ORAL WORD READING DEFICITS IN INDIVIDUALS WITH CEREBELLAR LESIONS

Register No. 06SLP003

A Dissertation submitted as a part fulfillment of
Final year M.Sc (Speech-Language Pathology)

University of Mysore, Mysore

APRIL 2008

**ALL INDIA INSTITUTE OF SPEECH & HEARING,
MANASAGANGOTHRI, MYSORE – 570006**

CERTIFICATE

This is to certify that this dissertation entitled ***"Oral Word Reading Deficits in Individuals with Cerebellar Lesions"*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Speech-Language Pathology) of the student, Register No. 06SLP003. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any Diploma or Degree.

Mysore

April, 2008

(Dr. Vijayalakshmi Basavaraj)
Director
All India Institute of Speech and Hearing
Naimisham Campus, Manasagangothri,
Mysore-570 006

DECLARATION

I declare that this dissertation entitled ***"Oral Word Reading Deficits in Individuals with Cerebellar Lesions"*** is the result of my own study under the guidance of Dr. R. Manjula, Professor of Speech Pathology, Department of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other university for the award of any diploma or degree.

Mysore

April, 2008 Register no. 06SLP003

CONTENTS

ACKN0WLEDGEMENTS

My deepest gratitude to my Mentor, Dr. R. Manjula. Ma'am, thanks for all that you have been to me. This work would not have seen its shape but for your inputs and guidance. My earnest thanks for being an incessant source of encouragement since the first endeavor of my clinical conference till date. Your words of motivation have brought me quite far! I owe my academic growth to you.

Appa, Amma, Priya, Paati and Kannamma Paati, we make the best family. Don't we? 'Thanks' is too small a word for all the faith you have in me. 'Thanks' is too small a word for feeling proud even for the smallest of my achievements. I could not have asked for anything better in my life than you all. Love you loads. You mean the world to me!

Prabha Athai and Sundar Athimber, It's a blessing to have you around. Thanks a million for your selfless help in my subject hunt! You are true darlings!

I thank Dr. Vijayalakshmi Basavaraj, Director, AIISH, Mysore, for permitting me to carry out this study.

I am grateful to Dr. K. S Prema for her inputs in the design. Ma'am, you have been a great source of inspiration. Thanks for being so lovely.

My heartfelt thanks to all the participants of the study for their co-operation.

My due thanks to Dr. Balamurugan, Apollo First Med Hospital, Chennai, and Dr. Murali, Voluntary Health Services Hospital, Chennai for providing me the subjects for data collection.

I express my heartfelt thanks to Mr. L. N Reddy, Apollo Hospital, Chennai; Mr. Louis, Christian Medical College, Vellore; Mrs. Radha and Mr. Manimozhi, Malar Hospital, Chennai; Mr. Sreenivasan, Vijaya Health Centre, Chennai; Mr. Kamaraj and Maggie, Meenakshi Medical Mission, Madurai, for their immense help in the data collection.

I am highly indebted to all my teachers at AIISH. In particular, the expertise possessed by Dr. S.R. Savithri, Dr. R. Manjula, Dr. K.S Prema, Dr. Asha Yathiraj, Dr. K.C. Shyamala and Dr. C.S Vanaja is deeply acknowledged. I admire you all for what you are!

Dr. N. Sreedevi, Ms. K. Yeshoda, Dr. K. Rajalakshmi, Mrs. Vasanthalakshmi, Dr. S. P. Goswami, and Mr. Brajesh Priyadarshi, thanks for all the love and support. You all made my stay at AIISH worth it!

My sincere thanks to Mrs. Vasanthalakshmi for her help with the statistics. Ma'am I'm dumbstruck with the dedication you show in your profession!

I am grateful to the teachers at my Alma Mater, SBOA School and Junior College, for the strong base they have laid in me! I'm proud to call myself an SBOA product!

Shubha aunty, thanks for all the love and care! Time spent with you never made me miss home.

Poorna, my vocabulary fails me to express what you mean to me! Thanks for being there just for me whenever I wanted you the most! Will miss you greatly!

Janani, Sree and Anagha, the best gems in the treasure of friends I have found! Have relished each and every facet of the friendship we share. Will miss you loads!

Chithra, Anu, Karthi and Harini you made my stay at AIISH wonderful sharing a warm friendship. The bond we share is unique in its own ways. Will miss you lots!!

Abhi, Asha, Ceci, Hema, Kavitha, Kishore, Maggie, Mauly, Prasi, Prati, Ramia, Rubi, Sangu, Shasha, Selvi and Sumitha, this short period of six years of our relationship has made me rich a six-hundred times! You all have given the perfect connotation to what Friendship means!! Love you all lots! Will miss you all!

SimSom, Radhu and Preethi, found great friends in you. Your mere presence has always kept the class so lively. Will miss you lots!!

Santosh, Vijay Mohan, Vijay Shankar, Manuj, Vignesh, Jijo, Ankit, Swati, Rajani, Neha and Anjana, you guys gave a great company! Thanks for all the fun!

Special thanks to Simmy and Neha for being superb posting partners. AIIMS, no words for you all! Time spent with you has been one of the most memorable part of my life.

Radheesh, have learnt a lot from you. You make one of my best buddies! Thanks for all the care and support!

I thank the Symbionts for the fond memories that I would take back home! We just rock, any day!!

Sriram, Vivek, Naresh, Kuppu, Arun, Antony, Gnanu, Priyashri, Navitha, & Sruthy, it was more than a life time pleasure to have spent time with you all. Your company has always kept me moving! Thanks for the love and affection. My best Wishes to you.

Chaya, KD, Sumesh, Nambi, Nitish, Gopi Shankar, Gopee Krishna, Srikanth, Uday, Rahana, Priya, Bhuvana, Savitha, and Yatin, it was brilliant knowing you all. Thanks for all the support!

My love to all the tiny tots of AIISH Therapy Clinic, Varsha in particular for bringing a smile in our faces, whatever state of mind we were in.

My warm thanks to Mrs. R. Rajalakshmi, Mr. Shivappa, Mr. Ramaswamy, Mr. Mahadeva and Jaggu for their support throughout.

Committing the greatest folly of missing a lot of other silent contributors, I thank GOD for his blessings!

INTRODUCTION

Cerebellum is one of the most important structures that has anatomical and functional significance in the evolution of human brain. The cerebellum is located in the posterior fossa of the skull, inferior to the occipital lobe and dorsal to the pons and medulla, separated by the aqueduct of the Sylvius and the fourth ventricle. Anatomically, it is divided into three distinct areas namely, the vermis (the region in and around the midline) and the paravermis (the intermediate zone), while the reminder is referred to as the cerebellar hemispheres.

A lesion to the cerebellum leads to deficits in co-ordination and voluntary control of movement. Lesion to the cerebellum also causes a specific type of dysarthria named Ataxic Dysarthria. Darley, Aronson & Brown (1969a), identified imprecise production of consonants, excess and equal stress, irregular articulatory breakdown, distorted vowels and harsh quality as cardinal symptoms of ataxic dysarthria.

The cerebellum has been traditionally seen as part of the motor central nervous system responsible for initiation and co-ordination of motor movements, receiving stimuli primarily from the motor cortex, vestibular organs and propioceptive receptors (Strick and Middleton, 1994). However, recent evidences have pointed to additional roles of cerebellum which is not restricted to motor control alone. Neuro-imaging investigations of linguistic processing in the recent past have further supported the functional role of cerebellum. Various studies including that of Martin, Hexby, Lalonde, Wiggs & Ungerleider, 1995;

Schmahmann & Sherman, 1998; Fabbro, Moretti & Bava, 2000; and Cook, Murdoch, Cahill & Whelan, 2004 have reported various linguistic aspects that are affected when there is a lesion in the cerebellum. One such linguistic faculty of significance that cerebellum is believed to mediate is reading.

Reading is a neuropsychological domain involving sensory, semantic, morpho-syntactic, phonological attributes. It involves various levels of representations of which cerebellum is believed to take part in a wide array of functions. Investigations of Moretti, Bava, Torre, Antonello & Gazzato, (2002), and Eckert, Leonard, Richards, Aylward, Thomson & Berninger (2003) have suggested a strong correlation between cerebellar lesions and consequent reading disturbances.

Need for the Study:

Although many studies have addressed cerebellar involvement in reading, through neuro-imaging paradigms, behavioral data is relatively scanty. A study to analyze the reading deficits following cerebellar lesions using neuro-psychological tests is required to understand the deficits precisely.

Vandana (2007) reported lesion specific deviations in the speech-motor functions mediated by the cerebellum. This raises question of lesion specific deficits if any in the reading domain as well Marien, Saerens, Nanhoe, Moens, Nagels, Pickut, Dierckx and DeDyen, (1996) proposed that right cerebellar hemisphere mediates linguistic functions. Is this true with the reading faculty as well? This study hence attempts to derive answers to these issues by assessing reading functions in individuals with cerebellar tumors and to investigate if there are differences if any in the performance of individuals with left and right cerebellar lesion.

Aims of the study

1. To assess the oral word reading functions mediated by the cerebellum through a behavioral test paradigm.
2. To investigate for differences in oral word reading with respect to the left and right cerebellar hemispheric lesions.

Method

The method incorporated the development of a protocol to specifically assess oral word reading functions (Appendix 1). Structure of the test of Analysis of Acquired disorders of Reading in Kannada (Karanth, 1984) was reviewed in the process of the development of the protocol. The protocol consisted of the following tasks

1. Visual Discrimination
2. Lexical Decision
3. Synonym Judgment

4. Reading words (High and low imageable words, high and low frequency words)
5. Reading non-words (legal and illegal)

The words in the protocol were selected from standard Tamil text books and Tamil Phonetic Reader (Rajaram, 1975) and were further subjected to familiarity testing by native Tamil speakers.

The subjects included four individuals with a history of tumor in the left cerebellar hemisphere, three individuals with a history of tumor in the right cerebellar hemisphere and thirty normal controls matched for age, sex and education as control subjects. The protocol was administered on the subjects individually in a distraction-free environment and the responses were noted in a response sheet.

Quantitative and qualitative analysis of the data was carried out and statistical analysis was executed. Results are discussed in the perspectives of the differences in performance of subjects with left and right cerebellar tumors as compared to the normal subjects.

Implications of the study:

1. The outcome of the study will help in gaining insights regarding the functional control of cerebellum in reading; in particular it would facilitate understanding of differential function of the two cerebellar hemispheres for different tasks used to assess oral word reading deficits. .
2. The outcome of the study will also help in promoting the need for inclusion of activities of reading in the assessment and treatment of individuals with cerebellar lesions in speech-language therapy clinics.

Limitations of the Study:

1. The study included only seven subjects in the experimental group
2. Auditory processing deficits if any were not assessed.
3. Effect of word-length of the stimuli on performance of subjects was not evaluated.

REVIEW OF LITERATURE

Reading is a complex activity that usually involves the perception of printed visual stimuli to which meaning is attached following cognitive processing. The perisylvian region of the left-hemisphere is thought to support much of normal language function, and a significant number of studies have investigated how visual information for reading is processed in co-ordination with language centers during written-word comprehension and oral reading. These have included studies on acquired dyslexia, which attempt to understand the neuroanatomical correlates of sub components of reading. Amongst other neuro-anatomical regions, which play a crucial role in processing reading and reading related information, the cerebellum is included as one of the structures of significance to reading functions.

Cerebellum is a part of the central nervous system which is responsible for initiating and regulating movements, receiving stimuli primarily from the motor cortex, vestibular organs and propioceptive receptors (Strick and Middleton, 1994). The phylogenetic origin of the human cerebellum is reported to have evolved in two ways, (a) by increasing the population of nervous cells and dendritic processes, and (b) by an increase in the connections that link the cerebellum to pre-frontal cortex, thus suggesting that for information processing, the cerebellum acts quickly and in adjunct to the cerebral cortex (Leiner, Leiner and Dow, 1986).

Cerebellar Functions in Language and Cognition:

An understanding of the functional role of cerebellum with respect to motor coordination issues has overshadowed that of the linguistic functions mediated by the cerebellum. Various studies in the last few decades have attempted to identify the linguistic deficits associated with cerebellar lesions. These studies have pointed to evidences, which challenge the issue of cerebellar involvement in motor coordination alone. Riva and Giorgi (2000a, 2000b) analyzed the specific functions of both the cerebellar hemispheres and vermis in controlling the cognitive, language and executive functions of children who had undergone surgical removal of either a cerebellar hemispheric tumour or a vermal tumour. While the impact of both a right and left hemispheric lesions were considered separately, Riva and Giorgi (2000b) reported that groups with either left or right involvement were observed to show varying degrees of reduced ability in thinking flexibility and problem solving, suggesting a dissociation of circuits connecting the cerebellum to the supratentorial associative areas through the thalamus. With respect to the right hemispheric lesions, Riva and Giorgi (2000a) found that patients with right cerebellar tumors, exhibited disturbances in auditory sequential memory, an alteration in the processing of verbal intelligence and complex language tasks, deficits in spatial and visual sequential memory, a diminished capacity to process non-verbal tasks. Riva and Giorgi (2000b) also reported that few children with right hemispheric cerebellar tumour, demonstrated decreased verbal intelligence, significantly poor syntactic comprehension, deficits in verbal sequencing and impaired categorical memory. Scott, Stoodley, Anslow, Paul, Stein, Sugden et al. (2001) also supported a relationship between right cerebellar lesions and language, documenting an association between damage to the right cerebellar structures and a plateauing in verbal and literacy skills in children with cerebellar tumour.

Peterson, Fox, Posner, Mintun and Raichle (1998) reported the involvement of cerebellum in non-motor language through PET studies. The experimental paradigm required the subjects (1) to repeat a visually presented noun (motor task) and (2) to generate a semantically associated verb for a visually presented noun and to say this verb aloud (cognitive and motor task). Subtracting motor activation of the first task (motor) from motor activation of the second task (cognitive and motor) allowed for identification of activated areas during cognitive word association. The tasks which reflect on the capacity to generate words according to a given rule, are generally considered to depend on a close cooperation between verbal and executive abilities. During mere verbal-motor performance, the superior anterior lobe of the cerebellum was found to be activated and this was just lateral to the loci involved in finger and eye movement. The verbal association task activated the inferior lateral part of the right cerebellum, which projects to the left prefrontal language areas. Despite variations in the task and method, several studies have consistently shown activation of the right lateral cerebellum during word generation tasks (Fox, & Petersen, 1994)

A simultaneous activation of the right cerebellar hemisphere and the contralateral Brodmann areas 44 - 45 during word generation was reported and this was explained as due to an accelerated transmission of signals between these two regions during word finding (Leiner, Leiner & Dow, 1986). In another study, a silent verbal fluency paradigm during an fMRI study in a left- and a right-handed normal subject demonstrated an activation of the left fronto-parietal cortex and the right cerebellar region (Hubrich-Ungureanu, Kaemmerer, Henn & Braus, 2002). This led to the impression that the cerebellar activation is contralateral to that of the frontal cortex even under conditions of different language dominance. Clinical studies on patients with cerebellar disease further confirmed the implication of the right cerebellum in word production. Fiez, Peterson, Cheney & Raichle (1992) described a patient with an extensive cerebellar infarct in the territory of the right posterior inferior cerebellar artery who, in the absence of any other structural brain abnormalities, manifested semantic retrieval deficits despite good conversation skills. A study of verbal fluency in cerebellar patients demonstrated that cerebellar injury impairs verbal fluency by perturbing phonemic rule performances in particular while sparing semantic rule functioning (Leggio, Silveri, Petrosini & Molinari, 2000)

Silveri, Leggio & Molinari, (1994) reported that in two patients, a right cerebellar lesion caused agrammatism but in two other patients reported by Marien, et al. (1996) a right cerebellar stroke caused aggramatism with extensive linguistic impairments. These evidences broadened the implication of the right cerebellar hemisphere in non-motor language functions. Fabbro, Moretti and Bava (2000) reported lexical access and morphosyntactic defects in four patients suffering from cerebellar mass lesions. suggesting that the deficits might be due to an impairment of language control processes rather than an alteration of language components.

Studies have suggested that the cerebellum acts as an intensifier of neural responses, coordinating the selective attention, direction and, as a consequence, aiding in the execution of commands generated in the cortex in order to stimulate and inhibit different sources of information. Patients with cerebellar lesion, when subjected to tests of hearing attention, presented impairment in the subtle change of attention required between a visual and an auditory stimulus, suggesting that the cerebellum may somehow affect the voluntary control of a specific cognitive operation, thus contributing in the fast and accurate change of attention, without the participation of the cerebellar motor control function (Courchesne, Muller and Allen, 1998).

Word generation and production difficulties (Martin, Hexby, Lalonde, Wiggs & Ungerleider, 1995), grammatical difficulties including aggramatism (Schmahmann & Sherman, 1998; Fabbro, Moretti and Bava, 2000), reading and writing difficulties (Fabbro, Moretti and Bava, 2000), naming and word finding difficulties (Fabbro, Moretti and Bava, 2000, Cook, Murdoch, Cahill & Whelan, 2004), lexical decision tasks (Kiehl, Liddle, Smith, Mendrek, Forster and Hare, 1999), semantic functions (Mummery, Patterson, Hodges and Price, 1998; Vandenberghe, Price, Wise, Josephs & Frackowiak 1996) following a lesion to the cerebellum have been reported in the literature.

Studies support the view that cerebellum contributes significantly to executive functions such as mental planning, sequential reasoning, and mental operations closely associated with the functional role of the pre-frontal cortex (Hallett & Graffman, 1997). Keele and Ivry (1991) demonstrated that the cerebellum seems to act as an ‘internal clock’ during any process requiring temporal computations. A dysfunction of cerebello-thalamo-cortical pathways can disrupt selective attentional processes (orienting, distributing and shifting attention). Attentional processes largely depend on coordinated interactions between the reticular activating system and the frontal and parietal lobes (Shulman and Petersen, 1993). The linguistic functions mediated by the cerebellum are summarized in Table 1.

Table 1: Cerebellar involvement in Linguistic Functions

Investigators	*Function*	*Cerebellar activation*
Paulesu, Frith & Frackowiak (1993)	Pseudo-word reading and rhythm judgment	Bilateral activation
Price, Moore & Frackowiak (1996)	Visually presented word naming	Bilateral activation
Herbster, Mintun, Nebes & Becker (1997)	Reading aloud	Bilateral activation
Furey, Pietrini, Haxby, Alexander, Lee, VanMeter, Grady, Shetty, Papoport, Schapiro & Freo (1997)	Working memory for faces	Right activation
Price & Friston (1997)	Silent reading and reading aloud	Right activation
Mummery, Peterson, Hodges & Price (1998)	Semantic decision	Left activation
Kiehl, Liddle, Smith, Mendrek, Forster & Hare (1999)	Lexical decision on words	Bilateral activation
Perani, Cappa, Schnur, Tettamanti, Collina, Rosa & Fazzio (1999)	Lexical decision on nouns and verbs	Right activation

Buckner, Koutsaal, Schater & Rosen (2000)	Word generation	Right activation
Etard, Mellet, Papathanassiou, Benali, Houde, Mazoyer, Tzurrio-Mazoyer (2000)	Naming	Right activation
Ruby & Decety (2001)	Sentence generation	Right activation
Majerus, Collete, Linden, Peigneux, Laureys, Delfiore, Degueldre, Luxen & Salmon (2002)	Word and Non-word passive listening	Bilateral activation

Role of Cerebellum in Reading

Of the linguistic functions the cerebellum mediates, reading is a domain that has enjoyed significant research interest. Reading is the process of extracting meaning from print that involves both visual-perceptual and linguistic faculties. This complex neurocognitive activity involves multimodal component operations and requires the use of widely distributed areas of the brain. In brief, reading must begin with sensing of visual stimuli and processing of information through the pathway of retina, lateral geniculate nuclei and primary visual cortex (Kandel, Schwartz and Jessel, 2000). The process of reading has been understood by extensive use of brain imaging and through cognitive models.

Reading Mechanics

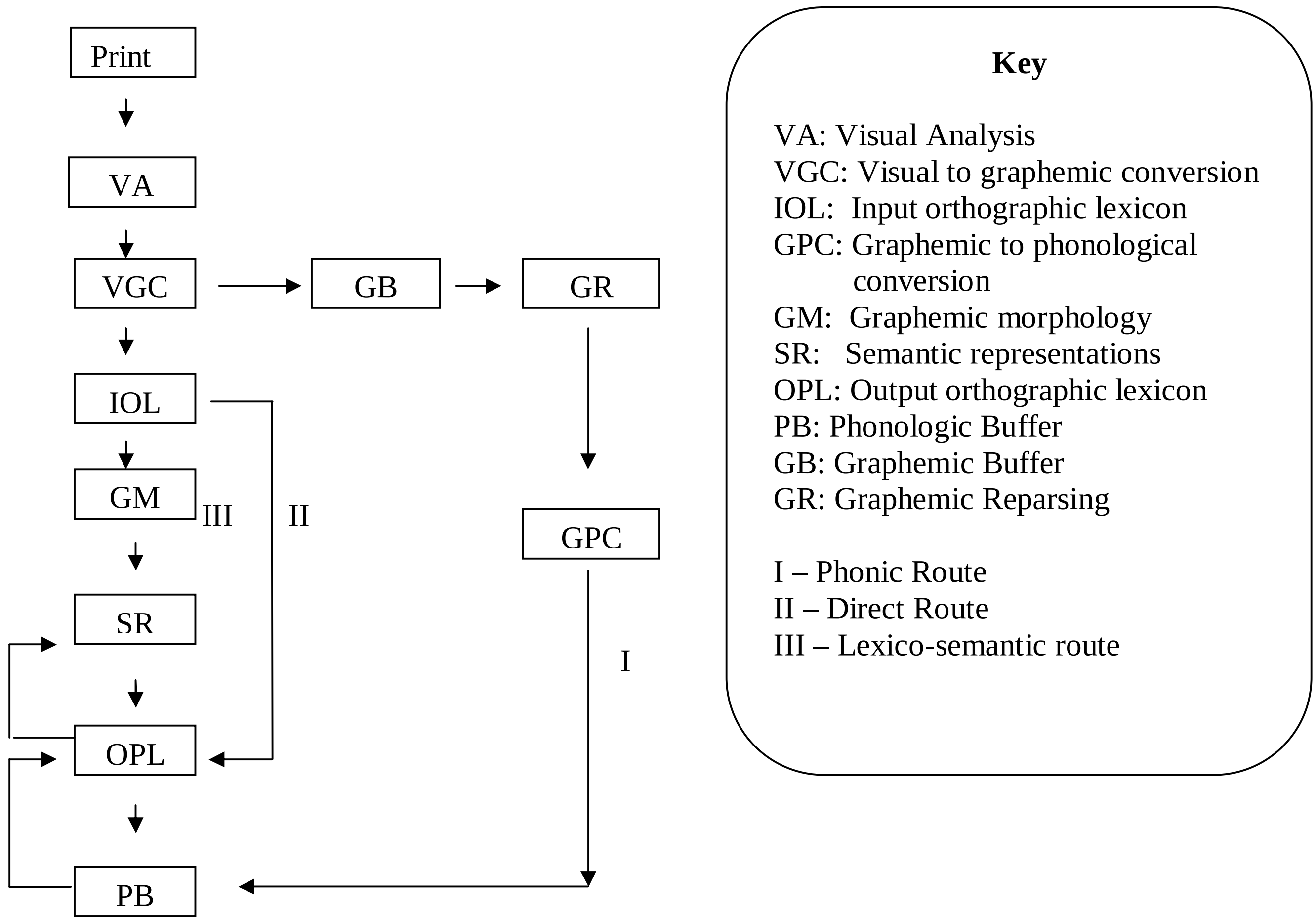
During reading, eye moves forward in a series of movements called saccades. The saccade is a ballistic movement, once launched forward, the eye must come to rest at some point, however briefly, and its movement cannot be altered in mid-movement. During these motions, no information from the page can be gathered. Following the saccade, the eyes are fixed at one point on the page and during this fixation, the eyes are relatively motionless and the cognitive processes work. Typically, readers fixate for approximately 200 to 250 msec, and the saccade can be accomplished in 10 to 20 msec. Just and Carpenter (1980) suggested that occasionally, a reverse saccade is launched, called regression. Regressions are launched when the reader detects difficulties in comprehension requiring re-access to previously presented material. They also distinguish between the fixation and gaze duration, the time summed over fixations. The cognitive-linguistic processes that take their function are explained through various models that explain normal reading process.

Marshall's model (1987) postulates three quasi independent, parallel routes in which the form, meaning, and pronunciation of a printed word are determined. Visual analysis determines the features and featural pattern of the text. These featural patterns are next assigned to their ultimate graphemic categories by the visual-to-graphemic conversion (VGC) routine. Marshall's theory proposes, the graphemic code as visual, but non-phonological, and abstract. Thus the line and contour segments have been acquired by the visual and cognitive systems and have been assigned to a grapheme. But these conglomerates of segments have not yet been named by the cognitive system with their specific letter names. At this place in the system, multi-letter strings are represented explicitly by their component letters.

The phonic route begins when the code is passed to the graphemic buffer (GB) and here the letters are given their specific names. From the graphemic buffer, the code is passed to the graphemic reparser (GR) where the code is reanalyzed into its graphemic chunks. These chunks are letters or multiletter strings that map onto a single phoneme. In the graphemic to phonological conversion (GPC) routine, the recoded grapheme will be assigned to its most prevalent phonological representation and is passed to the phonological buffer (PB).

In the direct route, from the Visual to grapheme conversion (VGC), the code also is passed to the input orthographic lexicon (IOL). This routine is the typical word-recognition device that underlies explanations of 'sight vocabulary'. This code can be transferred intact to the output phonological lexicon (OPL), which is repository for phonological information of all words that can be identified by the IOL. The third route i.e. the lexico-semantic route is used to know the word's meaning. After a letter string is recognized as a word by the IOl, it is passed to the graphemic morphology (GM) routine where operations are engaged that produce a morphological code suitable as an input for the semantic representation (SR route). This routine looks up the meaning of each morpheme in the string and passes this representation to OPL, which assigns a phonological representation to the code. Thus a printed word is read. Fig. 1 represents the Marshall's (1987) model.

Fig. 1: Marshall's (1987) model of reading architecture



The process of feature extraction takes place prior to the action of the cognitive routes aforementioned. The feature extraction process is that through which individual features of the letters of the target word is recognized e.g., a curve in the letter 'C' and a line in the letter 'N' etc. The Interactive Activation and Competition Model proposed by McCleland and Rumelhart (1981) incorporates the feature extraction process. The model suggests of many simple processing units arranged in three levels. There is an input level of visual feature units, a second level where units correspond to individual letters, and an output level where each unit corresponds to a word. Spreading activation takes place through which visual word recognition takes place. Accordingly, each unit is connected to each unit in the level before and after it. Each of these connections is either excitatory if appropriate or inhibitory if inappropriate. Initially, the visual feature extraction process takes place and based on the activation or inhibition of individual units, letter strings are recognized and eventually, the word is ‘read’.

Models incorporating the dual routes have provided a powerful theoretical framework for interpreting the written language performance of individuals with acquired alexia / agraphia. In particular, by specifying the functional architecture of the written language processing system it becomes possible to use the impaired and preserved reading / spelling abilities of neurological patients to identify the damaged or dysfunctional cognitive module. For instance, damage to the lexical route gives rise to surface dyslexia / dysgraphia, characterized by a disproportionate difficulty in reading / spelling irregular words (Patterson, Marshall, & Coltheart, 1985; Rapcsak & Beeson, 2004). Reading/spelling of regular words and non-words is relatively spared, however, as these items can be processed successfully by the intact non-lexical route. By contrast, damage to the non-lexical route results in phonological dyslexia / dysgraphia, characterized by poor reading / spelling of non-words (Coltheart, 1996; Henry, Beeson, Stark, & Rapcsak, 2007).

Cerebellum and Reading – Where is the bond?

At some stage, among the several stages involved in reading, visual information is probably made available to neural systems that apply learned, language-specific rules to convert symbolic images into component representations of language (Castles & Colthart, 1993) and that perhaps evolved for processing of spoken language. Reading-related cognition is accompanied by high activation of left-hemisphere cortical regions, including some areas known to be important in language processing (Eden & Zefferio, 1998). Learning to read however may also depend on other implicit learning processes, which allow acquiring and executing new motor, perceptual and cognitive skills. Thus, these processes lead to automatization of the mechanisms on which reading is based upon, such as phonological processing and the ability to automatize elementary articulatory and auditory skills, which are perhaps mediated partly by the cerebellum (Nicolson, Fawcett & Dean, 2001), and on feedback between these mechanisms.

Since the cerebellum has its connections to the visual apparatus, it probably plays a role in the initial visual processing involved in reading. Fine sensori-motor coordination is integral to the complex phenomenon of reading and cerebellum apparently plays a role in assisting this coordination using the feedback and feed-forward loops. The saccadic action involved in reading must have a coordinated action of the visual and the vestibular systems, which again is connected to the cerebellum.

Bracke-Tolkmitt, Linden, Canavan, Rockstroch, Scholz, Wessel et al. (1989) identified cerebellum’s activation in procedural learning processes. Paulesu, Frith & Frackowiak (1993) established that activation was found in the right cerebellum when subjects were performaing tasks relying on the rehearsal system implicating the role of cerebellum in functions of short term memory. Schlaug, Gab, Gaser, Zaehle and Jancke

(2003) reported that there is a multicentric cerebral neural network that participates in auditory and visual memory functions, of which the cerebellum is one of the region which integrates itself in order to carry out the tasks of memory coding, storage and recovery.

These processes are highly noteworthy in the normal reading modules implicating the significance of cerebellum in reading. Additional evidences suggested by Wallesch and Horn (1990) and Molinari, Petrosini, Misciagna & Leggio (2004) indicating abnormalities related to visuo-spatial functions following cerebellar lesions makes it intriguing to study reading functions in relation to the cerebellum. Thus, it is implicit that the cerebellum has a major role in the reading process. Various studies have investigated the role of cerebellum in reading.

Cerebellar input to reading has been studied using Neuro-imaging studies of normal individuals and subjects with reading difficulties, particularly the dyslexic population. Finch, Nicolson & Fawcett (2002) identified a significantly larger mean cellular area in the medial, posterior and the anterior lobe of the cerebellar cortex for the dyslexic subjects. Eckert, Leonard, Richards, Aylward, Thomson & Berninger, (2003), using MRI, found significant morphological cerebral alterations in dyslexic children, such as smaller right anterior cerebellar lobes, pars triangularis of the inferior frontal gyrus bilaterally and overall brain volume. All these areas showed significant correlations with reading, spelling and language measures.

In an MRI morphometric study of the cerebellum, Rae, Lee, Dixon, Blamire, Thompson, Styles, Talcott, Richardson & Stein (1998) found that, although normal controls had larger right hemispheric cerebellar cortical surface, the cerebellar hemispheres in the dyslexic subjects were symmetric. The degree of cerebellar symmetry was correlated with the severity of the dyslexic individuals' phonological decoding deficit. Those with a more symmetric cerebellum made more errors on a non-word reading measure of phonological decoding ability. Anatomical studies also found biochemical differences between dyslexic individuals and controls in the left temporoparietal lobe and right cerebellum (Rae, Lee, Dixon, Blamire, Thompson, Styles, Talcott, Richardson and Stein, 1998). These metabolic abnormalities showed that the cerebellum is biochemically asymmetric in dyslexic subjects, indicating altered development of this structure. These differences are cited as evidence for the involvement of the cerebellum in dyslexic dysfunction. Brown, Eliez, Menon, Rumsey, White & Reiss, (2001), compared the MR images of 16 clients with dyslexia with those of 14 control subjects .They found evidence of decreases in grey matter in dyslexic subjects, most notable in the left temporal lobe and bilaterally in the temporo-parieto-occipital juncture, but also in the frontal lobe, caudate nucleus, thalamus and cerebellum.

Moretti, Bava, Torre, Antonello & Gazzato, (2002), studied 10 clients with cerebellar vermis /paravermis lesions using reading tests. An increased number of reading errors were observed in these subjects and this was explained as resulting from a possible alteration of the diffuse connections between the cerebellum and cerebrocortical structures. They also concluded that acquired dyslexia due to cerebellar impairment may be due to oculomotor alteration or, more subtly, to the intimate cerebellar-encephalic projections, connecting the cerebellum to the attentive and alerting processes and to the language system. Leonard, Eckert, Lombardino, Oakland, Kranzler, Mohr, King and Freeman (2001) reported four anatomical measures that differentiate phonological dyslexic subjects from the reading-disabled and normal controls: (i) Marked rightward cerebral asymmetry, (ii) marked leftward asymmetry of the anterior lobe of the cerebellum, (iii) combined leftward asymmetry of the planum temporale and posterior ascending ramus of the Sylvian fissure and (iv) large duplication of Heschel's gyrus on the left.

Eckert, Leonard, Richards, Aylward, Thomson & Berninger (2003), also using MRI, found significant morphological cerebral alterations in dyslexic children, such as smaller right anterior cerebellar lobes , pars triangularis of the inferior frontal gyrus bilaterally and overall brain volume. All these areas showed significant correlations with reading, spelling and language measures.

Studies have largely concentrated on dyslexic children and have tried to examine cerebellum's role in reading. Consonant to this, Nicolson, Fawcet and Dean (2001) proposed the cerebellar deficit hypothesis stating an abnormality in the cerebellum as a cause of Developmental Dyslexia. Developmental dyslexics have been proven to show cerebellar abnormalities (Pavlidis. 1981).

Thus, it appears that a lesion to the cerebellum in the post-lingual period would cause symptoms similar to the language disturbances seen following cerebral lesions. Acquired dyslexia is one of the disorders caused due to the lesions in specific sites in the cortex. The review of literature on the contribution of cerebellum to language also appears to suggest a positive role of cerebellum in acquired dyslexia. However, it is not clear if the reading disturbances following a cortical lesion are akin to those manifested subsequent to a cerebellar lesion.

Various studies have suggested the possible involvement of cerebellum in a broad spectrum of reading functions. However, there seems to be a wide heterogeneity in the deficits exhibited by the dyslexic population. This warrants for investigation of lesion specific deficits within the cerebellum itself. Vandana (2007) reported a difference in the dysarthric speech dimensions in different lesion sites in the cerebellum. A possible difference could be observed with respect to linguistic functions as well. Marien et al. (1996), in a review of the non-motor functions of the cerebellum, suggested that the right cerebellum is implicated in a majority of linguistic functions. Is this true with reading as well? A study to investigate the reading deficits following cerebellar lesions in the two hemispheres and the medial vermal regions would pave way for a better understanding of the role of these sites in the cerebellum with respect to reading.

Most of the studies have majorly used objective paradigms, including MRI, PET, CT scan etc., in assessing reading functions. Not many studies have used a behavioral approach in assessing the function of reading in individuals with cerebellar lesions. The use of a behavioral test to assess reading would aid in a clear understanding of the specific reading functions mediated by the cerebellum. Also, the exact nature of the reading deficits is not clearly put-forth in the studies mentioned. It is unclear whether the acquired dyslexia following a lesion to the cerebellum mimics that seen following a cortical lesion. The results of a study addressing these issues could have significant implications in the inclusion of activities of reading in the assessment and therapy for individuals with cerebellar lesions. Also, it would have a bearing on the understanding of the functional connectivity of the cerebellum and the other regions of the brain.

METHOD

The study attempted to investigate word reading deficits if any in individuals following a lesion to the cerebellar hemispheres. An Ex-Post facto design was incorporated where in, individuals with history of cerebellar tumor were included as subjects. An assessment protocol was developed which comprised items to examine visual and linguistic domains in the process of reading.

Subjects: There were two groups of subjects

Group I (Experimental Group) – 7 subjects diagnosed as having cerebellar tumors in the left or right hemisphere. They were sub-grouped into 2 groups:

Group I a - 3 subjects with tumor in the right cerebellar hemisphere,

Group I b - 4 subjects with tumor in the left cerebellar hemisphere

Group II (Control Group) - 30 normal individuals matched for age, sex and educational background of the experimental groups were included in order to establish confidence levels for the items included in the protocol which was specifically developed for the study. Thirty normal subjects were equally divided in the range of 20-30, 30-40 and 50-60 years with 10 individuals (5 M and 5F) in each age range.

The demographic details of the experimental subjects are shown in Table 2.

Table 2: Demographic details of the subjects

Groups	*Patient*	*Age/Sex*	*Type of tumour*
Left Cerebellar Tumor	SM	60 years/Male	Astrocytoma
	DR	36 years/Male	Medulloblastoma
	IW	23 years/ Female	Lymphoma
	NA	22 years/Male	Astrocytoma
Right Cerebellar Tumor	MS	46 years/Male	Tuberculoma
	MV	52 years/Female	Astrocytoma
	GD	30 years/Female	Medulloblastoma

Subject selection criteria:

Group I

1. Age range of the subjects was as follows:
    a. Individuals with Left Cerebellar tumors: 22 - 60 years with a mean age of 35.25 years
    b. Individuals with Right Cerebellar tumors: 30 - 52 years with a mean age of 42. 67 years.
2. Education: The qualification of subjects varied from matriculation to graduation. The subjects were proficient in reading and writing and had good literacy skills pre-morbidly (as assessed through case history profiles of the subjects).
3. The native language of all the subjects was Tamil.

4. All the subjects had no pre-morbid or post-morbid history of visual and auditory impairments but for one client who had a mild hearing loss at 8 KHz on Puretone audiometry. It was unclear if the hearing loss was pre-morbid or post-morbid. However, it was ensured that the client had no difficulty in listening to the instructions given by the investigator during testing.
5. All the subjects were diagnosed as having cerebellar tumor (as shown in Table 2) by an experienced neurologist after an MRI / CT scan testing in a neurological set up.
6. The subjects were not operated for the tumors. They were however prescribed drug therapy. None of the subjects were put on radiation therapy.
7. The subjects presented mild dysarthria as tested on a 7 point rating scale by a Speech-Language pathologist. The scale originally developed by Vandana (2007) was adapted for the purpose.
8. The protocol of the study was administered within 4 months of the onset of the symptoms.

Group II (Control):

The normal subjects presented no history of speech, language or any neurological problem as assessed through informal screening test and the administration of Mini Mental Status Examination (Folstein, Folstein &, McHaugh 1975). Absence of soft neurological signs was also ensured through interview and based on history.

Stimuli

A Protocol (Appendix 1) to assess the oral word reading deficits was developed. The protocol consisted of the following items:

Table 3: Tasks in the Protocol to assess Oral Word reading deficits in Tamil

Task	*Number of items*
1. Visual Discrimination task	15
2. Reading words	
a. High imagebale and low imageable words	20 (10 + 10)
b. High frequency and Low frequency words	20 (10 + 10)
3. Lexical decision task	20
4. Synonym judgment task	15
5. Reading non-words – Legal and illegal non-words	20 (10 + 10)

Development of the Protocol

The protocol included different tasks selected from the Tamil Phonetic Reader (Rajaram, 1975). Also, structure of the test Analysis of Acquired disorders of Reading in Kannada (Karanth, 1984) was kept as the basis for the construction of the protocol. All the target words selected represented the syllables which commonly occurred in Tamil namely VC, CV, CCV, CCCV. The words varied from monosyllable to tri-syllable. The items in each task of the protocol (Refer Appendix 1) were developed with the following considerations:

1. *Visual Discrimination:*

The stimuli were arranged in 5 columns namely A, B, C, D and E. The column A consisted of target words and columns B to E consisted of the target word and 3 distracters. The subjects were required to identify the target word (in column A) from the four options given in columns B to E. The three distracters were formed with the following rules:

a. Transposition of two of the syllables
b. Words with visual similarity to one of the graphemes in the target word
c. Reduction or elongation of a vowel of the target word.

An example of the stimulus is as follows.

A	B	C	D	E
rhtp sa:vi Key	fhtp ka:vi	rhtp sa:vi	thrp va:si	rtp s∂vi

2. *Imageability and reading aloud*

Two lists of ten words each, one with words of high imageability and one with those of low imageability were made. Words were taken from other tests incorporating imageable and non-imageable words.These words were subjected to rating for imageability by 12 native speakers of Tamil who rated the words on a 5 point rating scale where in, a score of 5 was given to words with high imageability and 1 to the words of low imageability. The words that were rated 4 and 5 were included in the high imageability list and those with a rating of 1 and 2 were included in the low imageability list. An example of the stimuli is as follows:

High Imageable: kuk; - m∂r∂m (Tree)

Low Imageable: cjtp - ud∂vi (Help)

3. *Frequency of occurrence and reading aloud*

Two lists of ten words each, one with words of high frequency of occurrence and one with those of low frequency of occurrence were made. Words were adapted from Tamil Phonetic reader (Rajaram, 1975) based on the linguistic reports of frequency of occurrence. An example of the stimuli is as follows:

High Frequency: ge;J - p∂ndu (Ball)

Low Frequency: gw;gir - p∂rp∂sæ (tooth paste)

4. *Reading Non-words*

Two sets of non-words – ten legal and ten illegal non-words were constructed. Legal non-words are those defined as the non-words incorporating the phonotactic combinations in the language but with no meaning or those that lack semantic features. Illegal non-words are those that do not follow the phonotactic combinations of the language. The list of legal non-words were made by taking real words from the Tamil Phonetic reader (Rajaram, 1975) and changing one of the syllables/graphemes to form a non-word yet sounding like a real word. The list of illegal non-words was formed by taking words from the Tamil phonetic reader (Rajaram, 1975) and randomly incorporating wrong phonotactic rules. These words were further analyzed by a linguist and approved as legal and illegal non-words. An example of the stimuli is as follows.

Legal Non-words: gh;ik - p∂rmæ

Illegal Non-words: d;NgY - npe:lu

5. *Lexical Decision*

A list of 20 words consisting of real words and legal non-words was made. Legal non-words were formed by changing graphemes of real words to distort the word and make it non-meaningful. It was ensured that words thus formed did not over lap with those in the section on reading non-words. The real words were taken from Tamil Phonetic reader and were analyzed by a Linguist for the appropriateness of the stimuli. An example of the stimuli is as follows.

- ehL - na:du (Country)
- If;fhy; - ækka:l (Non-Word)

6. Synonym judgment

Twenty pairs of words were selected from a standard Tamil Dictionary and the Tamil Phonetic reader as references.. The selected pairs were further subjected to familiarity testing by 12 native speakers of Tamil on a 5 point rating scale. Only those words which were rated as highly familiar (a rating of 4 or above) were included in the test stimuli. The subjects were required to indicate if a pair of stimulus carried the same meaning or not. An example of the stimuli is as follows.

mr;rk; Fear atʃtʃæm	gak; Fear b∂j∂m

fij Story k∂dæ	fl;Liu Article k∂tturæ

Procedure:

The words selected for various tasks of the protocol were printed on a 3” X 4” cardboard sheet and the subjects were instructed to read the words aloud for the first four sections.

Instructions:

For Task 1: The subjects were asked to indicate where the target word (shown in column A) is present in columns B to E.

For Task 2 & 3: The subjects were asked to read the word presented on the card aloud.

For Task 4: The subjects were asked to read the non-word presented on the card aloud

For Task 5: The subjects were asked to indicate if a given word had a meaning in the language.

For task 6: The subjects were asked to indicate if the pair of stimuli presented carried a similar meaning or not.

No cues were given for any of the tasks. All the subjects were tested individually in a quiet room with minimal distraction. As and when the client responded, the responses were written down on a response sheet.

Analysis

The responses were verbatim transcribed using the Broad transcription method in the International Phonetic Alphabet (IPA). A neuro-linguistic analysis was carried out to identify differences among the groups if any. The transcribed data for all the tasks was analyzed through quantitative and qualitative measures. A score of 1 was given to each correct response and 0 to an incorrect response. Individual scores of each domain were tabulated and compared. Error analysis was carried out to analyze for the type of error made. The errors were grouped as visual errors, semantic errors, morphological errors and other errors. Each of these were defined as follows:

Visual error: The error response incorporated sounds that are visually similar to the graphemes in the target word.

Semantic error: The error response is related semantically to the target response

Morphological error: The error response has an altered morphological rule compared to the target word.

Statistical Analysis:

Mann Whitney U Test was administered as a part of statistical analysis of the data.

RESULTS AND DISCUSSION

This study was carried out to investigate oral word reading deficits following cerebellar lesions as assessed through a reading assessment protocol. Quantitative scores depicting the performance of the subjects was tabulated and subjected to statistical procedures. In the qualitative domain, an attempt at error analysis was made where in, the errors were classified as visual, semantic, morphological and other error types. The results are discussed under the main heads of each task incorporated in the protocol namely, visual discrimination task, lexical decision task, synonym judgment task, reading words (High and low imageable, High and Low frequency) and reading non-words (legal and illegal). A comparison between the scores of subjects with right & left cerebellar tumors and normal subjects has been attempted.

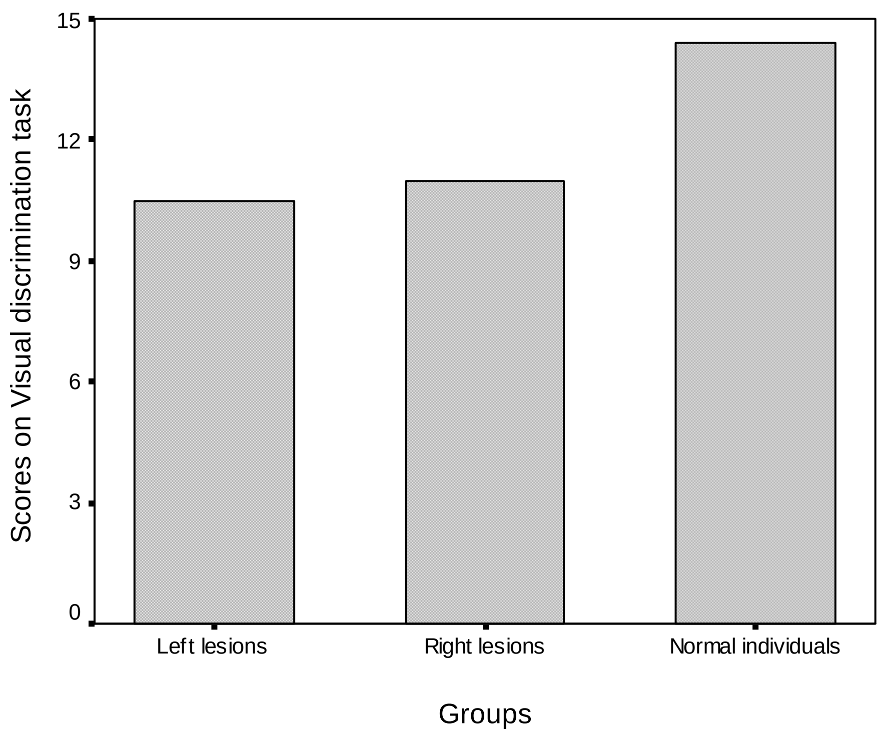
1. Visual Discrimination:

The visual discrimination task involved the subjects to identify a target word from 3 other distracters. The task was included to check for the visual deficits which could lead to dyslexic symptoms. The Results of the visual discrimination task are represented in Table 4 and Graph 1.

Table 4: Comparison of scores of Visual discrimination task in Normal individuals and individuals with cerebellar lesions

Groups	*Mean*	*95 % Confidence Interval for Mean*		*Standard deviation*
		Lower Limit	*Upper Limit*	
Individuals with Left Cerebellar Lesions	10.50	8.45	12.55	1.29
Individuals with Right Cerebellar Lesions	11.00	8.52	13.48	1.00
Normal Individuals	14.40	14.13	14.67	0.72

Graph 1: Comparison of scores of Visual discrimination task in Normal individuals and individuals with cerebellar tumors.



It is seen from Table 4 and Graph 1 that there is a marked difference in the scores obtained by the individuals with cerebellar lesions and normal subjects. The results of this domain points to the fact that visual discrimination function which is a vital strategy in reading is impaired in individuals with cerebellar lesions causing deficits in reading as a whole. However, differences in scores across the groups of left and right cerebellar lesions were not found. Mann Whitney U Test was administered to examine levels of significance. It can be observed that the scores of the control subjects fell a way below the lower limit scores of the normal subjects. A significant difference ($Z = 0.000$, $p < 0.001$) between normal subjects and the experimental subjects was evident. However, the difference between the mean of subjects with right and left tumors was not significant ($Z = 0.586$, $p > 0.05$). This finding contributes to the existing body of literature concerned with sensory discrimination attributes of the cerebellum. Clayes, Orban, Dupont, Sunaert, Hecke and Schutter (2003) used an fMRI and PET paradigm in which the subjects had to discriminate shades of brown while the rate and difficulty were altered. The investigation used various networks namely rate dependant network, rate independent network and motor-end-detection networks. Their results pointed to a bilateral involvement and varied multiple loci of activation in the cerebellum supporting the involvement of cerebellum in visual discrimination. The results are also in support of the visual deficit theory in developmental dyslexics in whom skills of visuo-spatial, visuo-temporal processes are affected (Eden, Vanmeter, Rumsey & Zeffiro, 1996).

Revisiting Marshall's model, the results of this domain suggest a deficit in the visual analysis module or the visual to graphemic conversion module in reading mechanics. To explain on anatomical grounds, the visual cortex receives messages from the retina through fibers concerned with visual processing and sends it to Wernicke's area for comprehension to be accomplished. Cerebellum has been believed to share a lot of afferent/efferent fibers with the visual system. Thus it is evident that visual discrimination is affected in individuals with cerebellar lesions that would impair reading. However, a bilateral involvement of the cerebellar hemispheres is inferred due to the lack of differences in scores across patients with left and right cerebellar lesions.

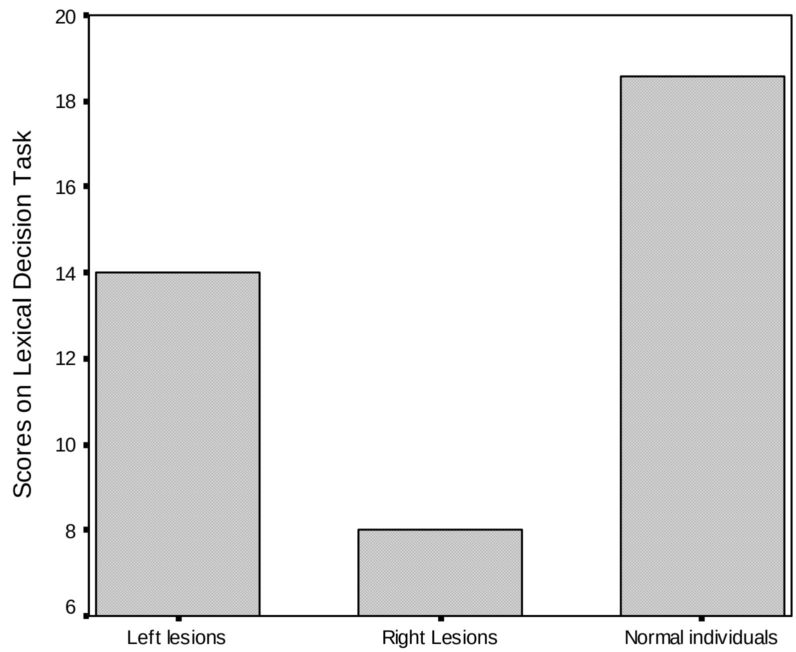
2. Lexical Decision

This task involved the subjects to identify if a presented stimulus was a word or a non-word. The results of this task are represented in Table 5 and Graph 2.

Table 5: Comparison of scores of Lexical Decision task in Normal individuals and individuals with cerebellar lesion

Groups	*Mean*	*95 % Confidence Interval for Mean*		*Standard deviation*
		Lower Limit	*Upper Limit*	
Individuals with Left Cerebellar Lesions	14.00	11.09	16.91	1.83
Individuals with Right Cerebellar Lesions	8.00	3.03	12.97	2.00
Normal Individuals	18.57	18.13	19.00	1.17

Graph 2: Comparison of scores of Lexical Decision task in Normal individuals and individuals with cerebellar lesion



The scores obtained on the lexical decision task are noteworthy. A significant difference (Z = 0.000, $p<0.01$) in the scores of individuals with cerebellar lesions and normal subjects was obtained on the administration of Mann Whitney U Test. Also, the scores did not fall between the limits of the scores of normal subjects. This suggests that the cerebellum is perhaps participating in linguistic process and not motor coordination alone. Studies of Leiner et al (1986) and Fiez et al (1989) that implicated the role of cerebellum in language could be drawn as support to the findings of the present study. Kiehl, Liddle, Smith, Mendrek, Forster and Hare (1999) reported a bilateral activation of cerebellum in lexical decision tasks. Thus the findings of the present study are in support of these investigations. More interesting is the differences seen across individuals with left and right cerebellar lesions. There is a considerable difference (Z = 0.034, $p <0.05$) in the scores of individuals with left and right cerebellar lesions on the administration of Mann Whitney U Test. This suggests that there is a lateralization phenomenon seen in the cerebellum also, as in the cortical structures, in mediating the linguistic faculties. Support can be drawn from the study of Marien et al (2001) who suggested that there are contralateral connections from the cortical hemispheres to the cerebellum, such that the right cerebellar hemisphere takes a lead in linguistic functions. Valdois, Carbonnel, Juphard, Baciu, Ans, Peyrin & Segebarth (2006) reported a strong activation in the right cerebellar hemisphere in lexical decision tasks and activation in the left cerebellar hemisphere for reading words with varying lengths. The results of the study by Perani et al. (1999) suggested right cerebellar activation in lexical decision tasks involving nouns and verbs. However, this finding contradicts Kiehl et al. (1999) who suggested a bilateral activation of the cerebellum in lexical decision.

Going with cognitive dual-route models of reading, it appears that a lesion to the right cerebellum affects lexical decision tasks indicating damage to the orthographic to phonological conversion module. Anatomically, there could be connection between the semantic system, which is believed to rest in the inferior temporal areas, and the cerebellum through the Temperopontine and Ponto cerebellar tracts. This is just a speculation and needs investigations through neuro-imaging paradigms.

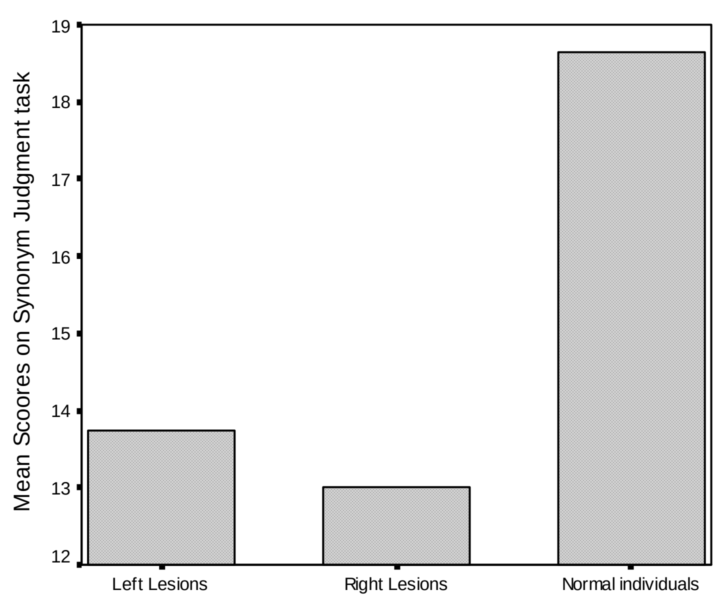
3. Synonym Judgment

This task involved the subjects to judge whether two stimuli presented carried a similar meaning or not. The results of this section are included in Table 6 and Graph 3.

Table 6: Comparison of scores of Synonym judgment task in Normal individuals and individuals with cerebellar lesion

Groups	*Mean*	*95 % Confidence Interval for Mean*		*Standard deviation*
		Lower Limit	*Upper Limit*	
Individuals with Left Cerebellar Lesions	13.75	9.57	17.93	2.63
Individuals with Right Cerebellar Lesions	13.00	10.52	15.48	1.00
Normal Individuals	18.63	18.21	19.05	1.13

Graph 3: Comparison of scores of Synonym judgment task in Normal individuals and individuals with cerebellar lesion



The results of this section are significant in understanding the semantic relationships and organization, which is probably mediated in part by the cerebellum. The results reveal the fact that individuals with cerebellar lesions performed poor as compared to normal subjects with high significance scores ($Z = 0.000$, $p < 0.001$). The upper and lower limits of the scores of the experimental subjects was significantly low as compared to that of normal subjects. Interpretation of these findings in consonance with the previous section is noteworthy. The results complement the findings of the lexical decision task suggesting impairment to the lexico-semantic route in reading modules. The results could be compared with that of Mummery, Patterson, Hodges and Price (1998) who reported a cerebellar activation in a semantic decision task. Table 10 presents the results of the synonym judgment task across the subjects with left and right cerebellar lesions.

A comparison of the performance of subjects with right and left cerebellar lesions was made using Mann Whitney U Test and the comparison did not offer a significant difference ($Z = 0.372$, $p>0.05$). This suggests that there exists no difference in the performance of subjects with right and left cerebellar tumors. Hence, a bilateral involvement in semantic functions is present. However, this finding does not support the results of Mummery et al. (1998) and Vandenberghe, Price, Wise, Josephs & Frackowiak (1996) who suggested a right cerebellar activation for tasks involving semantic functions. It is intriguing to compare the results of lexical decision task and the synonym judgment task, which share semantic attributes in their function. It is observed that there is difference in performance of subjects with left and right cerebellar lesions in the lexical decision task and not in the synonym judgment task. The reasons could be attributed to the concepts of lexicality effect and red integration. Lexicality effect is the advantage the cognitive mechanism gives in accurately reading/uttering a word and distinguishing it from a non-word. The process that aids lexicality effect is termed redintegration. Thus, the results of this section insinuate that probably the lexicality effect is in part mediated by the right cerebellar hemisphere.

4. Reading Words

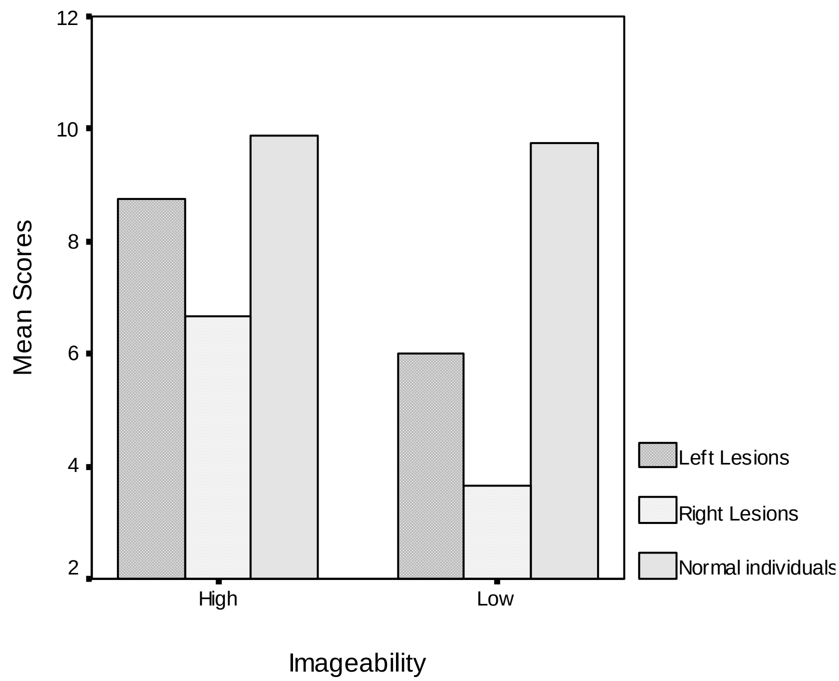
a. The Effect of imageability of the word:

This task involved the individuals to read aloud two sets of real words namely high imageable and low imageable. The responses were written down on a response sheet and were subjected to analysis. The results are presented in Table 7 and Graph 4.

Table 7: Comparison of scores of Reading high imageable and low imageable words in Normal individuals and individuals with cerebellar lesion

Groups	*High Imageabile Words*		*Low Imageable Words*	
	Mean	*Standard deviation*	*Mean*	*Standard Deviation*
Individuals with Left Cerebellar Lesions	8.75	0.96	6.00	0.82
Individuals with Right Cerebellar Lesions	6.67	0.58	3.67	1.15
Normal Individuals	9.87	0.35	9.73	0.58

Graph 4: Comparison of scores of Reading high imageable and low imageable words in Normal individuals and individuals with cerebellar lesion



It can be implicated from Table 7 and Graph 4 that there is an evident difference of scores in the low imageablity list in normal individuals and individuals with cerebellar lesions. A significant ($Z = 0.000$, $p < 0.001$) difference was obtained on the administration of Mann Whitney U Test suggesting that imageability of words does have an effect in reading tasks by individuals with cerebellar lesions. Similar findings have been reported in acquired dyslexias following cortical lesions. This suggests that a cerebellar lesion would lead to a similar deficit as a cortical lesion implicating a possible disruption of important connections in the cerebro-cerebellar loops. Comparison of mean scores of the individuals with right and left cerebellar lesions are interesting. Administration of the Mann Whitney U Test revealed a significant difference for both high ($Z = 0.031$, $p < 0.05$) and low ($Z = 0.046$, $p < 0.05$) imageable words.

Jones (1985) suggested that the ease that a word gives to an image (imageability) is a powerful determinant of reading performance. Baddeley, Ellis, Miles, and Lewis (1982) reported that the exact reason for this effect is unknown. Paivio (1983) opined that a word's imageability is an indication of the readiness with which it is encoded by an imagery component of an imagery-verbal dual coding memory system. Imageability effects are said to be mediated by a phenomenon called 'semantic activation' by which lexical knowledge is associated with its corresponding meaning in the semantic memory. Semantic activation is generally easier for high imageable words than for low imageable words (Caramazza, 1997). Hence compiling these evidences, it seems that imageability is affected in individuals with cerebellar lesions, more so, in individuals with a lesion to the right cerebellar hemisphere implicating a role of cerebellum in semantic functions and hence reading. These results are in support of Mummery et al. (1998) and Perani et al. (1999) who suggested right cerebellar activation in semantic functions.

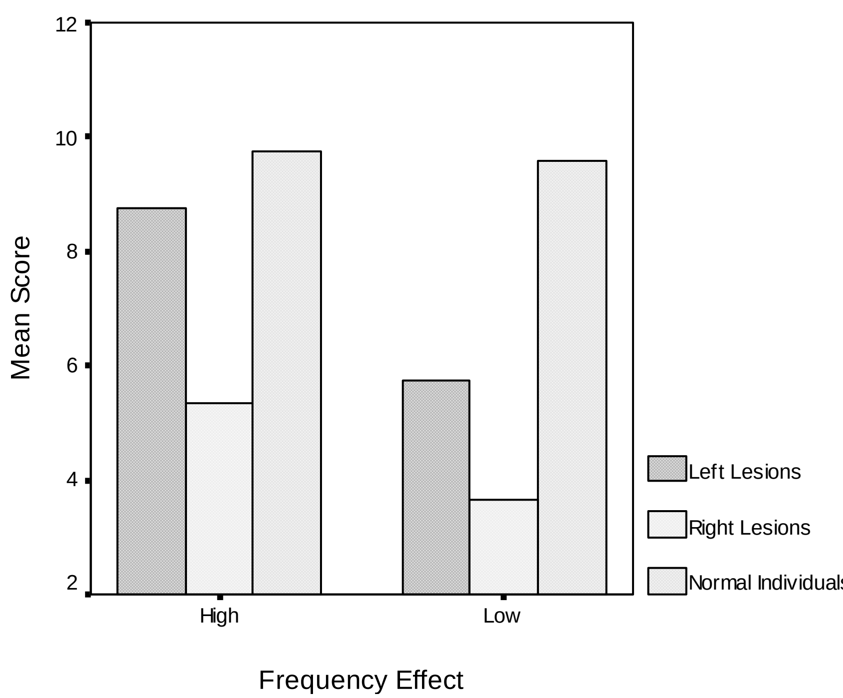
b. Effect of Frequency of Word Occurrence

This task involved the subjects to read aloud two sets of real words that whose frequency of occurrence was high and low in the language. The results are presented in Table 8 and Graph 5.

Table 8: Comparison of scores of Reading high frequency and low frequency words in Normal individuals and individuals with cerebellar lesion

Groups	*High Frequency Words*		*Low Frequency Words*	
	Mean	*Standard deviation*	*Mean*	*Standard deviation*
Individuals with Cerebellar Lesions	7.29	4.86	4.86	1.98
Individuals with Left Cerebellar Lesions	8.75	0.96	5.75	1.26
Individuals with Right Cerebellar Lesions	5.33	0.58	3.67	0.58

Graph 5: Comparison of scores of reading high frequency and low frequency words in Normal individuals and individuals with cerebellar lesion



The results indicate a fair reading of high frequency words but a marked deficit in reading low frequency word by individuals with cerebellar lesion with significanc differences (Z = 0.00, p < 0.001).. During oral reading, phonological lexical activation can occur through the lexico-semantic route or the direct route. Hence a significant difference in the scores of normal individuals and individuals with cerebellar lesions suggests a damage to the lexical access and hence in Marshall's model either the direct or the lexico-semantic route could be affected.

The results of the comparison of scores of normal subjects and those with cerebellar lesions reveal high significance ($Z = 0.031$, $p < 0.01$) for the high frequency words and $Z = 0.064$, $p < 0.01$) for the low frequency words suggesting that there exists a marked difference in the scores of individuals with left and right cerebellar lesions for the high frequency word list alone. This has implications with reference to the phonological buffer where the phonemic knowledge is stored. The process of phonological lexical activation is believed to play a role in frequency effects. It is the process by which knowledge of the phonological form of words is retrieved. Lexical activation is thought to be more difficult for low-frequency words than for high frequency words (Caramazza, 1997). Yet, in individuals with right cerebellar lesions, a disturbance occurs in reading high frequency words also. This suggests that a lesion to the right cerebellar hemisphere leads to a damage to the phonological buffer and thereby affects the reading process. Similar results have been reported in individuals with acquired dyslexias following cortical lesions. This implicates that the cerebellum acts as a mediator in consonance with the regions of the left hemisphere in reading related cognition.

5. Reading Non-Words

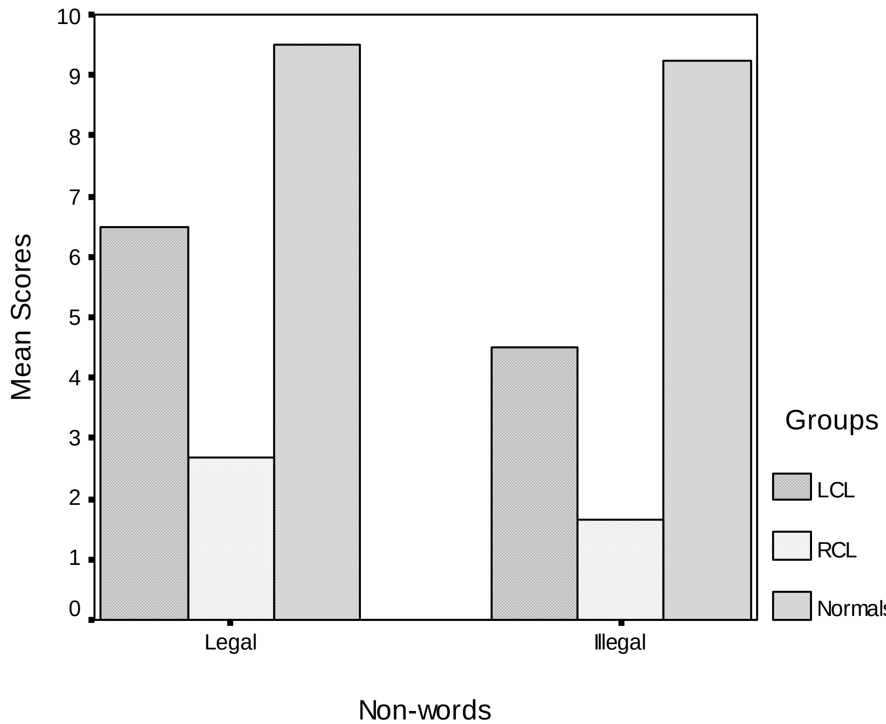
Legal and Illegal Non-Words

This task involved the subjects to read phonologically plausible non words i.e. those non-words which followed the graphemic and phonotactic rules of the language and phonologically non-plausible non-words which violate graphemic and phonotactic rules. The results are tabulated in Table 9 and presented in Graph 6.

Table 9: Comparison of scores of reading Legal and illegal non- words in Normal individuals and individuals with cerebellar lesion

Groups	*Legal Non-Words*		*Illegal Non-Words*	
	Mean	*Standard deviation*	*Mean*	*Standard deviation*
Individuals with Left Cerebellar Lesions	6.50	1	4.50	1.73
Individuals with Right Cerebellar Lesions	2.67	0.58	1.67	1.53
Normal Individuals	9.50	0.63	9.23	0.90

Graph 6: Comparison of scores of Reading Legal and illegal non- words in Normal individuals and individuals with cerebellar lesion



It is evident from Table 9 and Graph 6, that there exists a difference in the scores of normal individuals and individuals with cerebellar lesions. A significant difference ($Z = 0.000$, $p < 0.01$) was obtained in the comparison using the Mann Whitney U Test. Thus, individuals with cerebellar lesions have difficulty in reading non-words and hence a deficit in the Grapheme to phoneme conversion routine is affected in these subjects. The results of the comparison of scores in individuals with left and right cerebellar lesions are captivating.

The results of this comparison using the Mann Whitney U test gave a significance of $Z = 0.026$, $p<0.05$ for legal non-words and $Z = 0.105$, $p>0.05$ for illegal non-words. This hints that there exists no difference in the scores of legal non-words but a difference occurs with respect to the illegal non-words. This suggests that the phonic route is relatively better in individuals with left cerebellar lesions sparing the production of legal non-words. However, when there is a requirement to read out illegal non-words, the route fails to accomplish the task in both right and left cerebellar lesions. A deficit at these levels indirectly causes a reduced activation at the phonological buffer and hence the deficits in reading non-words are manifested.

These results are to be interpreted in consonance with the lexical decision task which incorporates the reading of non-words. Forster and Chambers (1973) suggested that reading non-words entirely depends on the phonological encoding. These authors also suggested an increased latency for reading non-words in normal individuals. As discussed in the section of lexical decision, reading non-words involves the orthographic to phonologic conversion and input from the lexical route as well.

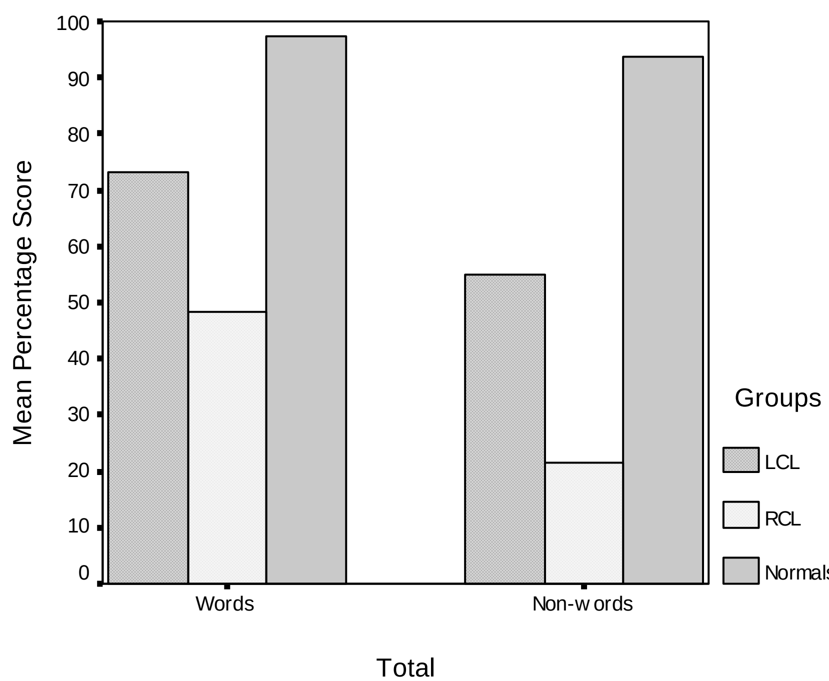
Comparison of reading words and non-words

A comparison of scores between reading out words (High and low imageable + high and low frequency) and non-words (legal and illegal) was also attempted and the results are presented in Table 10 and Graph 7

Table 10: Comparison of scores of words and non-words in normal individuals and individuals with cerebellar lesions

	Groups	*Mean*	*Std. Deviation*
Words (Imageable + Frequency)	Individuals with left cerebellar lesions	73.1250	2.3936
	Individuals with right cerebellar lesions	48.3333	1.4434
	Normal individuals	97.2500	2.8880
Non-Words (legal + Illegal)	Individuals with left cerebellar lesions	55.0000	13.5401
	Individuals with right cerebellar lesions	21.6667	10.4083
	Normal individuals	93.6667	5.8624

Graph 7: Comparison of scores of words and non-words in normal individuals and individuals with cerebellar lesions



On observation of the result it is evident that there is a marked difference in the scores of individuals with cerebellar lesions and normal individuals. Administration of Mann Whitney U Test suggested a significant difference ($Z = 0.00$, $p<0.001$) for reading words and reading non-words. A comparison of scores of individuals with right and left cerebellar tumors revealed a difference of $Z = 0.031$, $p<0.05$ for reading words and $Z = 0.032$, $p<0.05$ for reading non-words. On observation of the Table 10 and Graph 7, it is evident that there is a clear difference in reading words and non-words in subjects with both right and left cerebellar tumors. The reading of real words involves the lexical route and the reading of the non-words involves the phonic route. Since the scores of words and non-words in individuals with cerebellar lesions are markedly reduced as compared to normal individuals, both these routes are probably damaged. It also implies that the right cerebellum, when affected causes more serious a damage as compared to left cerebellar lesions as seen from the graph and the results of the statistical comparison. This finding can draw support from the study of Marien et al (2001) who suggested the role of right hemisphere in cognitive-linguistic functions.

A summary of the Comparisons of scores of normal individuals and cerebellar lesions and individuals with right and left cerebellar lesions is listed in Tables 11 and 12 respectively.

Table 11: Comparison of scores in normal individuals and individuals with cerebellar lesions using Mann Whitney U Test

Domain	*Z*	*Asymp. Sig. (2-tailed)*
Visual Discrimination	-4.296	.000
Synonym judgment	-4.145	.000
Lexical Decision	-4.145	.000
High frequency word list	-3.724	.000
Low Frequency word list	-4.515	.000
High imageable word list	-4.273	.000
Low imageable word list	-4.780	.000
Legal Non-words	-4.349	.000
Illegal Non-words	-4.247	.000
Reading words (Imageable + frequency)	-4.178	.000
Reading Non-Words (Legal + Illegal)	-4.150	.000

Table 12: Comparison of scores in individuals with right and left cerebellar lesions using Mann Whitney U test

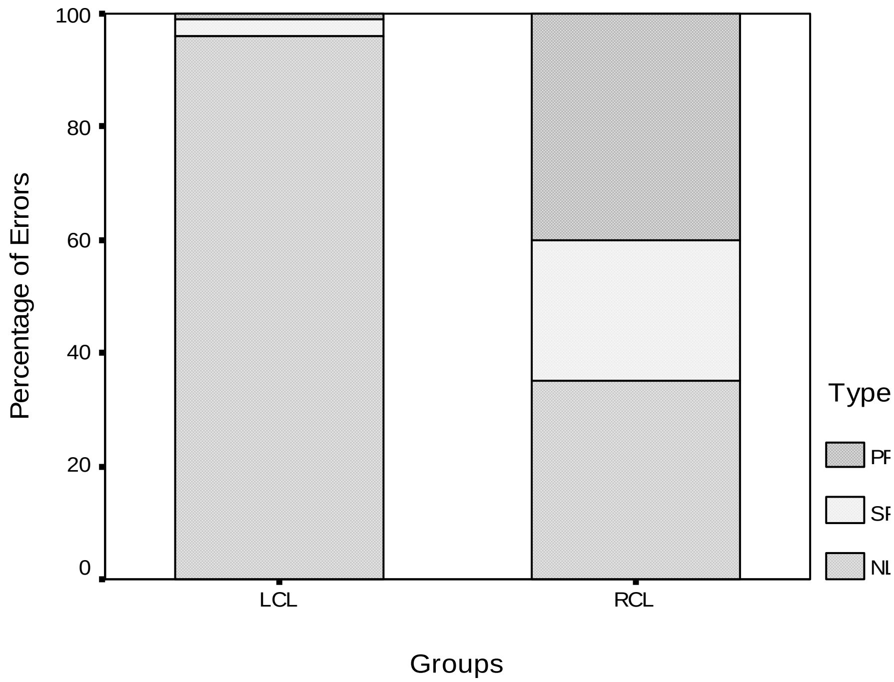
Domain	*Z*	*Asymp. Sig. (2-tailed)*
Visual Discrimination	-.545	.586
Synonym Judgment	-.892	.372
Lexical Decision	-2.121	.034*
High frequency Word list	-2.160	.031*
Low frequency Word list	-1.852	.064
High imageable words	-2.160	.031*
Low imageable words	-1.999	.046*
Legal non-words	-2.223	.026*
Illegal non-words	-1.620	.105
Reading Words (imageable + Frequency)	-2.160	.031*
Reading non-Words (Legal + Illegal)	-2.141	.032*

* Significant at $P < 0.05$

Error Analysis

An error analysis was done to classify the types of error to get better insights about the type of errors made. Fig.2 represents the types of errors made by the individuals with left and right cereballar lesions. Interestingly, none of the subjects produced morphological errors.

Fig.2: Error patterns in individuals with right and left cerebellar lesions



It can be observed that a lesion to the left cereballar hemisphere predominantly caused visual/phonologic errors with minimal semantic, morphological errors and a lesion to the right cerebellar hemisphere caused semantic, visual and neologistic errors. This suggests that the right cerebellum is more active in linguistic processes than the left hemisphere. Also, other interesting issues emerged about the performance of individuals with right cerebellar lesions. By and large, the individuals with right cerebellar lesions used a letter-by-letter strategy in reading. More fascinatingly, most of individuals used a letter-by-letter strategy spelling out the individual letters accurately but reading the whole word inaccurately. Also, an increased latency was observed for all the patients irrespective of the site of lesion in reading. These features mimic the features of letter-by-letter dyslexia. Patterson and Kay (1982), reported that the main behavioral correlates of letter-by-letter dyslexia is slow reading that is characterized by a word length effect i.e. a linear increase in the time required for the overt recognition of a word as a function of the number of letters it comprises. Although the study did not aim at investigating word length effects, informal observations did reveal a word length effect. This calls for further investigations.

Cognitive models of reading could better offer explanations to this difference and error types. Considering the Marshall's (1987) model, a visual error could stem from impairments at two levels, one in the initial visual processing i.e. the visual analysis module (and/or the visual-graphemic module) in the various stages of reading or could be a level at the phonological buffer or orthographic output lexicon such that a phonological error is manifest as error pattern close to a visual error. Secondly, semantic errors could be caused due to a deficit in the semantic representation module of the routines. In particular, the lexico-semantic route is affected leading to errors manifested as paralexias. Thirdly, neologistic errors could stem from a deficit in any of the routes namely the direct route, phonic route or the lexico-semantic route, as the response is markedly different from both the semantic and phonological attributes of the target response.

This suggests that the right cerebellum would cause deficits in the aforementioned routes when there is a lesion, thereby causing a wider variety of deficits. In contrast, a lesion to the left cerebellar hemisphere would cause a deficit only at the visual analysis level or the phonological buffer level leaving the semantics spared. Interestingly, morphological errors were not found suggesting that a cerebellar lesion would selectively impair the linguistic faculty thereby causing a disturbance in reading.

Plausible explanations for the results:

There could be various reasons for an underlying reading deficit seen following a cerebellar lesion. The cerebro cerebellar anatomical circuitry consists of a feedforward link (the corticopontine and pontocerebellar pathways) and a feedback link (the cerebellothalamic and thalamocortical systems) (Schmahmann and Sherman, 1998). Anatomical investigations have revealed highly organized projections to the pons arising from the association areas in the dorsolateral and dorsomedial prefrontal cortex (Schmahmann & Pandya, 1997a), posterior parietal region (May and Anderson, 1986), superior temporal polymodal (Schmahmann & Pandya, 1991), posterior parahippocampal (Schmahmann & Pandya, 1993) and dorsal prestriate regions (Fries, 1990) and cingulated gyrus (Vilensky and Hoesen, 1981). Further, the medial mamillary bodies that have implications of memory and the superior colliculus that has underpinnings in attention have connections to the pons (Aas and Brodal, 1988) and reciprocal connections with the cerebellum (Haines and Dietriches, 1984). Brodal (1979) suggested that the associative cortices are linked with more recently evolved lateral cerebellar hemispheres. These evidences suggest that cerebellum could be a mediator in higher level linguistic processes such as memory, attention etc are in part controlled by the cerebellum. These processes in turn are highly inherent in reading processes.

The phenomenon of Crossed cerebellar diaschisis (CCD) is significant in understanding the reading deficits exhibited by the clients. Crossed cerebellar diaschisis is defined as a reduction in metabolic activity and blood flow of the cerebellum contralateral to a supratentorial cerebral lesion (Boetz, Leveille, Lambert & Boetz, 1991). Boetz et al.

(1991), used SPECT to demonstrate a reversible matched decrease in blood flow and oxygen metabolism in the cerebellum of patients with contralateral supratentorial lesions. There has also been a report on the phenomenon of reverse crossed cerebellar diaschisis/cerebellocerebral diaschisis, which is a reduction in the CBF of the cerebral hemisphere contralateral to a unilateral cerebellar lesion (Boetz et al., 1991). This effect has been observed in cerebellar hemorrhages, cerebellar hemispheric venous malformations, brain stem infarction and herpes simplex encephalitis. Decreased rCBF in the contralateral cerebral cortex may be caused by the destruction of the cerebello thalamo-corticalpathway (Boetz et al., 1991).

Thus there arises a possibility that probably a lesion to the cerebellum has affected the contra lateral cerebral hemispheres and hence a reading deficit is seen. The results carry more weightage in learning that the right cereballar hemisphere has been found to have more linguistic functions which according to this phenomenon must be in association with the left cortical hemisphere. Aphasia- like alterations after right cerebellar damage is considered to result from diminished excitatory impulses through cerebello- ponto- thalamo – cortical pathways (Marien et al., 1996). Consequently, aphasia-like disorders in cerebellar pathology do not point to representation of language functions at the level of the cerebellum but bespeak abolished function of remote supratentorial eloquent areas as a result of decreased cerebellar input via cerebello- cerebral pathways (Marien, Engelborghs, Fabbro, & De Deyn , 2001)

Cerebellum has also been studied for cognitive functions including working memory, attention etc (Schmahmann & Sherman, 1998). Studies have suggested that working memory capacity is directly linked to the reading ability of an individual. Daneman & Green (1986) suggested that individuals with large working memory spans are skilled in guessing the meaning of unusual words on the basis of sentence context. Miyake & Shah (1994) reported that working memory plays a role in decoding sentences. Probably due to dysfunction of cerebello-thalamo-cortical pathways, cerebellar damage can disrupt selective attentional processes (orienting, distributing and shifting attention). Attentional processes largely depend on coordinated interactions between the reticular activating system and the frontal and parietal lobes (Shulman and Petersen, 1993). Within the integrated system the cerebellum has been considered to enhance neural responsiveness in advance to stimulation (Thompson, 1986). Thus the cerebellum could directly affect such cognitive processes, indirectly causing a reading deficit.

Temporal coordination is one major role of cerebellum in motor functions. Apart from the motor domain, the cerebellum could have a hand in temporal processing of spoken/written messages and hence a deficit could lead to processes related to temporal processing such as reading.

This study thus, can be taken as an adjunct to the existing literature on the role of cerebellum in reading. Also, conceivable explanations could be made for differences in the performance of individuals with right and left cerebellar lesions on certain parameters. The error analysis suggests that there is a differential contribution of both the cerebellar hemispheres in the reading function. The left cerebellum, as the results point to, is primarily concerned with the motor movements involved in reading including the saccadic action of the eyeballs. On the other hand, the right cerebellum is probably involved in mediating linguistic and neuro-psychological domains of semantics etc. in reading functions. Support for these findings can be drawn from those of Eckert et al (2003) who found smaller anterior right cerebellar lobes in dyslexic children. Marien et al (2001) reported the right cerebellar hemisphere to control a lot of cognitive and linguistic functions. However, Murdoch & Whelan (2007) have reported that left cerebellar lesions with a vascular origin lead to higher level language deficits. However, this study did not incorporate subjects with a lesion of vascular region and hence comparison of the obtained data with that of Murdoch & Whelan (2007) would not be appropriate. Murdoch & Whelan (2007) also suggested that cerebellar involvement in language is bilateral and that cerebellar lesions, regardless of hemispheric location, may result in language disturbances as a consequence of contralateral and ipsilateral cerebral diaschisis.

Hence, with this preliminary attempt, it can be conceived that cerebellum has enormous cognitive-linguistic underpinnings, the reading faculty being one of the important ones. However, the results need to be interpreted with caution as the sample size in the experimental group was small. The results have a wide implication in understanding cerebellar physiology and inclusion of assessment and treatment of acquired dyslexia following cerebellar lesions. The cerebellum has been underestimated for its linguistic and cognitive functions and research focusing such issues is hence warranted.

SUMMARY AND CONCLUSIONS

Reading has been understood as a complex cognitive activity involving the sensory and linguistic faculties. The peri-sylvian language areas have been traditionally stated as the primary language centers controlling a variety of linguistic functions including reading. However, growing body of evidence suggests the activation of cerebellum in a variety of linguistic tasks. (Martin, Hexby, Lalonde, Wiggs & Ungerleider, 1995; Schmahmann & Sherman, 1998; Fabbro, Moretti & Bava, 2000; Cook, Murdoch, Cahill & Whelan, 2004). One such linguistic task that the cerebellum is recently implicated with is reading. Although various studies have suggested the involvement of cerebellum in reading tasks, studies incorporating behavioral paradigms are relatively scanty. Also, differences in the contributions of the right and left cerebellar hemispheres to reading are unclear. This study was taken up to derive answers to these issues.

A protocol to assess oral word reading deficits in Tamil was specifically developed for the study. The protocol incorporated the tasks of visual discrimination, lexical decision, synonym judgment, reading real words (high and low imageable, high and low frequency of occurrence) and reading non-words (legal and illegal). This protocol was administered on 4 subjects with history of left cerebellar tumor, 3 subjects with right cerebellar tumor and thirty normal subjects. Data was analyzed using quantitative and qualitative measures.

The following were the salient results obtained:

Task	*Comparison of normal subjects and subjects with cerebellar lesions*	*Comparison of subjects with right and left cerebellar lesions*
Visual Discrimination Task	Significant difference present	No significant difference
Lexical Decision	Significant difference present	Significant difference present
Synonym judgment	Significant difference present	No significant difference
Reading High imageable words	Significant difference present	Significant difference present
Reading low-imageable words	Significant difference present	Significant difference present
Reading high frequency words	Significant difference present	Significant difference present
Reading low frequency words	Significant difference present	No significant difference
Reading legal non-words	Significant difference present	Significant difference present
Reading illegal non-words	Significant difference present	No significant difference

The obtained data points to the verity that individuals with cerebellar tumors performed significantly poor on the tasks included in the protocol. Interestingly, a difference in the performance of subjects with right and left cerebellar tumors where the individuals with right cerebellar tumors performed poor as compared to those with left cerebellar tumors emerged implicating a lateralization of functions in the right cerebellar hemisphere with respect to reading. Considering the tasks in the protocol, tasks of lexical decision, reading high and low imageable words, reading legal non-words showed significant differences between subjects with left and right cerebellar tumors. Regularity effect was not tested as Tamil does not posses irregular word forms. These findings are represented by means of tables and graphs. Qualitative analysis of the data revealed predominantly visual errors in subjects with left cerebellar tumors and semantic, visual and neologistic errors in subjects with right cerebellar tumor.

Bearing in mind the cognitive models of reading, a possible deficit in the visual analysis routine is inferred following a left cerebellar tumor and a deficit to the direct, lexico-semantic routines and the phonological buffer is inferred following a right cerebellar tumor.

A variety of reasons could underlie the manifestation of reading errors following cerebellar dysfunction. The widely accepted phenomenon of crossed cerebral-cerebellar diaschisis is significant in understanding the errors. According to this phenomenon, a relation in the outputs of cortical and cerebellar structures exists whereby a lesion at the cortical structures might hamper cerebellar functions or a lesion at the cerebellar structures might affect the output of the cortical structures. Thus, it is seen that the obtained errors could be because of the fact that the cerebellum is one of the primary areas for reading to be accomplished or that reading errors are just a reflection due to the phenomenon of crossed cerebral-cerebellar diaschisis. These findings are significant in understanding the underpinnings of acquired dyslexia. An indirect evidence of the functional connectivity of the cerebellum with the cortical and other sub-cortical structures is thus obtained. However, the results should be interpreted with caution because of the small sample size of the experimental groups.

The results have a wide implication in understanding cerebellar physiology and inclusion of assessment and treatment of acquired dyslexia following cerebellar lesions. The cerebellum has been underestimated of its linguistic and cognitive functions and research focusing such issues is hence warranted.

Recommendations for future:

1. Deficits of reading sentences, text reading and reading comprehension could be analyzed.
2. A comparison of dyslexic syndromes seen following cortical lesions could be made with those following cerebellar lesions.
3. Variables like neighborhood effects on word reading, effect of the word length on reading, effect of regularity in individuals with cerebellar lesions could be assessed.
4. Reaction time for reading, in individuals with cerebellar lesions could be carried out.

REFERENCES

Aas, J-E., & Brodal, P. (1988) Demonstration of topographically organized projections from the hypothalamus to the pontine nuclei: An experimental anatomical study in the cat. *Journal of Computaional Neurology*, 268, 313-328

Baddeley, A. D., Ellis, N. C., Miles, T. R., & Lewis, V. J. (1982). Developmental and acquired dyslexia: A comparison. *Cognition*, 11, 185-199.

Boetz, M. I., Leveille, J., Lambert, R., & Boetz, T. Single Photon emission computed tomography (SPECT) in cerebellar disease: cerebro-cerebellar disachisis. *European Neurology*, 31, 405-421.

Bracke-Tolkmitt, R., Linden, A., Canavan, A. G., Rockstroch, B., Scholz, E., Wessel, K. et al. (1989). The cerebellum contributes to mental skills. *Behavioral Neuroscience*, 103, 442-446

Brodal, P. (1979). The pontocerebellar projection in the rhesus monkey: an experimental study with retrograde axonal transport of horseradish perioxidase. *Neuroscience*, 4, 193-208

Brown, W., Eliez, S., Menon, V., Rumsey, J., White, C., & Reiss, A. (2001). Preliminary evidence of widespread morphological variations of the brain in dyslexia. *Neurology*, 56, 781-783

Buckner, R. L., Koutsaal, W., Schater, D. L., & Rosen, B. R. (2000). Functional MRI evidence for a role of frontal and inferior temporal cortex in amodal components of priming. *Brain*, 123, 620-640

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology, 14*, 177-208.

Castles, A., & Coltheart, M.(1993). Varieties of Developmental Dyslexia. *Cognition*, 47, 149-180

Claeys, K. G., Orban, G. A., Dupont, P., Sunaert, S., Van Hecke, P., & De Schutter, E. (2003). Involvement of multiple functionally distinct cerebellar regions in visual discrimination: a human functional imaging study. *NeuroImage*, 20(2), 810-854.

Coltheart, M. (1996). Phonological dyslexia: Past and future issues. *Cognitive Neuropsychology, 13*, 749-762.

Cook, M., Murdoch, B., Cahill, L., & Whelan, B.(2004). Higher-level language deficits resulting from left primary cerebellar lesions. *Aphasiology*, 18, 771-784

Courchesne, E, Muller, R. A., & Allen, G. (1998). The cerebellum: so much more. *Letters Science*, 282, 879-880.

Daneman, M., & Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Memory and Language, 25*, 1-18.

Darley, F. L., Aronson, A.E., & Brown, J.R. (1969). Differential diagnostic patterns of dysarthria. *Journal of Speech and Hearing Research*, 12, 246-269.

Eckert, M., Leonard, C., Richards, T., Aylward, E., Thomson, J., & Berninger, V. (2003). Anatomical correlates of dyslexia: frontal and cerebellar findings. *Brain*, 126, 482-494

Eden, G. F., VanMeter, J. W., Rumsey, J. M., & Zeffiro, T. A. (1996). The Visual Deficit Theory of Developmental Dyslexia. *NeuroImage*, 4(3), S108-S117

Eden, G., & Zeffiro, T. (1998). Neural systems affected in developmental dyslexia revealed by functional neuroimaging. *Neuron*, 21, 279-282

Etard, O, Mellet, E., Papathanassiou, D., Benali, K., Houde, O., Mazoyer, B., & Tzourio-Mazoyer, N. (2000). Picture naming without Broca's and Wernicke's area. *Neuroreport*, 11, 617-622

Fabbro, F., Moretti, R., and Bava, A.(2000). Language Impairments in patients with cerebellar lesions. *Journal of Neurolinguistics*; 13: 173-188

Fiez, J. A., Peterson, S. E., Cheney, M. K., & Raichle, M. E. (1992). Impaired non-motor learning and error detection associated with cerebellar damage: a single case study. *Brain*, 115, 155-178.

Finch, A., Nicolson, R and Fawcett, A. (2002). Evidence for a neuroanatomical difference within olivo-cerebellar pathway of adults with dyslexia. *Cortex;* 38; 529-539

Folstein, M. F., Folstein, F. E., & McHaugh, P. R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician" *Journal of Psychiatric Research*, 12(3), 189-98.

Forster, K. I., & Chambers, S. (1973). Lexical access and learning time. *Journal of Verbal Learning and Verbal Behavior*, 12, 627-635

Fries, W. (1990). Pontine projection from striate and prestriate visual cortex in the macaque monkey: an anterograde study. *Vision Neuroscience*, 4, 205-216.

Furey, M. L., Pietrini, P., Haxby, J. V., Alexander, G. E., Lee, H. C., VanMeter, J., Grady, C. L., Shetty, U., Papoport, S. I., Schapiro, M. B., & Freo, U. (1997). Cholinergic stimulation alters performance and task-specific regional cerebral blood flow during work memory. *Proceedings of the National Academy of Sciences of the United States of America*, 94, 6512-6516.

Haines, D. E., & Dietrichs, E. (1984). An HRP study of hypothalamo-cerebellar and cerebello-hypothalamic connections in squirrel monkey (Saimiri sciureus). *Journal of Computational Neurology*, 229, 559-575.

Hallett M, Grafman J (1997) Executive function and motor skill learning. In: Cognition and the cerebellum (Schmahmann JD, ed), pp 297-324. San Diego: Academic Press.

Henry, M. L., Beeson, P. M., Stark, A. J., & Rapcsak, S. Z. (2007). The role of left perisylvian cortical regions in spelling. *Brain and Language*, 100(1), 44-52.

Herbster, A. N., Mintun, M. A., Nebes, R. D., & Becker, J. T. (1997). Regional cerebral blood flow during word and non-word reading. *Human Brain Mapping*, 5, 84-92.

Hubrich-Ungureanu, P., Kaemmerer, N., Henn, F. A., & Braus, D. F. (2002). Lateralized organization of the cerebellum in a silent verbal fluency task: a functional magnetic resonance imaging study in healthy volunteers. *Neuroscience Letters*, 319, 91-94.

Jones, G. V. (1985). Deep dyslexia, imageability, and ease of predication. *Brain and Language*, 24(1), 1-19.

Just, M. A., AND Carpenter, P. A. 1980. A theory of reading: From eye fixations to comprehension. *Psychological Review*, 87, 329-354.

Kandel, E., Schwartz, J., & Jessel, T. (2000). *Principles of Neuroscience*. Newyork, McGraw-Hill.

Karanth, P. (1984). Analysis of Acquired disorders of reading in Kannada. *Journal of All India Institute of Speech & Hearing*, 15, 123-132.

Keele, S. W., & Ivry, R. (1991). Does the cerebellum provide a common computation for diverse tasks? A timing hypothesis. Annals of New York Academy of Sciences, 608, 179-211.

Kiehl, K. A., Liddle, P. F., Smith, A. M., Mendrek, A., Forster, B. B., & Hare, R. D. (1999). Neural processing involved in concrete and abstract words. *Human Brain Mapping*, 7, 225-233.

Leiner, H. C., Leiner, A. L., & Dow, R. S. (1986). Does the cerebellum contribute to mental skills? *Behavioral Neuroscience*, 100(4), 443-454.

Leggio, M. G., Silveri, M. C., Petrosini, L., & Molinari, M. (2000). Phonological grouping is specifically affected in cerebellar patients: a verbal fluency study. *Journal of Neurology, Neurosurgery and Psychiatry*, 69, 102-106.

Leonard, C. M., Eckert, M., Lombardino, L. J., Oakland, T., Kranzler, J. H., Crandell, C., Mohr, C., King, W., & Freeman, A. (2001). Anatomical risk factors for dyslexia. *Cerebral Cortex, 11,* 148-157.

Majerus, S., Collete, F., Van Der Linden, M., Peigneux, P., Laureys, S., Delfiore, G., Degueldre, C., Luxen, A., & Salmon, E. (2002). A PET Investigation of lexicality and phonotactic frequency in oral language processing. *Cognitive Neuropsychology*, 19, 343-363.

Marien, P., Engelborghs, S., Fabbro, F., & Deyn, P. P. (2001) The lateralized linguistic cerebellum: a review and a new hypothesis. *Brain and Language,* 79, 580- 600.

Marien, P., Saerens, J., Nanhoe, R., Moens, E., Nagels, G., Pickut, B., Dierckx, R. A., & DeDyen, P. P. (1996). Cerebellar induced aphasia: case report of cerebellar induced prefrontal aphasic language phenomena supported by SPECT findings. *Journal of Neurological Science*, 144, 34-43.

Marshall, J., C., & Newcombe, F. (1973). Patterns of paralexia: a psycholinguistic approach. *Journal of Psycholinguist Research*, 2(3):175-199

Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., and Ungerleider, L. G. (1995). Discrete Cortical regions associated with knowledge of colour and knowledge of action. *Science*; 270; 102-105.

May, J. G., & Andersen, R. A. (1986). Different patterns of corticopontine projections from separate cortical fields within the inferior parietal lobule and dorsal prelunate gyrus.of the macaque. *Experimental Brain Research*, 63, 256-278.

Mclelland, J. & Rumelhart, D. (1981). An interaction model of content effects in letter perception. An account of the basic findings, *Psychological Review*, 88, 375-801.

Miyake and Shah, (1999). Models of working memory: Mechanisms of active maintenance and executive control. Cambridge University Press, Cambridge, UK.

Molinari, M., Petrosini, L., Misciagna, S., & Leggio, M., G. (2004). Visuospatial abilities in cerebellar disorders. *Journal of Neurosurgery and Psychiatry*, 75(2):235-40.

Moretti, R., Bava, A., Torre, P., Antonello, R., & Gazzato, G. (2002). Reading errors in patients with cerebellar vermis lesions. *Journal of Neurology;* 249, 461-468.

Mummery, C.J., Patterson, K., Hodges, J. R., & Price, C. J. (1998). Functional neuroanatomy of the semantic system: divisible by what?. *Journal of Cognitive Neuroscience*, 10, 766-777.

Murdoch, B. E., & Whelan, B-M. (2007). Language disorders subsequent to left cerebellar lesions: A case for Bilateral cerebellar involvement in language. *Folia Phoniatrica et Logopaedica*, 59, 184-189

Nicolson, R., Fawcett, A., & Dean, P.(2001). Developmental Dyslexia: the cerebellar deficit hypothesis. *Trends Neuroscience*, 24, 508-511.

Patterson, K., & Kay, J. (1982). Letter by letter reading: Psychological descriptions of a neurological syndrome. *Quaterly Journal of Experimental Psychology*, 34A, 411-441.

Paivio, A. (1983). The empirical case of dual reading. In Yuile, J. C. (Ed.), Imagery, memory and cognition. Hillsdale, N. J.: Erlbaum. Pp. 307 - 322.

Patterson, K. E., Marshall, J. C., & Coltheart, M. (1985). *Surface dyslexia*. London: Erlbaum.

Paulesu, E., Frith, C. D., & Frackowiak, R. S. (1993). The neural correlates of verbal component of working memory. *Nature*, 362, 342-345.

Pavlidis, G. (1981). Do eye movements hold the key to dyslexia? *Neuropsychologia*, 19, 57–64.

Perani, D., Cappa, S. F., Schnur, T., Tettamanti, M., Collina, S., Rosa, M. M., & Fazio, F. (1999). The neural correlates of verb and noun processing: a PET study. *Brain*, 122, 2337-2344.

Petersen, S., Fox, P., Posner, M., Mintun, M., & Raichle, M. (1998). Positron emission tomographic studies of the cortical anatomy of single word processing. *Nature*, 331, 585-589.

Price, C. J., & Friston, K. J. (1997). Cognitive Conjunction: A New approach to brain activation experiments. *Neuroimage,* 5, 261-270.

Price, C. J., Moore, C. J., & Frackowiak, R.S. (1996). The effect of varying stimulus rate and duration on brain activity during reading. *Neuroimage,* 3, 40-52.

Rae, C., Lee, M., Dixon, R., Blamire, A., Thompson, C., Styles, P., Talcott, J., Richardson, A., &Stein, J. (1998). Metabolic abnormalities in developmental dyslexia detected by H-I Magnetic resonance spectroscopy. *Lancet,* 351, 1849-1852.

Rajaram, S. (1973). *Tamil Phonetic Reader*. Central Institute of Indian languages, Mysore.

Rapcsak, S. Z., & Beeson, P. M. (2004). The role of left posterior inferior temporal cortex in spelling. *Neurology,* 62(12), 2221-2229.

Riva, D & Giorgi, C. (2000a). The Cerebellum contributes to higher functions during development: Evidence from a series of children surgically treated for posterior fossa tumours. *Brain*, 123, 1051-1061.

Riva, D & Giorgi, C. (2000b). The contribution of the cerebellum to mental and social functions in developmental age. *Human Physiology*, 26(1), 21-25.

Ruby, P., & Decety, J. (2001). Effect of subjective perspective taking during simulation of action: a PET investigation of agency. *Nature and Neuroscience*, 4, 546-550.

Schlaug, G., Gaab, N., Gaser, C., Zaehle, T., & Jancke. L. (2003) Functional anatomy of pitch memory- an fMRI study with sparse temporal sampling. *Neuroimage*, 19, 1417-1426.

Schmahmann, J. D., & Pandya, D. N. (1991). Projections to the basis pontis from the superior temporal sulcus and superior temporal region in the rhesus monkey. *Journal of Computational Neurology,* 308, 224-248.

Schmahmann, J. D., & Pandya, D. N. (1993). Prelunate, occipitotemporal, and parahippocampal projections to the basis pontis in rhesus monkey. *Journal of Computational Neurology*, 337, 94-112.

Schmahmann, J. D., & Pandya, D. N. (1997). Anatomic organization of the basilar pontine projections from prefrontal cortices in rhesus monkey. *Journal of Neuroscience*, 17, 438-458.

Schmahmann, J. D., & Sherman, J. C. (1998). The cerebellar cognitive affective syndrome. *Brain*, 121, 561-579.

Scott, R. B., Stoodley, C. J., Anslow, P., Paul, C., Stein, J. F., Sugden, E. M., et al. (2001). Lateralized cognitive deficits in children following cerebellar lesions. *Developmental medicine and Child Neurology*, 43, 685-691.

Seigneuric, A., Ehrlich, M-F., Oakhill, J. V., & Yuill, N. M. (2000). Working memory resources and children's reading comprehension. *Reading and Writing*, 13 (1-2)

Shulman, G. L., & Petersen, S., E.(1993). A PET study of visuospatial attention. The *Journal of Neuroscience*, 13, 1202-1226.

Silveri, M. C., Leggio, M. G. & Molinari, M. (1994). The cerebellum contributes to linguistic production: a case of agrammatic speech following a right cerebellar lesion. *Brain*, 121, 2175-2187.

Strick, P. L., & Middleton, F. A. (1994). Anatomical evidence for cerebellar and basal ganglia involvement in higher cognitive function. *Science*, 266, 458-461.

Valdois, S., Carbonnel, S., Juphard, A., Baciu, M., Ans, B., Peyrin, C., & Segebarth, C. (2006). Polysyllabic pseudo-word processing in reading and lexical decision: Converging evidence from behavioral data, connectionist simulations and functional MRI. *Brain Research*, 1085(1), 149-162.

Vandana, V. P. (2007). *Speech Dimensions in Dysarthria with lesions in different cerebellar loci*. Unpublished Doctoral thesis submitted to Unversity of Mysore, Mysore.

Vandenberghe, R., Price, C., Wise, R., Josephs, O., & Frackowiak, R. S. (1996). Functional anatomy of a common semantic system for words and pictures. *Nature*, 383, 254-256.

Vilensky, J. A., & van Hoesen, G. W. (1981). Cortico-pontine projections from the cingulated cortex in the rhesus monkey. *Brain Research*, 205, 391-395.

Wallesch, C-W., & Horn, A. (1990). Long-term effects of cerebellar pathology on cognitive functions. *Brain and Cognition*, 14, 19-25.

APPENDIX 1

PROTOCOL TO ASSESS ORAL WORD READING DEFICITS

This protocol was developed specifically for the study. The protocol was developed considering the Test of Analysis of Acquired disorders of Reading in Kannada (Karanth, 1984). The protocol consists of five domains.

I. Visual Discrimination

Sl. No.	A	B	C	D	E
1.	rhtp sa:vi Key	fhtp ka:vi	rhtp sa:vi	thrp va:si	rtp s∂vi
2.	kpUfk; mirug∂m Animal	kpUjk; mirud̪∂m	fpUkk; kirum∂m	kpUfk; mirug∂m	kp&fhk; miru:g∂m
3.	Ngh po: To go	Ngh po:	ngh po	Nkh mo:	Ng pe:
4.	rYif s∂lugai Concession	jYif t̪∂lugai	rY}if s∂lu:gai	yRif l∂sugai	rYif s∂lugai
5.	mk;kh ∂mma: Mother	mg;gh ∂ppa:	mkhk; ∂ma:m	mk;kh ∂mma:	Mk;k a:mm∂
6.	Kj;J mut̪t̪u Pearl	%j;J m:ut̪u	Jk;K t̪umu	Kj;J mut̪u	Kr;R mutʃu
7.	igj;jpak; pait̪iy∂m Fool	itj;jpak vait̪iy∂m	igj;jpak; pait̪iy∂m	iga;apjk; paiyit̪∂m	igj;jpahk; pait̪iya:m
8.	ntw;wp	ntw;wp	ntw;wP	nwt;tp	nte;ep

	vɛṭri Sucess	vɛṭri	vɛṭri:	rɛvvi	vɛnni
9.	fha;r;ry; ka:itʃ∂l Fever	fha;r;ry; ka:itʃ∂l	jha;r;ry; ta:itʃ∂l	fa;r;ry; kaitʃ∂l	fhr;ay; ka:tʃj∂l
10.	thh;g;G va:rpu Mould	khh;G ma:rbu	thh;g;G va:rpu	th;g;G+ va:rpu:	ghh;T pa:rvu
11.	Gfo;e;j pug∂ḷnḏ∂ To be praised	Gjo;e;f puḏ∂ḷng∂	Gfho;e;j pug:ḷnḏ∂	Gfo;e;r pug∂ḷntʃ	Gfo;e;j pug∂ḷnḏ∂
12.	tha;f;fhy; va:ika:l Canal	tha;f;fy; va:ik∂l	tha;f;fhy; va:ika:l	gha;fhy; pa:ika:l	thf;ahy; va:kja:l
13.	vq;fs; ɛŋŋl Ours	Vq;fs; e:ŋŋl	vq;rs; ɛŋtʃl	vq;fs; ɛŋŋl	vq;sf; ɛŋḷ∂k
14.	Ch; u:r Town	Ch; u:r	ch; Ur	h;C ru:	th; v∂r
15.	gf;Ftk; p∂kkuv∂m Maturity	gt;Tfk; p∂vvuk∂m	gf;Fthk; p∂kkuva:m	kf;Ftk; m∂kkuv∂m	gf;Ftk; p∂kkuv∂m

II. Lexical Decision

1. ehL - na:ḍu (Country)
2. If;fhy; - aikka:l (NW)
3. neU - nɛru (NW)

4. NgQ - pe:nj∂ (NW)

5. rf;fuk; - tʃ∂k∂r∂m (Wheel)

6. miw - ∂rai (Room)

t

7. Fye;j - kuḷ∂nd̪∂ (NW)

8. Gj;jfk; - put̪∂g∂m (Book)

9. efEk; - n∂g∂num (NW)

10. ghsp - pa:ḷi (NW)

11. td;F - v∂ngu (NW)

12. tPjp - vi:d̪i: (Street)

13. fg;G - k∂ppu (NW)

14. jP - t̪i: (Fire)

15. Nfhd;D - ko:nnu NW

16. njhy;iy - t̪ollæ (Nuisance)

17. kdpjs; - m∂nid̪∂l (NW)

18. fhfpjk; - ka:gid̪∂m (Paper)

19. k#jp - masu:d̪i (Mosque)

20. mirT - asævu (Movement)

III Synonym Judgment

1	mr;rk; Fear atʃtʃ∂m	gak; Fear b∂j∂m
2	jfg;gd; Father t̪∂g∂pp∂n	je;ij Father t̪∂ndæ
3	fg;gy; Ship k∂pp∂l	glF Boat p∂ḍ∂gu
4	nra;As; Poem sɛjjuḷ	ghl;L Song pa:ṭṭu
5	gR Cow p∂su	M Cow a:
6	Nghh; Battle po:r	rz;il Fight s∂nḍai
7	G+ Flower pu:	kyh; Flower m∂l∂r
8	ngha; Lie poi	Vkhw;wk; Disappointment e:ma:ṭr∂m
9	ghh; To see pa:r	fz; Eye k∂ṇ
10	fij Story k∂d̪ai	fl;Liu Article k∂ṭṭuræ
11	fapW Rope k∂jiru	E}y; String nu:l
12	tPL Home vi:ḍu	Fif Cave gugai
13	Mfhak;	thdk;

	Sky a:ga:j∂m	Sky va:n∂m
14	Jd;gk; Sadness t̪unb∂m	rq;flk; Sadness saŋ∂ḍ∂m
15	Kfthp Address mug∂v∂ri	mQ;ry; Post andz∂l
16	ehw;fhyp Chair na:rka:li	Nkir Table me:sæ
17	jz;zPh; Water t̪∂ṇṇi:r	ePh; Water ni:r
18	mj;ij Paternal Aunt ∂t̪t̪ai	khkp Maternal Aunt ma:mi
19	md;id Mother ∂nnai	jha; Mother t̪a:i
20	neUg;G Fire nɛruppu	jP Fire t̪i:

IV Reading Words

1. *High and Low Imageability*

S.no.	*Low*	*S.no.*	*High*
1.	ngha; Lie poi	1.	gzk; Money p∂ṇ∂m
2.	,d;gk; Happiness inb∂m	2.	E}y; String nu:l

3.	fUiz Kindness k∂runai	3.	mhprp Paddy ∂risi
4.	gak; Fear b∂j∂m	4.	glF Boat p∂ḍ∂gu
5.	tpjp Fate vid̪i	5.	kyh; Flower m∂l∂r
6.	nfsutk; Pride g∂ur∂v∂m	6.	fhJ - Ear ka:d̪u
7.	cjtp Help ud̪∂vi	7.	tpsf;F Lamp viḷ∂kku
8.	Fzk; Quality guṇ∂m	8.	fhgp Coffee ka:pi
9.	fopj;jy; Subtract k∂ḷit̪∂l	9.	mk;kh Mother ∂mma:
10.	kd;dpg;G To Forgive m∂nnipu	10.	kuk; Tree m∂r∂m

***2**. High and Low Frequency*

S.no.	*Low*	*S.no.*	*High*
1.	gw;gir Tooth paste p∂rp∂sai	1.	ge;J Ball p∂nd̪u
2.	ikak; Concentration majj∂m	2.	kio - Rain m∂ḷai
3.	nfhzh;f To Bring koṇ∂rg∂	**3.**	Njq;fha; Coconut te:ŋa:i

4.	Nts;tp A Ritual ve:ḷvi	4.	it To Keep vai
5.	fPo;ik Of very low status ki:ḷmæ	5.	epyh - Moon nila:
6.	El;gk; Minute nuṭp∂m	6.	vy;yhk; All εlla:m
7.	mQ;ry; Post andz∂l	7.	gpr;ir Alms pitʃtʃ∂i
8.	ngha;if Waterfall poigai	8.	tz;b Vehicle v∂nḍi
9.	kFlk; - Crown m∂guḍ∂m	9.	fhJ - Ear ka:du
10.	thif - A type of a flower va:gai	10.	G+ - Flower pu:

V Reading Non-Words

S.no	LEGAL	*ILLEGAL*
1	gh;ik p∂rmai	drk; n∂s∂m
2	tz;K vaṇmu	oyh;k ḷ∂l∂rm∂
3	kho;R maḷsu	d;NgY nbe:lu
4	Njhh;j;jp ṯorṯi	w;Njo; rrṯe:l

5	Qhry nja:s∂l∂	spNQhl; linjo:t
6	,w; ir	f;Nohsp klo:li
7	irk;Nkh saimmo:	y;gpLkh lbiḍumo:
8	bk;Ngh ḍimbo:	DLq;hp nuduŋri
9	kq;fU m∂ŋ∂ru	wPrh rri:sa:
10	fs;bK k∂lḍimu	k;NqNyh mŋe:lo: