sequence of pitch. They were also asked to guess if unsure of the correct answers. Every alternate subject was asked to answer verbally first and then hum or vice versa i.e., hum and then verbally respond. The listener noted down the sequences. Responses were scored in terms of percentage correct per ear separately for humming and verbal responses.

(8) Dichotic CV test

Subjects were presented dichotic CVs with 90 ms right ear lag (REL), 0 ms and 90 ms left ear lag (LEL) through the earphones at 70 dBHL. Subjects were instructed to repeat both the CVs heard in any order after each presentation. They were encouraged to guess if they were unsure of the correct answers. The tester recorded their responses. Subject responses were scored in terms of single correct scores i.e., total number of correct responses individually for right and left ear (correct responses out of 30). The double correct responses i.e., correct repetition of the stimuli presented to both ears (correct responses in two ears out of 30). Scores were converted into percentages. Number of correct scores for each syllable was also computed.

II. PHYSIOLOGICAL TESTS

Tympanometry and Acoustic Reflex Thresholds (ART)

Tympanograms were recorded using 226 Hz probe tone. Ipsilateral and contralateral ARTS were obtained at octave frequencies from 500 Hz to 4000 Hz.

III. ELECTRO PHYSIOLOGICAL TESTS

Subjects were made to sit comfortable relaxed. Electrodes were placed after cleaning electrode sites and connected to the electrode box. It was ensured that the electrode impedance at each site was less than 5 kΩ and the inter-electrode impedance was less than 2 kΩ.

The electrode montage and test protocol varied depending on the evoked potential being measured. Stimuli was presented through headphones.

1) ABR

Subjects were instructed that they will hear a stimuli and they do not have to respond to it. They needed to sit quietly and relax.

Electrode placement

1. Forehead (Fpz) : non inverting electrode.
2. Mastoid of test ear : inverting electrode.
3. Mastoid of non test ear : common electrode.

Test protocol

Stimuli	Clicks
Intensity	70 dBnHL
Filter	100-3000 Hz
Repetition rate	11.1/s, 65.1/s, 90.1/s
Polarity	Rarefraction
Gain	x 75,000
Maximum stimulus	2000

2) ALLRs and MMN

The child was asked not to pay any attention to the auditory stimuli.

Electrode placement

1. Forehead (Fpz) - common electrode.
2. Vertex (Cz) - non-inverting electrode.
3. Parietal (Pz) - non-inverting electrode.

4. Mastoid left (Ml) - inverting electrode.
5. Mastoid right (M2) - inverting electrode.

Ml and M2 were interlinked using a jumper.

Test Protocol

Stimulus type - alternating tone burst.
Frequency : Frequent = 1000 Hz, infrequent = 1000 Hz.
Intensity : frequent = 60 dBnHL, infrequent = 65 dBnHL
Repetition rate : 1.1/sec.
Rise time : 10 ms
Plateau : 30 ms
Fall time : 10 ms
Gain : x 30,000
Maximum stimuli: 500 artifact free rare stimuli
Band pass filter : 0.1 Hz to 300 Hz
Probability ratio : frequent: infrequent stimuli = 5:1.

3) P300

The subjects were told that there will be two stimuli or tones heard, one will be frequently occurring and the other is a rare one. They will have to count the rare stimuli. Subjects were familiarized with the odd-ball paradigm before starting the test.

Electrode placement: same as ALLR/MMN.

Test Protocol :

Stimuli type : Alternating tone bursts
Frequent stimuli: 1000 Hz.
Infrequent stimuli : 2000 Hz.
Intensity : 70 dBnHL

Filter setting : 0.1 Hz to 300 Hz

Repetition rate : 1.1 /sec

Rise time : 10 ms

Plateau time : 30 ms

Fall time : 10 ms

Gain = x 50,000

Maximum stimuli : 500 artifact free infrequent stimuli

Probability Ratio : frequent: infrequent stimuli = 5:1

Analysis

a) ABR : The following were analyzed :

1. Latencies of I, III and V waves.
2. Interpeak latency differences of **I-III, III-V** and **I-V.**
3. Relative amplitudes of I, III and V waves.
4. Amplitude ratio of V/I
5. Morphology.

b) ALLRs : The following were analyzed from the frequent wave of the ALLR recording.

1. Latencies of P_1, N_1, P_2, N_2.
2. Interpeak latency difference of P_1-P_2-
3. Peak to peak amplitudes of P_1 N_{15} N_1 P_2 and P_2 N_2.
4. Morphology.

c) P300 : The following were analyzed from the infrequent waveform :

1. Latency of P300.
2. Relative amplitude of N_2P_3
3. Morphology.

d)MMN : This was obtained from subtracting of the infrequent stimuli wave from the frequent stimuli waveform. The following were analysed :

1. Onset, offset and peak latency.
2. Relative offset and onset amplitudes.
3. Absolute peak amplitude.
4. Onset time : duration from onset of the negativity to the peak of negativity.
5. Offset time : duration from peak of the negativity to the end (offset) of the negativity.
6. Duration : Duration from onset to offset of the negativity.
7. Magnitude : Duration x absolute peak amplitude.
8. Morphology.

Latencies of all the potentials were measured at the peak of each wave. If there was no sharp peaks, the center point was considered. Relative amplitudes were measured from trough to peak or peak to trough.

RESULTS & DISCUSSION

The data collected from the learning disabled (LD) and normal subjects were tabulated and suitable statistical analysis was carried out for behavioural as well as physiological and electrophysiological tests.

I. BEHAVIORAL TESTS

Descriptive statistics which included Mean, Standard Deviation and Range were calculated for both experimental and control groups. A non-parametric test, the Wilcoxn matched paired t-test, was used to check if there is significant difference between means of the two groups. Two tables are given in this chapter the 'A' series, shows the mean, SD, range, for learning disabled as group as compared to the control group and also the results of 't' test. 'B' series of tables show the number of children showing abnormal or normal scores when compared to their age and sex matched controls.

1. Speech Identification Test in Quiet

Table 2A shows the mean scores of speech identification test in quiet for learning disabled and normal groups.

Table 2A : Scores of Speech Identification test in Quiet

Ear	Group	Mean (%)	SD	Range (%)	Z score	P
Right	E	98.57	2.51	94-100	0.37	0.72
	C	98.86	1.95	96-100		
Left	E	97.71	4.54	88-100	0.80	0.42
	C	99.43	1.51	96-100		

Referring to table 2A there was very little difference between the speech identification scores of the experimental group and normal subjects Wilcoxn matched pair t-test showed no significant difference between the two groups.

Table 2B : Distribution of LD children on Speech Identification Test in Quiet

Scores	R	L
Abnormal	Nil	1
Normal	7	6

(R = Right ear L = Left ear)

A closer inspection of data in table 2B shows that all the LD subjects had normal speech identification scores in the right ear and only one showed poorer scorer than his counterpart in the left ear. These results reinforce the consensus that routine speech identification scores do not identify CAPD in LD children. Presentation of conventional monosyllabic phonetically balanced word test does not constitute a test for CAPD because these do not present a difficult enough task to cause a breakdown in performance when central pathology exists (Katz and Pack, 1975).

2. Speech Perception in Noise (SPIN)

Table 3A : Scores of Speech Perception in Noise Test

Ear	Group	Mean (%)	SD	Range (%)	Z score	P
Right	E	81.71	10.55	60-92	0.37	0.018*
	C	97.71	3.15	92-100		
Left	E	82.29	4.54	76-88	-2.37	0.018*
	C	97.14	3.80	92-100		

* Significant at 0.05 level

It can inferred from the table 3A that learning disabled as a group performed significantly poorer on the SPIN test as compared to control group in both ears. The lowest scores was 60% and highest was 92% in any ear with a mean of 81.71% in right and 82.29% in left ear.

Table 3B : Distribution of LD Children on SPIN Test

Scores	R	L
Abnormal	7	7
Normal	-	-

Individual scores shown in Table 3B were in accordance with the group findings. All seven LD children scored poorer than control in both ears. This findings is in support to Greenblatt et al. (1983) who also used +10dB SNR and found poor scores in LD children. Similar findings were also reported by Rupp et al. (1986), Jerger, Martin and Jerger (1987); Chermak, Vanhof and Bendel (1989). These results show that LD children present greater susceptibility to noise than normal children. Chermak, Vanhof and Bendel (1989) have reported that LD children have difficulty in communicating in noisy places and situations. However results of SPIN test do not give information about the site of lesion in the auditory system. Poorer scores on SPIN test has been reported in patients with cochlear pathology, VIII Nerve; brainstem or cortical lesions (Olsen et al, 1975). Therefore the diagnosis of CAPD cannot be made based solely on the results of SPIN test.

p.T.O.

3. Time Compressed Speech Test

Table 4A : Scores of 40% Time Compressed Speech Test

Ear	Group	Mean (%)	SD	Range (%)	Z score	P
Right	E	70.29	8.28	60-80	2.37	0.018*
	C	94.29	7.25	80-100		
Left	E	76.0	8.0	64-84	2.37	0.018*
	C	95.43	4.28	88-100		

* Significant at 0.05 level

A study of table 4A shows that LD group performed significantly poorer than normal subjects on time compressed speech test. The mean score for LD children was 70.29% in right and 76% in left ear with a range of 60% to 80% in any ear.

Table 4B : Distribution of LD children on 40% time compressed speech test

Scores	R	L
Abnormal	6	7
Normal	1	

It can be observed from the table 4B that all the scores of children scored poorer than normal in the left ear and only one subject had near normal scores in the right ear. The reports of the present study supports earlier studies (McCorsky, and Thompson, 1973a; Manning, Johnson and Beasley, 1977; Watson and Rostatter, 1985 and McNutt and Chia-Yenki 1980) which state that LD subjects perform poorly on compressed speech test. It is seen that temporal alteration of speech stimuli in the form of time compression reduces the intrinsic redundancy of the speech signal, thereby increasing the processing load on the temporal aspect of the auditory perceptual process (DiSimoni, 1974). Recognition of these temporally altered stimuli requires limited linguistic background and represents a signal focused processing task (Ferre and Wilber, 1986). It has been postulated that LD children may experience an excessively rapid decay of information from their short term memory. Thus auditory information presented at faster rates should prevent information decay by reducing the time the signal had to remain in memory (Manning, Johnston and Beasley, 1977). Another postulation in that they have problems in processing of rapid acoustic information, which can be tested with expanded speech (McMutt & Chia-Yenki, 1980). Further investigation comparing performance on time compressed and time expanded speech is required to check which of these hypothesis is true.

Thus the results indicate that LD children may have auditory closure deficit which is due to cortical dysfunction.

3. **Masking Level Difference (MLD)**

Table 5A : Masking Level Difference in LD and normal group

Ear	Group	Mean (dB)	SD	Range (dB)	Z score	P
SΠNO- SoNo	E	5.36	1.73	2.5-7.5	2.37	0.018*
	C	10.71	2.78	7.5-15		
SONΠ SoNo	E	6.07	2.44	2.5-10	2.20	0.027*
	C	11.79	1.89	10-15		

* Significant at 0.05 level

Inspection of Table 5A shows that MLD was significantly reduced in subjects with LD. Reversing the phase of either signal or noise in one ear did not improve signal detection.

Table 5B : Distribution of LD children on MLD Test

Scores	SПNO- SONO	SoNπ- SoNo
Abnormal	6	5
Normal	1	2

Individual scores as seen in table 5B were consistent with group scores. Release from binaural masking was seen only for one subject in *Sn* No condition and 2 subjects in So N7t condition. These results supports the study by Grant (1980a, b). However these findings do not agree with the reports of Roush and Tait (1984) who showed no difference between LD and normals. This may be due to heterogeinety seen in LD groups.

It can be concluded from these results that LD children may have a binaural interaction deficit which is a brainstem function.

4. Pitch Pattern Sequence Test (PPST)

Table 6A : Scores of Pitch Pattern Sequence Test for Humming & Verbal Responses

Response	Ear	Group	Mean	SD	Range	Z score	Prob
Humming	R	E	22.71	9.45	2-30	1.69	0.091*
		C	28.0	1.29	26-30		
	L	E	21.0	9.24	2-30	1.78	0.075
		C	•26.57	1.99	24-29		
Verbal	R	E	12.71	6.97	8.28	1.99	0.046*
		C	16.57	5.41	12.28		
	L	E	13.43	8.30	3.29	0.8	0.93
		C	14.0	6.58	9.28		

* Significant at 0.05 level

Table 6A shows the mean, SD, range, for the total scores of humming and verbal responses for learning disabled and control group

These scores show that learning disabled group performed poorer than normal group in both verbal and humming responses. Left ear scores were poorer than right ear scores for humming response for both the groups. Though the scores obtained for LD children in both the ears was lower than that of normals, it was not statistically significant. For verbal responses, normal children scored better in right ear when compared to left ear. But children with LD showed slightly better performance in the left ear. Comparison of scores for normal and LD children showed a significant difference between the two groups for right ear scores and no significant differences for the left ear scores.

Table 6B : Distribution of LD children on PPST for humming and verbal response

Scores	Humming		Verbal	
	R	L	R	L
Abnormal	3	3	4	2
Normal	4	4	3	5

Table 6B revealed that three out of seven subjects showed poor scores on PPST in both ears in the humming response. In the verbal response mode more number of LD subjects show abnormal scores in right ear than that of left ear. Overall, four of the LD subjects failed on either the humming or verbal response of PPST. One failed on both responses and two had normal scores. Reversal errors were also seen for verbal response in LD subjects.

Abnormal humming scores has been reported by Pinheiro (1977) and Musiek, Geurkink and Kietel (1982). Musiek and Geurkink (1980) observed abnormal scores for verbal responses. However, in the present study three showed normal responses in right and 5 in left ears. A deficit in the corpus callosum or the right hemisphere can be suspected (Pinheiro, 1977) in subjects who showed poor scores for hummed response. Poor scores in verbal responses is indicative dysfunction in linguistic labeling which is a left hemisphere dysfunction (Bellis, 1996). The two subjects with normal hummed and verbal scores had normal cortical functioning on this temporal ordering task.

This study hence shows that some of the children with LD have a problem in temporal ordering including frequency discrimination, linguistic labeling and interhemispheric transfer. Children with temporal ordering deficits may Exhibit difficulty recognising and using prosodic aspects of speech. Bellis (1996) reported that they may have difficulty in extracting words from a spoken message and may be unable to discriminate subtle differences in meaning brought about by changes in relative stress and in-tonation. They may also have problems in sequencing of critical elements within a message, as well as individual speech sounds within a word.

5. **Dichotic** CV **Test**

a) Oms lag

Table 7A : Scores of Dichotic CV test with Oms

Ear	Group	Oms				
		Mean	SD	Range	1Z1	P
Right	E	9.71	3.64	3-14	2.18	0.028*
	C	17.71	3.45	13-23		
Left	E	12.86	5.84	7-24	0.85	0.39
	C	14.86	2.12	13-19		
Double correct scores	E	3.0	1.63	1-6	2.20	0.028*
	C	7.14	2.04	4-10		

* Significant at 0.05 level

As shown in table 7A, the LD children showed poorer scores on CVs presented with Oms lag when compared to their controls. This was found to be significant at 0.05 level for right ear scores and double correct scores but was not statistically significant for the left ear.

Table 7B : Distribution of LD children on Dichotic CV test with Oms lag

Score	R	L	DCS
Abnormal	6	4	5
Normal	1	3	2

Inspection of table 7B indicated that more number of children showed deficits in right ear scores and double correct scores than left ear when compared to normals.

It can also be observed from table 7A that normal children showed a right ear advantage whereas a left ear advantage was seen in LD children. However the difference between the two ear scores was not statistically significant for both **the** groups [z=1.36 in experimental group and -1.52 in control group]

b) 90 ms left ear lag

Table 8A : Scores of Dichotic CV test with 90 ms Left ear lag

Ear	Group	90 ms left ear lag				
		Mean	SD	Range	Z	Probability
Right	E	12.86	3.63	7-17	0.85	0.398
	C	15.71	2.81	11-19		
Left	E	14.29	2.89	11-17	2.20	0.028*
	C	19.71	2.89	16-23		
Double correct scores	E	4.29	2.56	1-8	2.37	0.018*
	C	9.0	2.58	6-13		

*Significant at 0.05 level

Referring Table 8A, the scores for both the groups were better than that obtained with Oms lag. LD children showed poorer scores when compared to normal controls for right, left and double correct scores. The mean scores being 12.86 for right, 14.24 for left and 4.29 for double correct scores. The difference was significant at 0.05 level for scores. It can also be seen that lag effect was seen in both the groups. That is, the performance in left ear was better than that of right ear. This difference between the two ear scores was significant for the normal group at 0.05 level (z =2.37) but was not statistically significant in the experimental group (z = 0.68)

Table 8B : Distribution of LD children for Dichotic CV test with 90 ms LEL

Score	R	L	DCS
Abnormal	3	5	5
Normal	4	2	2

As shown in table 8B more number of children showed deficits in left ear scores and in double correct scores than in right ear when compared to normals.

c) 90 ms right ear lag

Table 9A shows the right, left and double correct scores for dichotic CV test with 90 ms REL for learning disabled and control group. The scores were again better than that obtained for dichotic CV with Oms lag for both the groups.

Table 9A : Scores of Dichotic CVs test with 90 ms right ear lag

Ear	Group	90 ms right ear lag				
		Mean	SD	Range	1Z1	Probability
Right	E	14.71	4.92	5-19	1.78	0.075
	C	18.57	2.23	15-22		
Left	E	11.43	3.15	6-16	2.20	0.028*
	C	15.43	1.99	12-18		
Double scores	E	5.0	1.41	3-7	2.37	0.018*
	C	8.86	1.35	7-11		

* Significant at 0.05 level

LD children performed poorer than normals for right and left ear and double correct scores for dichotic CV with 90 ms REL. This difference was significant at 0.05 level for left ear scores and double correct scores. The mean scores for right was 14.71, left ear was 11.43 and double correct scores were 5.0 for LD group.

A clear right ear lag effect was seen for both the groups with right ear scores being better than left ear scores. However, this difference was not statistically significant.

Table 9B : Distribution of LD children on dichotic CV test with 90 ms REL

Score	R	L	DCS
Abnormal	3	4	4
Normal	4	3	3

Table 9B reveals that more number of subjects showed poorer left ear scores and double correct scores than right ear scores.

Table 10 : No. of LD and normal children showing ear advantage on dichotic CV test

Ear	90 ms LEL	Oms	90 ms REL
Right	4	2	4
Left	3	5	3
Normals (All subject)	Left ear	Right ear	Right ear

Table 10 shows that all the normal subjects showed lag effect for 90 ms LEL and 90 ms REL conditions. At Oms lag they showed a clear right ear advantage. This was not so in the LD group. Three subjects showed lag effect in 90 ms LEL condition and four subjects showed lag effect in the 90 ms REL condition. Lag effect was not seen in other subjects. In Oms lag condition, only two subjects showed REA and five subjects showed LEA.

A review of dichotic tests on LD children shows varied findings. A majority of the studies indicate that LD children show poorer performance in dichotic condition with CVs. (Obruzt et al, 1985; Bowen & Hynd et al, 1988; Kershner and Micaleef, 1992). These investigators have also reported that LD children show LEA on free recall. This study contradicts the study by Ganguly, Rajagopal and Yathiraj (1994) who found REA at Oms. REA in LD children have also been reported by Hynd et al (1983) Roser, Millay & Morrow (1983), and Bowen & Hynd (1988). The results of the present study support the consensus that LD children perform poorly on dichotic tasks.

All the LD subjects showed significant poor double correct scores in all three conditions, hence showing poorer auditory capacity as also found by Swanson and Cochran (1991) and Ganguly, Rajagopal and Yathiraj (1994) at Oms suggesting impaired two channel processing capacity in LD children.

The children in the present study were all right handed, but left ear advantage on dichotic test for 5 children show that they may have right hemisphere dominance for auditory signals. This is hence supporting crossed dominance hypothesis of Bryden (1970). Kimura (1961) found that left hemisphere in previewed for language and a weakness of this may lead to poorer asymnetry of perceptual discrimination. Obrzut et al (1985) hypothesized that LD children function with inadequate suppression of the non dominant hemisphere. A more clearer picture about hemisphereic asymmetry can be obtained if directed ear performance on lag condition is evaluated.

Inspection of individual data revealed that lag effect was not seen in approximately 50% of the subjects. This supports the results of investigation by Swanson & Cochran (1991) and Hynd et al (1983) who also reported absence of lag effect in LD children.

Analysis of the scores for each syllable showed that both normals and children with LD percieved voiceless syllables better than the voiced cognates in all the conditions [i.e., with and without lag]. This supports the study by Brandt and Rosen (1980) who did not find any difference between LD and normal groups in the identification of voiced and voiceless stops. Berlin et al (1973) and Ohde et al (1997) found that since voiceless sounds have longer VOTs than voiced sounds, they are perceived better than their cognates.

Thus, to conclude, the results of dichotic CV test indicate that LD children may have a dysfunction at the primary auditory cortical level.

II. PHYSIOLOGICAL TESTS

Acoustic Reflex Thresholds (ARTs)

Table 11 shows the Ipsilateral reflex thresholds for right and left ear from 500Hz to 4kHz

TABLE 11: Acoustic Reflex thresholds to Ipsilateral Stimulation

Freq.	Ear	Group	Mean (dB)	SD	Range (dB)	1Z1 scores	Prob.
500 Hz	R	E	84.29	7.32	75-95	0	1.0
		C	84.28	6.73	75-90		
	L	E	82.14	7.56	70-90	1.15	0.25
		C	86.43	6.90	80-95		
1kHz	R	E	87.14	5.67	80-95	0	1.0
		C	87.14	5.67	80-95		
	L	E	85.71	7.87	75-95	1.26	0.21
		C	90.71	4.49	85-95		
2 kHz	R	E	89.29	6.07	85-100	-0.31	0.75
		C	88.57	6.27	80-100		
	L	E	88.57	6.90	75-95	-0.54	0.59
		C	86.43	5.56	80-95		
4 kHz	R	E	95.71	4.49	90-100	0.10	0.92
		C	95.71	3.45	90-100		
	L	E	95.86	6.99	90-110	-1.36	0.17
		C	92.14	4.88	85-100		

All the learning disabled subjects had ipsilateral reflexes well within the normal limits. No differences was found between the learning disabled and the control groups.

Table 12 : Acoustic Reflex Thresholds for Contralateral Stimulation

Freq.	Ear	Group	Mean (dB)	SD	Range (dB)	Z scores	Prob.
500 Hz	R	E	91.43	14.35	70-110	-0.84	0.40
		C	86.43	5.56	75-90		
	L	E	88.57	11.80	80-110	-0.13	0.89
		C	87.14	4.88	80-95		
1kHz	R	E	93.57	12.15	80-110	-1.07	0.29
		C	89.29	4.49	85-95		
	L	E	90.71	11.34	80-110	-0.42	0.68
		C	89.29	3.45	85-95		
2 kHz	R	E	94.29	11.70	80-110	-1.36	0.17
		C	87.86	7.56	75-95		
	L	E	92.14	11.49	80-110	-1.36	0.17
		C	87.14	5.67	80-95		
4 kHz	R	E	100.0	10.0	85-110	-0.73	0.47
		C	96.43	2.44	95-100		
	L	E	97.14	11.5	80-110	0.40	0.69
		C	97.86	2.67	95-100		

Inspection of table 12 reveals that all seven learning disabled subjects also had contralateral reflexes within the normal limits. No differences was found between the learning disabled and the control group.

ART assess the CANS upto the level of superior olivary complex. No dysfunction was observed in this arc in these seven learning disabled children. This supports the finding by Greenblat et al (1983) but contradicts findings of Jerger, Martin & Jerger (1987) and Lenhardt (1981) who reported of elevated or absent reflexes. The reason for the discrepancy in results is not clear.

III. ELECTROPHYSIOLOGICAL TESTS

Electrophysiological data was analysed in terms of latency, amplitude and wave morphology. In a few children with LD, some of the potentials could not be recorded. Mean, standard deviation and range was calculated for all the potentials that could be recorded. Significant differences between mean was calculated only for ABR using Mann - Whitney - t-test. The results have been tabulated for different potentials.

1. Auditory Brainstem Response

ABR could be recorded from all the subjects with LD. Only one subject showed abnormality in latency of wave I and two subjects showed poor mophology. Fig 1 shows the sample recording of normal ABR obtained from a child with LD.

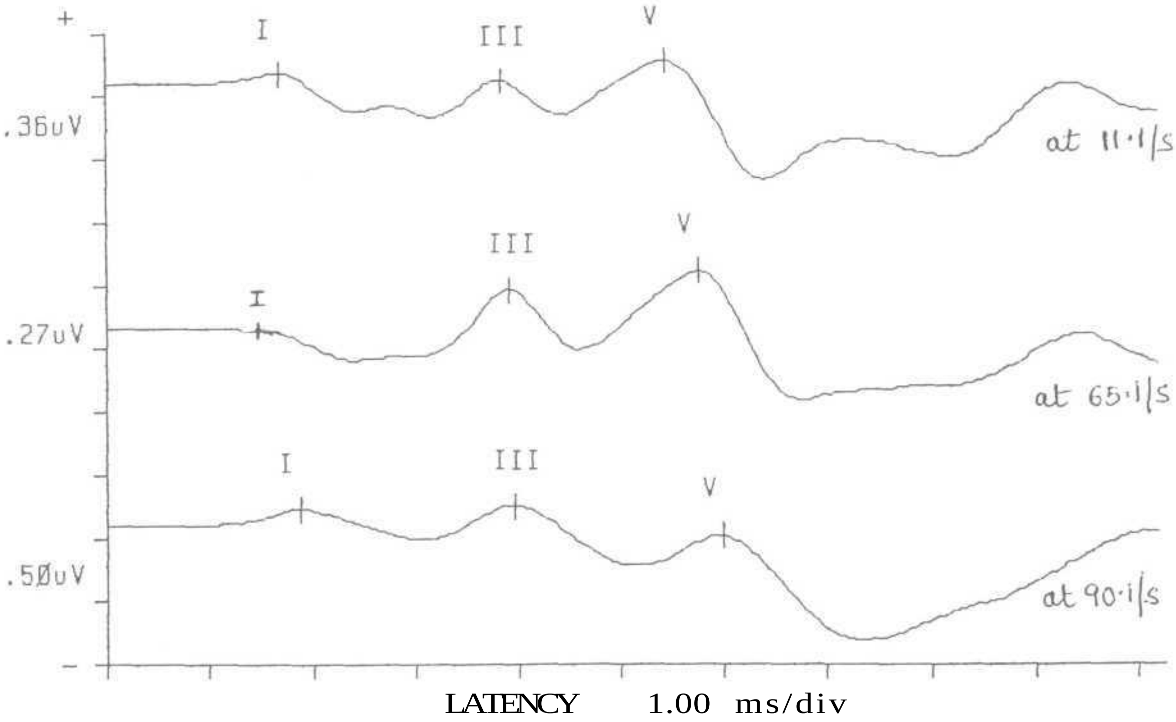

Fig 1: Normal ABR latencies at 3 repetition rates. There is increase in latency with increase in rate.

Table 13 : Absolute latency, interpeak latencies and amplitude ratios of ABR for clicks presented at rate of 11.1/s

Parameter	GP	Right		Left	
		Mean	SD	Mean	SD
I lat (ms)	E	1.63	0.12	1.49	0.07
	C	1.58	0.15	1.55	0.05
III lat (ms)	E	3.67	0.29	3.72	0.27
	C	3.59	0.21	3.69	0.13
V lat (ms)	E	5.40	0.31	5.31	0.11
	C	5.33	0.14	5.43	0.17
I-III IPL (ms)	E	2.01	0.29	2.23	0.31
	C	2.01	0.11	2.16	0.17
III-V IPL (ms)	E	1.73	0.48	1.59	0.24
	C	1.7	0.12	1.7	0.15
I-V IPL (ms)	E	3.74	0.24	3.83	0.15
	C	3.75	0.11	3.91	0.16
V/1 amp ratio	E	4.48	4.18	1.65	0.46
	C	2.76	1.49	1.59	0.51

Table 13 showed no significant differences between absolute latency of waves (I, III & V waves), interpeak latency differences (I-III, III-V and I-V waves) and V/I amplitude ratio for the LD and normal group. Interaural difference for absolute latency and interpeak difference for LD children were also within normal limits. Inspection of the individual data revealed that only one subject had increased I-V and III-V interpeak latency difference.

Table 14 : Absolute latency, interpeak latencies and amplitude ratios of ABR for clicks presented at rate of 65.1/s

Parameter	GP	Right		Left	
		Mean	SD	Mean	SD
I lat (ms)	E	1.66	0.16	1.66	0.02
	C	1.66	0.19	1.6	0.16
III lat (ms)	E	3.90	0.27	4.01	0.14
	C	3.89	0.22	4.06	0.14
V lat (ms)	E	5.77	0.15	5.79	0.15
	C	5.74	0.15	5.71	0.2
I-III IPL (ms)	E	2.19	0.15	2.32	0.23
	C	2.21	0.22	2.45	0.20
III-V IPL (ms)	E	1.86	0.28	1.79	0.07
	C	1.85	0.68	1.65	0.08
I-V IPL (ms)	E	4.02	0.23	4.08	0.23
	C	4.06	0.10	4.11	0.25
V/1 amp ratio	E	4.3	3.2	5.45	0.78
	C	2.58	1.62	2.17	1.41

Inspection of table 14 shows that even when the stimuli were presented at a rate 65.1/s, the ABR of LD children was similar to that of normals. There was no significant difference between the two groups in terms of absolute latency of waves and interpeak latency difference. Only one individual data showed increased III-V and I-V interpeak latency difference.

Table 15 : Absolute latency, interpeak, latencies and amplitude ratios of ABR for clicks presented at rate of 90.1/s

Parameter	GP	Right		Left	
		Mean	SD	Mean	SD
I lat (ms)	E	1.7	0.15	1.7	0.04
	C	1.66	0.16	1.69	0.10
III lat (ms)	E	3.97	0.13	4.10	0.26
	C	3.97	0.18	4.13	0.24
Vlat(ms)	E	5.88	0.15	5.89	0.22
	C	5.86	0.12	5.94	0.15
I-IIIIPL (ms)	E	2.22	0.89	2.3	0.36
	C	2.29	0.09	2.39	0.22
III-V IPL (ms)	E	1.91	0.14	1.77	0.17
	C	1.89	0.23	1.8	0.26
I-V IPL (ms)	E	4.13	0.12	4.02	0.23
	C	4.24	0.15	4.26	0.26
V/1 amp ratio	E	4.78	0.7	3.07	4.9.2
	C	2.14	1.37	2.5	8.49

Referring table 15, normal ABR could be recorded in children for stimuli presented at a repetition rates of 90.1/s. Only one subject showed prolonged latency for wave III and V. Therefore interpeak latency difference between I-III and III-V was increased in that subject. Wave morphnology was poor in two subjects.

Thus, the results indicated that the ABR was normal in a majority of subjects with LD. This supports the findings of Roush & Tait (1984), Jerger, Martin and Jerger (1987), Pinheiro et al (1989). One subject who showed abnormal findings had prolonged wave V with normal latency for wave I and III at low repetition rates indicating upper brainstem lesion. Poor morphology, seen in two subjects was probably due to reduced synchronous firing. Pratt and Shower (1976) have also reported poor morphology in children with LD. More abnormalities were seen at higher repetition rates. Over all rate effect is a cumulative neural fatigue and adaptation and incomplete recovery, involving not only hair-cell-cochlear nerve functions but also subsequent synaptic transmission. The effect of rate is hence additive as the number of synapses increase. (Pratt and Shower, 1976). Prolonged latencies are attributed to slower axonal propagation, increased synaptic delay on dendritic disturbance (Shomer and Student, 1978). Interpeak latency abnormalities shows delay in brainstem transmission time (Hall, 1991).

2. Auditory Late Latency Responses (ALLR)

ALLRs could be recorded in all seven subjects. None of the subjects showed completely normal ALLRs. Fig-2 and 3 show sample of ALLR recordings from LD children.

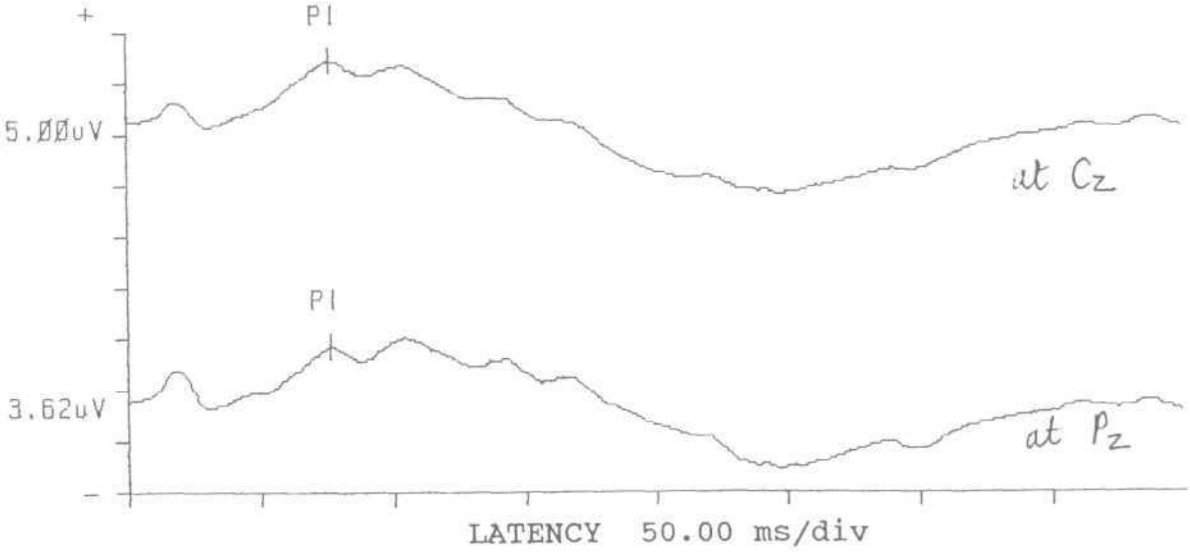

Fig 2: Showing P_1 wave and absent N_1 P_2 and N_2 waves

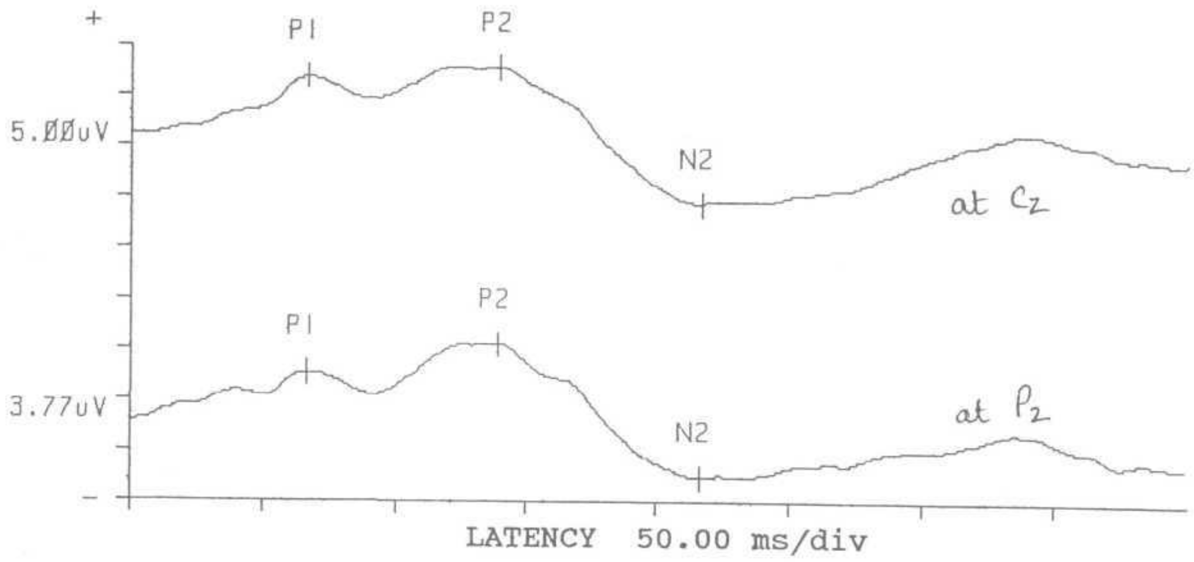

Fig 3: Showing P_1,P_2 and N_2 and reduced N_1P_2 amplitude

Table 16A : ALLR Latencies

Wave	Group	Mean (ms)	SD	Range (ms)
P,	E	69.12	6.70	60.92-74.98
	C	58.24	10.46	46.08-74.19
N,	E	82.3	2.89	80.25-84.35
	C	90.49	13.90	60.92-101.53
P_2	E	141.98	11.43	130.43-163.23
	C	146.94	19.55	133.58-185.88
N_2	E	224.93	16.79	201.5-252.26
	C	223.18	14.00	199.15-241.04
Pi-Pa	E	76.79	10.04	69.51-88.25
	C	134.18	34.75	83.57-176.51

A persual of table 16A shows that the mean latency value for P_1,N_I,P_2 and N_2 was within the normal range. However when compared with the mean value of normals, the latency of P_1 was slightly delayed. It appeared that there was early occurance of N_1 and P_2. Due to delayed P_1 and early P_2, P_1- P_2 interval was shorter than that seen in normals.

Table 17 : ALLR Relative Amplitudes

Name	Group	Mean (μs)	SD	Range (μs)
P_1N_1	E	-	-	-
	C	4.43	4.68	1.56-14.76
N_1P_2	E	6.0	0.71	5.5-6.5
	C	5.65	5.63	1.6-17.47
P_2N_2	E	9.78	2.34	7.24-13.84
	C	10.39	5.23	6.69-20.01

Inspecting table 17, it can be seen that P_1N_1 amplitude could not be calculated in any of the subjects due to absence of either P_1 or N_1. N_1P_2 and P_2N_2 amplitudes were near normal when the two group were compared.

Table 16B : Distribution of LD children on ALLR latencies

Scores	P.	N,	P_2	N_2	P,-P_2
Normal	2	-	5	4	-
Abnormal	2	4	1	2	3
Absent	3	3	1	1	4

Inspection of table 16B showed that P_1 wave was normal in 2 subjects but was abnormal in two subjects and absent in three subjects. Similar findings have been reported in literature. One child showed normal P_1 wave whereas five children had normalP_1 in an investigation by Radhika (1997). Satterfield et al (1984) and Byring and Jaryilehto (1985) also observed delayed P_1 and attributed it to delayed maturation in LD children. Longitudinal study on these children is required to check if theP_1 latency reaches normal value with maturation.

From table 16B it can be seen that N_1 was absent in three children with LD. Among the four children in whom N_1 could be recorded, all the children had poor morphology. Two children had shorter latencies when compared to the age and gender matched controls. Mason and Mellor (1984) found N_1, with shorter latencies in children with LD. Radhika (1997) reported absent N_1 in 8 out of 12 subjects and normal N_1 wave in 2 children with LD. Attention deficits can be said to be the cause of auditory processing deficits in those in which N, was absent. Earlier latency showed that LD also take shorter time to attend to the stimulus which contradicts findings which have found delayed N_1 latencies (Satterfield et al, 1984, Dawson et al, 1989; Jirsa and Clontz, 1990; Neville et al, 1993; Arehole, 1995; Tonnquist-Uhlen et al, 1996; and Radhika, 1997).

Latency of P_2 wave was normal in five subjects. P_2 could not be identified in one subject and was increased in another subject. Normal P_2 observed in a majority of LD children reflect good automatic processing of auditory signals in them. These results support the findings of Duncan et al (1994) and Radhika (1997). Korpihahti and Lang (1994) have also reported normal P_2 latency in LD children. Latency of N_2 wave was also normal in a majority of the children (i.e., 4 subjects). It was abnormal in two subjects and absent in one subject. A review of literature also shows equivocal findings in LD children. Duncan et al (1994) reported normal N_2 waves in LD children. Radhika (1997) observed that N_2 wave was normal in 10 children and abnormal in two children. Pinkerton et al (1989), Jirsa and Clontz (1990), Duncan et al (1994) and Radhika (1997) have also reported absence of N_2 in children with LD. Abnormal findings suggest that some of these children many have attentional problem due to dysfunction at the level of supra-temporal cortex (McPherson, 1996).

3. P300

Table 18 : Latency and amplitude of P300

Name	Group	Mean	SD	Range
P300 latency (ms)	E	360.0	27.07	329-379
	C	360.86	42.15	302 - 423
N_2 P300 (μv)	E	11.37	7.57	6.01 - 16.72
	C	10.87	4.69	6.69-20.84

P_3oo could not be identified in four subjects. Among the other three LD subjects, the mean latency of P_{30}o wave did not differ from the control group i.e., it was within normal limits. Mean N_2P_3 amplitudes also did not differ from the control group as seen in table 18.

Closer examination of the data revealed that only one subject had P_{300} within normal latency, amplitude and good morphology. Whereas, one subject had normal latency for P_{300} but reduced N_2P_3 amplitude and poor morphology, another subject had increased P_{300} latency, reduced N_2P_3 amplitude and poor morphology. Figure 4 and 5 show sample findings of abnormal P_{300} from LD children.

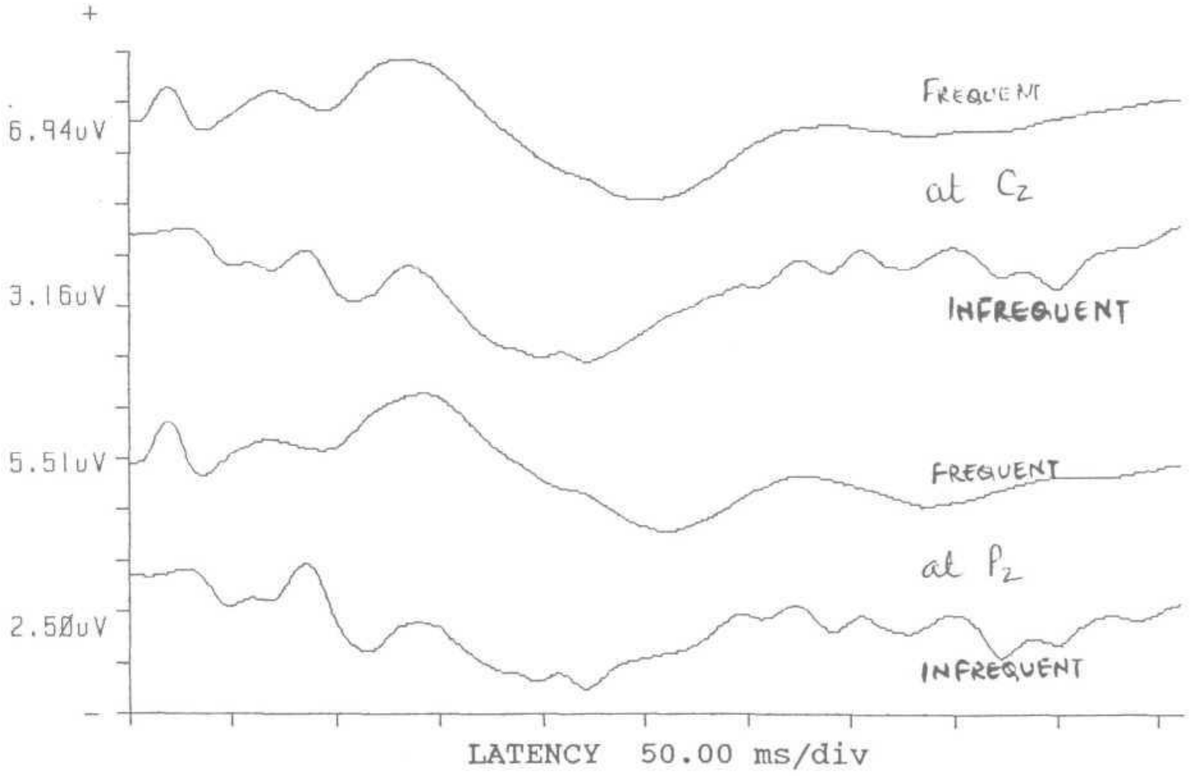

Fig 4: Showing absence of P_{300} wave.

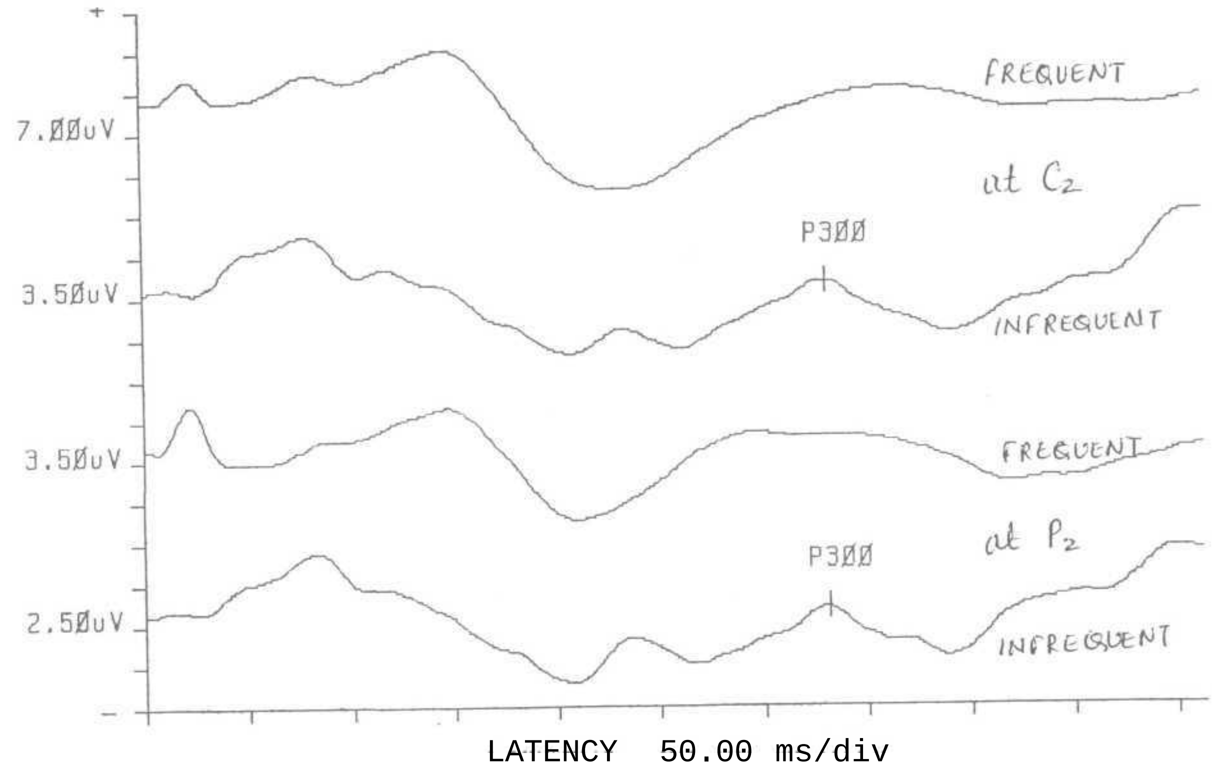

Fig 5: Showing P_{300} with poor morphology

P_{300} showing normal latencies was reported by Segalowitz et al (1992) and Radhika (1997). Absent waves were also reported by Radhika (1997) in 9 subjects in LD subjects. Increase in latency was reported by many investigators (Byring and Jaryilehto, 1985; Erez and Pratt, 1992; Mazzotta and Gallai, 1992; Neville et al, 1993; and Radhika, 1997).

Deficits in short term memory as well as overall memory performance is associated with increase in P_{300} latency (Polick et al, 1986). P_{300} latency is felt to be directly related to speed of information processing (Willis et al, 1985). Polick et al (1986) said that stimulus discrimination ability is related to P_{300} latency, hence more difficult the discrimination task, more prolonged its latency. Musiek (1989) found that prolonged latency resulted primarily from the abnormal maturational pattern rather than cognitive impairment.

Thus, it could be concluded that differences in P_{300} wave between LD and normal children reflect processing differences at higher cognitive levels. However, not all the children with LD show this deficit.

4. Mismatch Negativity

Table 19 : Absolute latency of MMN

Name	Group	Mean (ms)	SD	Range (ms)
Onset	E	156.46	73.14	78.88-224.15
	C	119.20	71.78	45.3-229.15
Peak	E	181.85	79.49	98.03-256.17
	C	149.17	77.64	56.32-263.89
Offset	E	221.81	95.18	122.62-312.4
	C	189.89	77.18	98.41-313.96

MMN was present in three LD subjects and absent in four subjects. The group data (Table 19) showed an increase in the onset, peak and offset latencies of MMN when compared to the normal group. On closer inspection of the MMN waveform, one subject had normal MMN latencies, one showed delayed MMN and another showed very poor morphology.

Fig 6 and fig 7 show a sample of abnormal MMN obtained by the LD group.

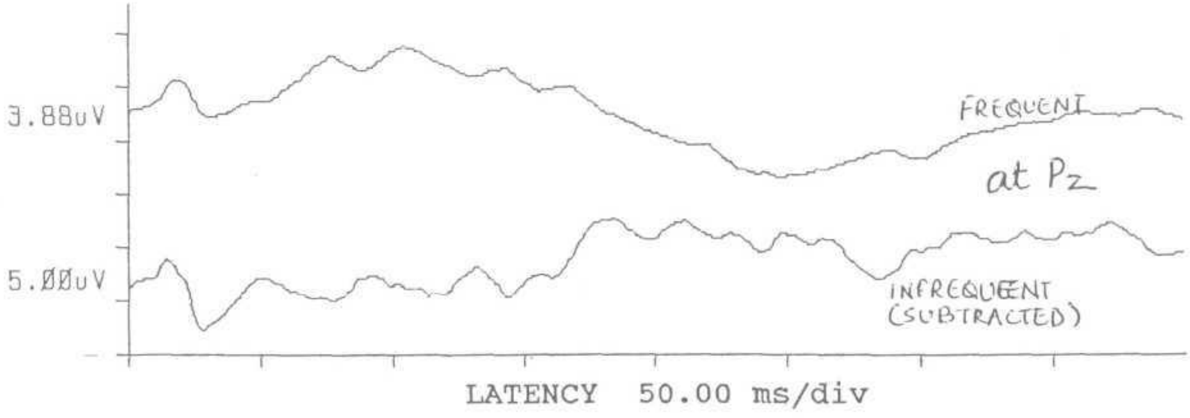

Fig 6: Showing absence of MMN waveform

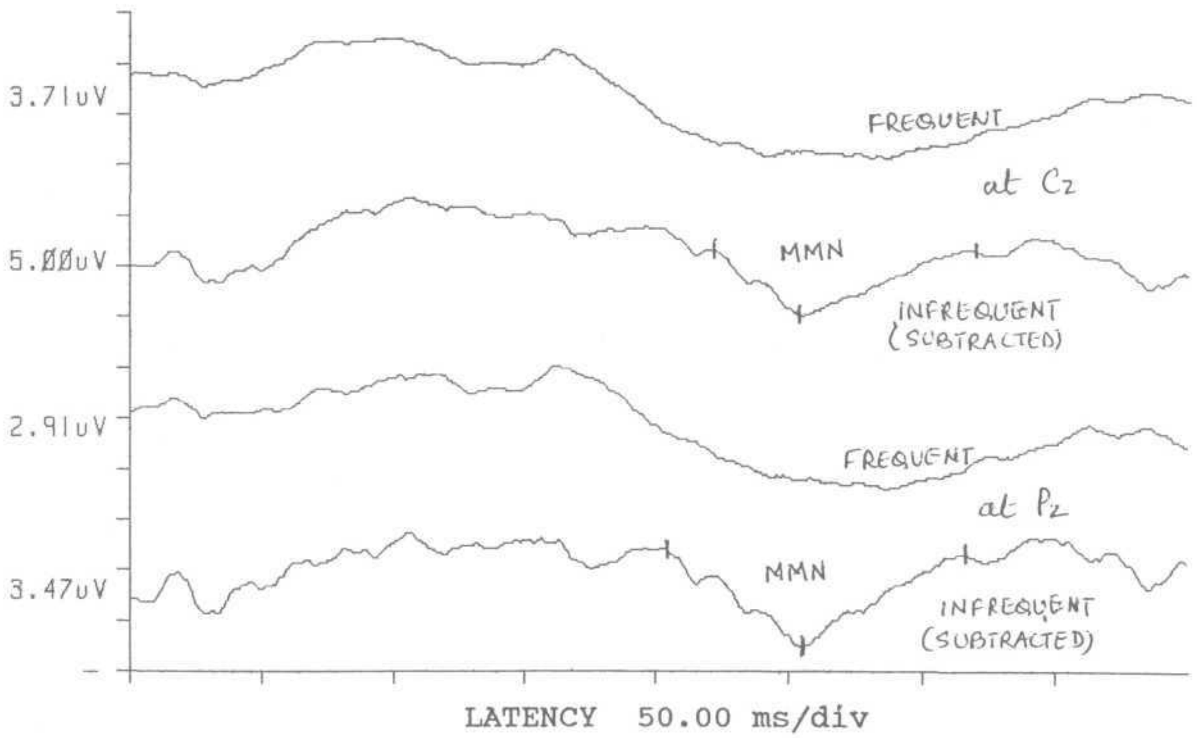

Fig 7: Showing delayed MMN waveform

Radhika (1997) found absent MMN for frequency in three of the LD subjects. Increase in latency has also been reported by Koriphahti and Lang (1994), Kemmer et al (1995) and Radhika (1997).

Table 20 : Amplitudes of MMN

Name	Group	Mean (µ,v)	SD	Range (µv)
Onset (relative)	E	4.83	2.25	2.39-6.31
	C	6.39	5.84	2.3-19.25
Peak (absolute)	E	20.32	27.44	4.41-52.0
	C	5.58	8.09	1.15-24.06
Offset (relative)	E	5.41	2.74	2.46-7.89
	C	7.68	8.98	2.98-27.78

Inspection of table 20 reveals that LD children showed a decrease in the relative onset and offset amplitudes and an increase in the absolute peak amplitude. Inspection of individual data showed normal amplitude in one subject, one showed increase and another showed decrease in amplitudes when compared to their age matched controls. Korpihahti and Lang (1994), Kemmer et al (1995), Leppamann and Lyytienn (1997) and Radhika (1997) have also reported reduced MMN amplitudes.

Table 21 : Total Duration, onset and offset time of MMN components

Time	Group	Mean (ms)	SD	Range (ms)
Onset time	E	25.51	6.27	19.51-32.02
	C	30.68	11.07	10.93-41.39
Offset time	E	39.56	15.84	24.59-56.23
	C	40.72	9.60	30.46-53.89
Total Duration	E	65.34	22.28	43.74-88.25
	C	71.41	13.73	53.11-89.82

Study of table 21 shows that LD group did not differ much from the controls in offset time. Onset time and total duration was slightly shorter than the controls as also reported by Korpihahti and Lang (1994), Kemmer et al (1995) and Radhika (1997). Only one subject showed normal duration and time..

Table 22 : Magnitude of MMN

Mag	Group	Mean (ms-µv)	SD	Range (ms-µv)
Magnitude	E	207.22	183.23	22.74-389.18
	C	377.28	445.14	61.08-1371.66

Table 22 shows the magnitude of MMN in LD and normal groups. The LD subjects showed reduced magnitude. All three LD subjects in whom MMN was recorded, MMN magnitude was reduced. Morphology was poor in two subjects.

MMN abnormalities in the subjects probably reflect delay in memory trace in time (Naatanen, 1992). Giard et al (1990) reported that this is indicative of poor listening skills in LD children, hence showing incomplete attention process as also reported by Korpihahti and Lang (1994). Hence abnormal MMN indicate deficits in sensory memory processes (Naatanen and Tender, 1991) at the level of primary auditory projection system.

IV AUDIOLOGICAL PROFILE OF LD CHILDREN

A total of ten tests were carried out on all the seven LD subjects. All the LD subjects failed on 7 or more than 7 of these tests. Table 23 gives a summary of the tests each subject failed on and the possible level as CANS

Table 23 : Audiological profile of LD children

Sl. No.	Test		Subjects P=pass F=fail						
			1	2	3	4	5	6	7
1	SPIN		F	F	F	F	F	F	F
2	MLD		F	F	F	F	F	F	F
3	Time compressed		F	F	F	F	F	F	F
4	PPST	Hum	F	P	P	F	F	P	P
		Verbal	F	P	F	F	P	P	F
5	Dichotic CV		F	P	F	P	F	F	F
6	ART		P	P	P	P	P	P	P
7	ABR		P	F	P	P	P	P	P
8	ALLR		F	F	P	F	F	F	F
9	P300		F	F	F	F	F	F	P
10	MMN		F	F	F	F	P	F	F
11	No. of tests failed		8/10	7/10	8/10	7/10	7/10	7/10	7/10

Table 24 shows the number of subjects who failed on the various tests and the level of CANS they are sensitive to.

Table 24 : Number of LD children failing on each test

SI. No.	Test		No. of subject failed (out of 7)	Level of CANS lesion the test in sensitive to
1	SPIN		7*	Cochlear, VIII Nerve, Brainstem and cortical
2	MLD		7*	Low brain stem
3	Time compressed		7*	Cortical
4	PPST	Hum	3#	High brainstem, cortical (including corpus callosum)
		Verbal	4#	Cortical
5	Dichotic CV		5*	Cortical including corpus callosum
6	ART		0°	VIII Nerve and low brainstem
7	ABR		1°	Low and high brainstem
8	ALLR		6*	Cortical
9	P300		6*	Cortical
10	MMN		6*	Cortical

* Sensitive in identifying CAPD in LD children

Sensitivity in identifying CAPD in LD children questionable

^{0} Not sensitive to identify CAPD in LD children

Inspection of table 23 and 24 reveals that all the children with LD showed poor performance on SPIN, MLD and Time Compressed Speech Test. As discussed in the earlier section SPIN is not a sensitive test for CAPD. But poor performance on MLD and Time Compressed tests indicate that children with LD have dysfunction at the level of brainstem as well as cortex. A comparison of results of various tests suggest that the performance also depend on the process that the test is tapping. For example, even though MLD indicated a dysfunction at the level of brainstem, ART was normal in all the subjects. ABR was not affected in a majority of the subjects. That is, processing of signals at the level of brainstem in individual ears was normal. But the binaural interaction of signals was affected. Probably binaural interaction component of ABR would have highlighted this aspect.

Results of PPST, Dichotic CV test, ALLR, P_{300} and MMN support the consensus that LD children form a heterogenous group Not all the tests showed abnormality in all the subjects. Nor did a single subject show abnormality on all the tests. Various investigators have found heterogeniety in LD subjects. Pinheiro (1977) found poor scores on competing sentences, PPST, SSW, simultaneous sentences but good scores on filtered speech, binaural fusion and RASP test in LD group. Investigations by Musiek and Geurkink (1980) and Greenblatt et al (1983) also reported similar findings. However, there is a difference in percentage of subjects who failed on this test. Where as Musiek and Geurkink (1980) reported that more than 70% failed on PPST, Pinheiro (1977) found that only 20% of LD children showed poor performance on this test. Musiek, Geurkink and Kietel (1982) reported that percentage of LD who showed poor performance on Dichotic CV varied from 50% to 80%. Welsh et al (1982) observed that 45% of LD children showed poor performance on time compressed speech test. Studies done on low pass filtered speech and binaural fusion tests show greater sensitivity varing from 80% to 100% (Welsh, Welsh and Healy, 1980; Willeford, 1976; Windham, 1985). These tests could be included in further studies for evaluating CAPD in LD children. There is a dearth of studies for MLD and SPIN tests. Varied results have also been obtained on ABR, ALLRs, P_{300} and MMN with few subjects showing normal (Roush and Tait, 1984; Radhika 1997) and abnormal (Welsh et al, 1982; Radhika, 1997) results. All these support the heterogeniety, of LD children as seen in this present study.

Overall, the results indicate that MLD and time compressed speech tests are more sensitive in detecting CAPD in LD children. This is followed by ALLRs both exogenous and endogenous potentials i.e. dichotic CV and PPST. ABRs and ARTs were least sensitive in detecting CAPD in LD children.

SUMMARY & CONCLUSION

Central Auditory Processing involves various processes which are influenced by higher level cognitive factors as memory, attention and learning apart from it being a preconscious activity (Jerger, 1998). Central Auditory Processing Disorder (CAPD) involve deficits in auditory decoding, integration, association and output organisation. These could be assessed using observation, by exclusion, behavioral, physiological and electro physiological tests. Central Auditory Processing Disorder may be one of the underlying deficits in children with Learning Disability (LD) (Welsh, Welsh and Healy, 1980). However, the results of various investigations of CAPD in LD children are inconclusive (Pinheiro, 1977; Musiek, Geurkink and Kietel, 1982). This may be due to the heterogeniety of LD group. Also very few studies have evaluated LD children on a battery of tests.

The present study was undertaken to evaluate CAPD in LD children using a battery of tests. Seven LD children and seven age and sex matched normal children were tested using five behavioral tests (SPIN, MLD, Time compressed speech, PPST - verbal and humming, Dichotic CV), one physiological test (ART) and four electrophysiological tests (ABR - at 11.1/s, 65.1/s, 90.1/s, ALLR, P_{300} and MMN)

The results of the study were as follows:

A. Behavioral tests

1. SPIN showed bilateral deficits in all seven subjects indicating auditory closure deficits.
2. MLD was reduced in all seven subjects indicating binaural interaction deficits.

3. Time compressed speech test showed bilateral deficits in all seven subjects indicating auditory closure or decoding deficits.
4. PPST showed bilateral deficits in three subjects for humming response and in four subjects for verbal response indicating deficits in temporal ordering.
5. Dichotic CV test showed bilateral deficits in five subjects. Both single correct and double correct scores were depressed. Majority of them showed left ear advantage.

B. Physiological test

1. ARTS were obtained at normal threshold levels showing no low brainstem involvement.

C. Electrophysiological tests

1. **ABR** were recorded with good morphology and replicability with normal latencies and amplitude for all three rates in six subjects indicating normal branistem functioning. Only one LD subject showed prolonged latency.
2. ALLRs were abnormal in six subjects. Abnormalities included the following:
    a) Three showed absence of P_1 and N_1, one showed absence of P_2 and N_2.
    b) Two showed prolonged P_1 four showed earlier N_1, one showed prolonged P_2 and two prolonged N_2.
    c) P_1N_1 amplitude could not be calculated in any subject, N_1P_2 and P_2N_2 amplitudes were more normal in all the subjects.
    d) All subjects had poor morphology.
3. P_{300} was abnormal in six subjects. Abnormalities included the following:
    a) P_{300} could not be elicited in four subjects.
    b) One subjects showed increased P_{300} latency.
    c) N_2P_3 amplitude were reduced in two subjects.
    d) Poor morphology was seen two subjects.

4. **Mismatch Negativity** was absent in four subjects and present in three subjects. Only one subject showed normal MMN. One or more of the following abnormalities were observed in the other subjects.
    a) Increase in onset, peak and offset latencies.
    b) Decrease in relative onset and offset amplitudes and normal absolute peak amplitudes.
    c) Shorter onset and total duration and normal offset time.
    d) Reduced magnitude of MMN.
    e) Poor morphology of MMN.

These results of evoked potentials showed deficits in higher cognitive functions i.e., deficits in attention and short term memory.

Results of this study showed that LD children do have CAPD. Both behavioral and electrophysiological tests were useful in evaluating CAPD in them. Physiological test was not sensitive in evaluating CAPD. Behavioral tests were more sensitive than electrophysiological tests. LD children showed auditory processing deficits involving the auditory cortex. A few subjects showed deficits at the level of brainstem and corpus callosum also. The variable results obtained in these children high light the heterogeniety in children with LD.

Limitations/ Further suggestions for the study

1. The study may be carried out on a larger group of patients.
2. A similar study may be carried out using other tests for CAPD (eg. LPFS and Binaural fusion tests).
3. Electrophysiological testing could be carried out using multiple electrode placement.
4. Binaural interaction of ABR in LD children may be investigated.

5. Different compression rates for compressed speech and time expanded speech can be studied.
6. Directed ear performance can be evaluated in dichotic CV test.
7. Monaural presentation of stimuli can be used for ALLRs, MMN & P300 to check hemispheric asymmetry.

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APPENDIX

APPENDIX - A

Monosyllabic word list la (Rout, 1996)

1. mug
2. hand
3. milk
4. shirt
5. door
6. school
7. cap
8. bed
9. foot
10. tongue
11. truck
12. bird
13. watch
14. fan
15. dog
16. purse
17. goat
18. nose
19. gun
20. house
21. lock
22. teeth-
23. sleep
24. pant
25. bus

APPENDIX -B

The 30 sequences used for PPST (Pinheiro, 1974)

H = high, L = low

1. HHL
2. HLH
3. LLH
4. HLL
5. LLH
6. HLL
7. LHL
8. HHL
9. HLL
10. LHH
11. HLH
12. LHL
13. LHH
14. HHL
15. HLH
16. LLH
17. HLH
18. LHH
19. LLH
20. LHL
21. LLH
22. HLH
23. LHL
24. HLL
25. HHL
26. LHH
27. HLL
28. LHH
29. HHL
30. LHL

APPENDIX -C

Dichotic CV stimuli at 90 ms LEL, 0 ms, 90 ms REL (Yathiraj, 1994).

	90 ms left ear lag	0 ms lag	90 m right ear
1.	ta 90 - ka	pa-ta	ka -ta 90
2.	ga 90 - da	ta-ka	da -ga 90
3.	ta 90 - ba	ka-da	ba -ta 90
4.	ba 90 - ga	ga-da	ga -ba 90
5.	ta 90 - da	pa-ka	da -ta 90
6.	da 90 - ga	ta-ba	ga -ba 90
7.	ka 90 - ba	ba-da	ba -ka 90
8.	ka 90 - ga	ba-ga	ga -ka 90
9.	ka 90 - ta	pa-ba	ta -ka 90
10.	ga 90 - ka	ta-da	ka -ga 90
11.	ba90- ta	pa-ga	ta -ba 90
12.	ga 90 - ba	da-ga	ba -ga 90
13.	da 90- ta	pa-da	ta -da 90
14.	ba 90 - ka	ka-ba	ka -ba90
15.	pa 90 - ga	ta-ga	ga -pa 90
16.	pa 90 - ta	ka-ga	ta -pa 90
17.	ka 90 - da	ta-pa	da -ka90
18.	pa 90 - ka	ka- ta	ka -pa 90
19.	ba 90 - da	da-ka	da -ba90
20	pa90-ba	ga- ka	ba -pa 90
21.	pa 90- da	ka- pa	da -pa 90
22.	ta 90 - ga	ba - ta	ga -ta 90
23.	ta 90 - pa	da-ba	pa -ta 90
24.	da 90 - ka	ga-ba	ka -da 90
25.	ka 90 - pa	ba-pa	pa -ka90
26.	da 90 - ba	da-ta	ba -da 90
27.	ba 90 - pa	ga-pa	pa -ba90
28.	ga 90 - pa	ba-pa	pa -ga90
29.	da 90 - ta	ba-ka	ta -da 90
30.	ga 90 - ta	ga-ta	ta - ga90

APPENDIX-D

Standardized spondee word list la for children (Swarnalatha, 1972)

1. birthday
2. busstop
3. football
4. playground
5. bedroom
6. blackboard
7. outside
8. sunshine
9. icecream
10. toothbrush
11. birdnest
12. sunset
13. rainbow
14. toyshop
15. hairbrush
16. daylight
17. shoelace
18. airplane
19. cowboy

;>20 ashtray

21. playmate
22. dollhouse
23. schoolroom
24. bathtub
25. doorbell