SUBTYPING OF CHILDREN WITH DEVELOPMENTAL DYSLEXIA: IMPLICATIONS FROM DUAL ROUTE CASCADED (DRC) MODEL IN THE INDIAN CONTEXT

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Dissertation submitted in part fulfillment

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

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<u>CERTIFICATE</u>

This is to certify that the dissertation entitled ***"Subtyping of Children with Developmental Dyslexia: Implications through Dual Route Cascaded (DRC) model in the Indian Context"*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Speech Language Pathology) of the student (Registration No.07SLP007). 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 other Diploma or Degree.

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DECLARATION

This dissertation entitled ***"Subtyping of Children with Developmental Dyslexia: Implications through Dual Route Cascaded (DRC) model in the Indian Context"*** is the result of my own study under the guidance of Ms. Jayashree.C.Shanbal, Lecturer in Language Pathology, Department of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any other University for the award of any Diploma or Degree.

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CHAPTER 1

Introduction

"Reading is to the mind what exercise is to the body".

- Richard Steele (1672-1729)

Literacy adopts the belief that reading, writing, speaking and listening processes are intertwined. Language and literacy are considered tools for thinking and communicating. When teachers plan meaningful ways for children to use language and literacy as tools, children are motivated to become readers and writers, and they learn about the features, forms, and functions of written and spoken language. Reading is a highly complex task that relies on the integration of visual, orthographic, phonological, and semantic information. The complexity of this task is clearly illustrated in recent computational models of reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; Perry, Ziegler, & Zorzi, 2007; Plaut, McClelland, Seidenberg, Patterson, 1996; Zorzi, Houghton, & Butter-worth, 1998).

Reading development in children

Reading is the process of understanding speech written down. The goal is to gain access to meaning. To acquire reading, children must learn the code used by their culture for representing speech as a series of visual symbols. The first step in becoming literate, therefore, require acquisition of the system for mapping between symbol and sound. Mastery of this system allows children to access thousands of words already present in their spoken lexicons. Children who are able to translate printed language into spoken language can usually, given their extensive spoken vocabularies and their syntactic knowledge, comprehend the meaning of print. This process of translating printed material into a speech-based form is commonly called decoding. Phonological decoding has often been considered to be an indispensible phenomenon for successful reading acquisition. This is because it functions as a self-teaching device, allowing children successfully to decode words that they have heard but never seen before (Ehri, 1992; Share, 1995).

Ehri's (1999) phases of reading acquisition are as follows,

a) Pre-alphabetic reading
b) Partial-alphabetic reading
c) Full alphabetic reading
d) Consolidated-alphabetic reading.

a) Pre-alphabetic reading

According to Ehri's (1999) theory, children begin reading in a pre-alphabetic phase, during which they use partial visual cues for word identification. This form of reading is also called as logographic stage, but the term visual cue reflects the finding that children reading this way, who may be pre-schoolers or kindergartners, are likely to use only part of the information available in a word to identify it.

Gough, Juel, and Griffith (1992) showed that this visual cue could be as arbitrary as a thumbprint on the card on which a word was printed. Similarly, Seymour and Elder (1986) found that very young readers read by relying on partial visual cues such as word-length, an approach that could lead to reading' rhinoceros' or children as '/tel-*-vizh-*n/'.To read using the partial visual cues of pre-alphabetic phase, children do not need to know anything about letter sounds or even the identity of letters.

b) Partial-alphabetic reading

This phase of development, is also been called as phonetic cue reading. Readers use their rudimentary knowledge of letter names or sounds to form partial connections between spelling and pronunciations (Ehri & Robbins, 1992). A child in this phase may read ‘slug’ as /snAl/, attending only to the words first letter and a picture or sentence context. In contrast to the readers in the pre-alphabetic stage, children are now attending to letter order and recognizing that letters imply sounds.

c) Full-alphabetic reading

This phase is also called as spelling-sound reading (Ehri& Robbins, 1992; Ehri & Mc Cormick, 1998; Juel, 1991).In this phase, the child is assumed to have an essentially complete system for reading words and pseudo-words. This system must include components that allow segmentation of written words into graphemes and fluent mappings of letter sequences onto phoneme sequences. Also in Ehri’s term, the child has a substantial sight word vocabulary of frequently occurring words.

d) Consolidated-alphabetic reading

Subsequent to the full-alphabetic phase, reading continues to become more fluent. What we call lexical process becomes stronger. (Ehri, 1999; Ehri & McCormick, 1998).In other words children's sight vocabulary continues to grow. Ehri and Mc Cormick (1998) suggested that child who move from full alphabet reading to consolidated reading would be able to read word in terms of its component grapho-syllabic units rather than sequencing of 10 phonemes. Ehri's Consolidated-alphabetic reading phase takes reading acquisition into a realm that is controversial and, to some extent, beyond the scope of current dual route models of reading.

To date, Dual Route Cascaded Model (DRC) by Coltheart, Rastle, Perry, Langdon and Ziegler (2001) is considered the most successful one in explaining visual word recognition and reading aloud (see Figure.1). As the name suggests, the DRC model has two core assumptions. First, processing throughout the model is cascaded. That is, any activation in earlier modules starts flowing to later modules immediately. Second, there are two routes for translating print into sound: a lexical route, which utilizes *word-specific knowledge,* and a non-lexical Grapheme-to-Phoneme Conversion (GPC) route, which utilizes a *sub-lexical spelling-sound* correspondence rule system. Another feature of DRC model is that processing is done in parallel. For example, all features across the stimulus array are extracted in parallel. Similarly, all the letter units are activated in parallel. Indeed, processing occurs in parallel within all modules except the GPC module, where processing is serial.

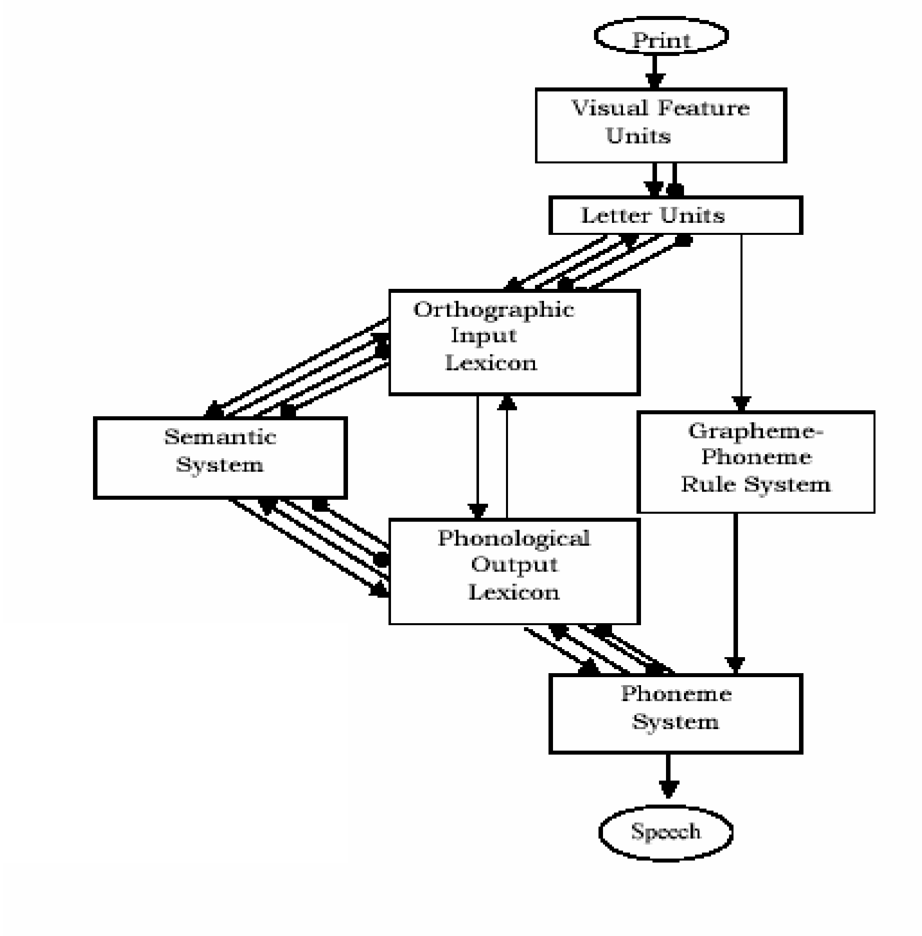


Figure1.Architecture of DRC model by Coltheart et al. (2001)

The lexical route translates the pronunciation of a word based on word specific knowledge. The route consists of components: the orthographic lexicon, semantic and the phonological lexicon, as seen in the left part of Figure1.The semantic system computes the *meaning* of a word, whereas the lexicons compute the words' *orthographic* and *phonological* form. Representations of a word in the orthographic lexicon and the phonological lexicon are linked so that activation in one leads to activation of the other. For instance, the letters "c," "a" and "t" will activate the orthographic representation of "cat," which will then activate its phonological representation of /kæt/. Frequency scaling is also applied to each orthographic and phonological lexicon. Thus, a high frequency word such as "the" will be named faster than a low frequency word such as "quench."

The non-lexical route differs from the lexical route in both the knowledge base and the type of processing it employs. The non-lexical route generates the pronunciation of letter string (be it a word or a non-word) via a set of *sub-lexical spelling-sound correspondence rules*. The set of rules is encapsulated in the GPC module. One important feature of the GPC module is that its processing is serial. The GPC module applies rules serially left to right to a letter. That is, letters activate phonemes in a serial, left to right fashion. Activation of the second phoneme does not start until a constant number of cycles after the start of activation of the first letter. For example, given a non-word like ‘bant’, the corresponding translation would be: B -> /b/, A -> /æ/, N ->/n/, and T -> /t/. Coltheart et al. (2001) argue that the non-word letter length effect produced by DRC model is a direct consequence of serial processing in the GPC module. That is, because GPC processes letters serially, the time to name a non-word increases as the length of non-word increases.

The lexical route utilizes word-specific knowledge to determine the corresponding pronunciation, whereas the non-lexical route translates graphemes into phonemes via a set of sub-lexical spelling-sound correspondence rules. Thus, given a word that is known to the reader, the correct pronunciation is quickly generated by the lexical route. A non-word that cannot be found in the orthographic lexicon and hence cannot be read by the lexical route can be read by the non-lexical route. Although the set of sub-lexical spelling-sound correspondence rules can also be applied when naming known words, the resulting pronunciation will regularize the pronunciation of exception words (e.g. PINT is pronounced /pInt/). Together, an intact system of lexical and non-lexical routes is capable of pronouncing both words and non-words.

According to the DRC model, successful reading depends on the interaction of sublexical and lexical procedures. Only when both of these procedures are functioning adequately, is then an individual able to read all forms of text. The sublexical procedure decodes novel letter strings via grapheme/ phoneme correspondence rules that exist in alphabetic writing systems. A break within the lexical or the sublexical routes can affect reading ability in a few children often referred to as children with dyslexia. The World Federation of Neurology definition of developmental dyslexia is a “learning disability which initially shows itself by difficulty in learning to read and later by erratic spelling and lack of facility in manipulating written as opposed to spoken words. The condition is cognitive in essence and usually genetically determined. It is not due to intellectual inadequacy, or to lack of socio-cultural opportunity, or to emotional factors, or to any known structural brain defect. It probably represents a specific maturational defect, which tends to lessen as child gets older and is capable of considerable improvement, especially when appropriate remedial help is afforded at the earliest opportunity” (Cited in Critchley & Critchley , 1978).

Although several different subtypes of acquired dyslexia have been proposed to equate to developmental dyslexia counterparts (e.g. Jorm, 1979; Rayner et al., 1989), the most influential corresponds to the auditory versus visual dichotomy. This phonological/surface classification was first considered within the framework of the Dual Route Model and, subsequently, by connectionist theories (Ellis, 1984, 1993), although the following brief account focuses on perspectives relevant to the procedures of Castles and Coltheart (1993). Castles and Coltheart (1993) proposed that these phonological and surface subtypes of acquired dyslexia also existed within the developmental dyslexic population. A break within the sublexical route results in the subtype of acquired dyslexia referred to as phonological dyslexia. Individuals who have acquired phonological dyslexia experience difficulties decoding unfamiliar words since the only way to read a novel letter string that is not represented in sight vocabulary is to implement some process of decoding (Funnell, 1983). The symptom most often associated with phonological dyslexia is, therefore, a difficulty with the reading of non-words or nonsense words like 'latsar' or'polmex'.

The second pathway for accessing pronunciation (the lexical procedure) treats written words as whole units. The visual or orthographic representation of a word is used to recover the connected pronunciation stored in the mental lexicon. This pathway represents the mechanism by which the sight vocabulary is accessed. Through this route, individuals are able to recognize words they have seen before and pronounce them without having to decode them. A break within the lexical procedure results in a subtype of acquired dyslexia referred to as surface dyslexia (Behrmann & Bub, 1992; McCarthy & Warrington, 1986).

Surface dyslexics, therefore, have difficulty accessing their sight vocabulary and have to rely on sublexical procedures to recover the pronunciation of a word. However, there are a sizeable number of phonetically irregular words within the English language that cannot be accurately pronounced via this sublexical route. For example, attempts to decode the irregular words 'pint',' have' and 'yatch' via grapheme–phoneme correspondence rules would result in pronunciations that rhyme with 'mint', 'save' and 'patch'. Such irregular words can only be read correctly by the lexical route. The defining characteristic of surface dyslexia is, therefore, a difficulty with reading irregular words. Thus, these are evidences of existence of subtypes in dyslexia of phonological and surface types.

Need for the study

Children with developmental dyslexia suffer from severe reading problems despite normal intelligence and teaching, and in the absence of an obvious sensory deficit (Snowling, 2001). Most of the research in developmental dyslexia has often strived to find a single unique deficit, e.g. a Cerebellar deficit (Nicolson, Fawcett & Dean, 2001), a rapid temporal processing deficit (Tallal & Piercy, 1973), a Magnocellular deficit (Stein & Walsh, 1997) or a phonological deficit (Snowling, 2001). There are in fact comparatively few studies that have investigated the relative importance of different or multiple components of reading and its deficits in children (Ramus et al., 2003; White, et al., 2006). So, each component of reading has to be investigated for the deficits at different levels of processing. This has been studied extensively using the DRC model (Coltheart et al., 2001). However, its application to clinical population is limited. There are few research studies who have adopted this psycholinguistic model of reading in Indian population (Shanbal & Prema, 2003) and further research need to be focused on how the various levels of processing in DRC model will help in developing various assessment tools and intervention strategies for the disordered population in India. Hence, there is a need to study the DRC model and its application to developmental dyslexia in Indian children.

There are two subtypes of developmental dyslexia found in previous research, as phonological and surface dyslexias, based on reading irregular words and non-words tasks (Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Griffiths &

Snowling, 2002). There are very few studies involved in interpreting the subtypes of developmental dyslexia whether it involves single dissociation deficits or double dissociation deficits based on dual route model (Ziegler, Castel, George, & Perry, 2008). The practical implication of DRC model of reading in the clinical population may give way to explaining delay or deficits in different component processes for reading.

Aims of the Study

The aims of the present study were

1. To assess each representational level of dual route cascade model in reading-letter level, orthographic lexicon, phonological lexicon and the phoneme system.

2. To investigate on the subtypes of developmental dyslexia which could be given a conceptual interpretation i.e. dyslexia as a unitary disorder or of heterogeneous type based on dual route model.

CHAPTER 2

Review of literature

This section will review various definitions to developmental dyslexia, theories existing to explain developmental dyslexia, discussing different subtypes of dyslexia and various developmental stage models that are used to substantiate reading process in developmental dyslexia.

The World Federation of Neurology definition of *developmental dyslexia is a "learning disability which initially shows itself by difficulty in learning to read and later by erratic spelling and lack of facility in manipulating written as opposed to spoken words. The condition is cognitive in essence and usually genetically determined. It is not due to intellectual inadequacy, or to lack of socio-cultural opportunity, or to emotional factors, or to any known structural brain defect. It probably represents a specific maturational defect, which tends to lessen as child gets older and is capable of considerable improvement, especially when appropriate remedial help is afforded at the earliest opportunity"* (Cited in Critchley, 1978).

Developmental dyslexia, also known as reading disability, is *a specific language-based disorder of constitutional origin characterized by difficulties in single word decoding, usually reflecting insufficient phonological processing. These difficulties in single word decoding are often unexpected in relation to age and other cognitive and academic abilities; they are not the result of generalized developmental disability or sensory impairment. Dyslexia is manifest by variable difficulty with* *different forms of language and often includes, in addition to problems with reading, a conspicuous problem with acquiring proficiency in writing and spelling. (the former Orton Dyslexia Society Research Committee and the National Institutes of Health, April, 1994, (cited in Lyon, 1995, p. 9; Wright & Groner, 1993).*

2.1 Theories on developmental dyslexics

Children with developmental dyslexia suffer from severe reading problems despite normal intelligence and teaching, and in the absence of any obvious sensory deficit (Snowling, 2000). While research on skilled reading has increasingly focused on the complex and dynamic interaction between various processes involved in reading (Van Orden, Jansen op de Haar, & Bosman, 1997), research in dyslexia has often strived to find a single unique deficit responsible for developmental dyslexia, for example, a cerebellar deficit (Nicolson, Fawcett, & Dean, 2001), a rapid temporal processing deficit (Tallal & Piercy, 1973), a magnocellular deficit (Stein & Walsh, 1997) or a phonological deficit (Snowling, 2001).

2.1.1 The phonological deficit theory

The role of phonology and awareness to the phonological structure of a lexical representation in learning to read and, hence, in failing to acquire that skill, is well represented in the literature on dyslexia. Phonological awareness refers to the ability to analyze words into consonant and vowel segments (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). This skill is related to learning the letters of the alphabetic system as the latter are symbols for sounds. Decoding words (relating graphemes to phonemes) requires efficient phoneme perception and analysis. Many studies have shown that the level of phonological awareness (as measured by tasks like phoneme blending: what word is /s//I//t/, and phoneme deletion: what word is sit without the /s/) in pre-schoolers is predictive of reading success Elbro (1996) .It has become clear that children with developmental dyslexia have difficulty with tasks tapping phonological awareness, indicating that dyslexia is related to the phonological component of language (Bryant, 1995; Elbro, 1996; Rack, 1994). In addition, children with developmental dyslexia perform more poorly than control children matched on the reading level of that of children with dyslexia, suggesting that poor phonological awareness is not primarily a consequence of poor reading. However, evidence is also given that being able to read enhances one's phonological awareness. When children learn to read, they are trained to link a phoneme to a grapheme. The individual phonemes of a word are being stressed and part of the process of reading acquisition involves breaking up words into sounds. The relationship between phonological awareness and reading thus seems to be reciprocal.

Dyslexic children across all languages so far studied show impairments in tasks that rely on the efficient functioning of the phonological system. Classically, they display deficits in three core areas:

(i) Phonological awareness (the ability to identify or manipulate sounds within words)

(ii) Phonological memory (the short-term retention of speech-based information)

(iii) Rapid production of familiar phonological labels in response to symbols (such as digit names, colour names, object names; this is often called 'rapid automatised naming' or RAN).

Tallal and Piercy (1973) who showed that children with developmental dysphasia display difficulties in discriminating (non-) speech tones that have a small inter-stimulus interval and in judging the temporal order of brief and rapidly presented (non-) speech sounds. Tallal (1980) proposed that children with specific reading difficulties are deficient in processing brief and rapidly changing acoustic information. With respect to speech perception this means that formant transitions of speech sounds, which are very brief acoustic events, will be hard to recognize. Therefore, discrimination of phonemes like stop consonants, which only contrast in their initial formant transitions, will be susceptible to impairment in contrast to vowels. This assumption is known as the temporal processing account.

Developmental dyslexia has been associated with poor phonological encoding. As verbal working Memory (WM) is dependent on the activation of phonological codes, a breakdown of the verbal working memory component is expected in dyslexia. Many studies have indeed found verbal memory difficulties (Jorm, 1983; Rack, 1994). For instance, the rhyme effect appears to be less detrimental in subjects with dyslexia compared to normal readers.

A comparison of dyslexic subjects with reading-level-matched controls shows that the rhyme effect in dyslexic individuals is comparable to that in the controls suggesting that dyslexic subjects make use of phonological codes but are less efficient in doing so (Rack, 1994).Van der Leij (1998) argues that measuring verbal short term memory with digit span tasks using meaningful verbal information may not be the best way since ‘top down’ knowledge may interfere with performance. For example, when words need to be remembered a certain level of language skill is required. Pseudoword repetition may be a better task as it measures more directly the ability to hold a phonological code in short term memory. Investigations show that pseudo-word repetition is often impaired in dyslexic children compared to age-matched controls and, more importantly, to reading-matched controls (Snowling, Stackouse, & Rack, 1986; Van der Leij, 1995).

Gathercole and Baddeley (1993) propose that verbal working memory is involved in the long term learning of the grapheme to phoneme mapping rules that are crucial in the process of literacy acquisition. Furthermore, phonological working memory is necessary for the temporary storage of sound segments of a word that a child is trying to identify by applying grapheme to phoneme rules. It is not hard to envisage how phonological awareness and WM are complementary and how they are combined in the development of reading acquisition. Awareness of the phonological structure of a word is necessary for segmenting off all the phonemes within a word that need to be linked to graphemes. This process calls upon a storage system (the phonological loop) and, hence, adequate memory skills enable the learning of phoneme to grapheme conversion rules that need to be applied to the segmented phonemes (Gathercole & Baddeley, 1993).

2.1.2 Visual processing deficits in dyslexias

The visual theory (Livingstone , Rosen, Drislane, & Galaburda,1991; Stein and Walsh, 1997) reflects another long standing tradition in the study of dyslexia, that of considering it as a visual impairment giving rise to difficulties with the processing of letters and words on a page of text. This may take the form of unstable binocular fixations, poor vergence, or increased visual crowding. The visual theory does not exclude a phonological deficit, but emphasizes a visual contribution to reading problems, at least in some dyslexic individuals. At the biological level, the proposed etiology of the visual dysfunction is based on the division of the visual system into two distinct pathways that have different roles and properties: the magnocellular and parvocellular pathways. The theory postulates that the magnocellular pathway is selectively disrupted in certain dyslexic individuals, leading to deficiencies in visual processing, and, via the posterior parietal cortex, to abnormal binocular control and visuospatial attention. Evidence for magnocellular dysfunction comes from anatomical studies showing abnormalities of the magnocellular layers of the lateral geniculate nucleus (Livingstone et al., 1991), psychophysical studies showing decreased sensitivity in the magnocellular range, i.e. low spatial frequencies and high temporal frequencies in dyslexics, and brain imaging studies

Earlier research was therefore focused on trying to identify perceptual factors that could contribute to dyslexia. Visual deficit explanations fell out of favor during the 1970’s and 1980’s when psychologists increasingly adopted a phonological deficit model of dyslexia, arguing that reading difficulties reflect primary problems with language processing. While the phonological deficit explanation is still popular and widely researched, there has been a resurgence of interest in the idea that there may be an underlying visual deficit that could explain difficulties in learning visual-phonological correspondences (Everatt, 1999; Whiteley & Smith, 2001).

More recently, the evidence for visual-sensory processing deficits in dyslexia has become robust. The challenge now is to determine whether these visual-perceptual problems affect the development of visual processing required for fluent and skilled reading, and if so how. Seymour (1986) has re-emphasised the obvious point that the cognitive systems specifically required for *written language* (as opposed to spoken language) are actually in the visual domain. He and others have shown that the reading performance of many dyslexic people reflects weaknesses in visual processing that can occur independently of phonological difficulties.

It has been claimed that phonological deficits are more common than visual deficits in dyslexia, and the fact that many dyslexic people show superior visual-spatial abilities is cited as supporting evidence. The trouble with this argument is that the psychological tests used to assess visuo-spatial abilities do not actually measure the same kinds of visual processing that Seymour refers to, which is more perceptual in nature. In fact, mild visual disturbances are consistently found in up to 70 per cent of individuals with dyslexia, and more importantly, these typically co-occur with phonological problems (Lovegrove, 1991). It has even been suggested that both types of problem might have a common cause.

It is misleading to think either that visual-perceptual and phonological problems must be mutually exclusive, or that all people with specific reading difficulties are the same. What is more, variation in the ‘clinical’ picture of dyslexia (at either the behavioural or the cognitive level of Frith's model) does not in fact rule out some common underlying ‘cause’ at the biological level. The complex interactions between biology and environment mean that the same biological ‘problem’ can result in different cognitive and behavioural consequences for different people.

2.1.3 Magnocellular system deficit

The magnocellular theory (Stein and Walsh, 1997) postulate that the magnocellular dysfunction is not restricted to the visual pathways, but generalised to all modalities (visual, auditory, as well as tactile). Furthermore, as the cerebellum receives massive input from various magnocellular systems in the brain, it is also predicted to be affected by the general magnocellular defect (Stein, 2001). Through a single biological cause, this theory therefore manages to account for all known manifestations of dyslexia: visual, auditory, tactile, motor, and, consequently, phonological. Beyond the evidence pertaining to each of the previously described theories, evidence specifically relevant to the magnocellular theory include magnocellular abnormalities in the medial as well as the lateral geniculate nucleus of dyslexics' brains, poor performance of dyslexics in the tactile domain (Stoodley, Talcott, Carter, Witton &Stein, 2000), and the co-occurrence of visual and auditory problems in certain dyslexics (Van Ingelghem et al., 2005; Witton et al., 1998).

A fundamental visual processing deficit that has received recent attention is the magnocellular system that predominates in peripheral vision and is thought to specialize in processing transient stimuli, thus detecting flicker or motion (Lovegrove, 1996). At present the evidence is inconsistent over studies and difficult to interpret (Hogben, 1996). If this processing deficit in perceptual tasks is to be tied to deficits in Orthographic Processing Skills, it is necessary to provide an empirically supported causal story that links a clearly identified magnocellular deficit with sequential processing of letters, and in turn, with Orthographic Processing Skills. One difficulty in making these links is that deficits in magnocellular function are more readily applied to reading connected text rather than individual word decoding, and thus may not apply to the single-word reading tests that are the focus of the literature on Orthographic Processing Skills (Lovegrove, 1993).

2.1.4 The automaticity/cerebellar theory

The automaticity/cerebellar theory of dyslexia (Nicolson & Fawcett, 1990; Nicolson, Fawcett, & Dean, 2001) (Henceforth, the cerebellar theory). Here the biological claim is that dyslexics' cerebellum would be mildly dysfunctional, and that a number of cognitive difficulties ensue. First, the cerebellum plays a role in motor control, and therefore, in speech articulation. It is postulated that retarded or dysfunctional articulation would lead to deficient phonological representations. Second, the cerebellum plays a role in the automatisation of overlearned tasks, such as driving, typing, reading, etc. A weak capacity to automatise would affect, among other things, the learning of grapheme-phoneme correspondences. Support for the cerebellar theory comes from evidence of poor dyslexic performance in a large number of motor tasks (Fawcett, Nicolson, & Dean, 1996), in dual tasks demonstrating impaired automatisation of balance (Nicolson & Fawcett, 1990), and in time estimation, a non-motor cerebellar task (Nicolson, Fawcett & Dean, 1995). Brain imaging studies have also shown anatomical, metabolic and activation differences in dyslexics' cerebellum (Brown et al., 2001; Leonard et al., 2001; Rae et al., 1998).

2.2 Individual differences in dyslexia

The most serious issue of the phonological representation view among the researchers is the individual differences. The phonological deficit theory has no difficulty in explaining the problems of child with poor word attack skills, unable to read non-words and their spelling is dysphonetic (Snowling,Stackhouse &

Rack,1986).and there are some dyslexic children who tend to pronounce irregular words as regular (glove-gloave),difficulty in distinguishing between homophones(pear-pair, leak-leek)and their spelling is phonetic.

While evidence in favor of distinct subtypes are lacking (Seymour, 1986) and most systematic studies of individual differences among dyslexics have revealed variations in their reading skills (Castles and Coltheart, 1993).A number of studies have shown that dyslexic children who have relatively more difficulty in reading non-words than exceptional words (phonological dyslexia) perform significantly less well than younger, reading age matched controls on tests of phonological awareness. In contrast dyslexic children who have more difficulty with exceptional words than nonwords (surface dyslexia) perform a similar level to controls in these tests.

More generally, it does not seem useful to classify dyslexic children into subtypes because all taxonomies leave a substantial number of children unclassified (Griffiths, 1999). Rather Snowling (2000) found that individual difference in the phonological processing, as measured on tests of phonological awareness and phonological memory predict individual difference in non-word reading, even when reading age been taken into account. In essence more severe a child's phonological deficit, the grater is impairment in nonword reading. In contrast, the variation in exception word reading was tied to the reading experience, reflecting the fact that print exposure is required to learn about the inconsistencies in English orthographic system.

2.2.1 Subtypes of Developmental dyslexias in literature.

Although several different subtypes of acquired dyslexia have been proposed to equate to developmental dyslexia counterparts (e.g. Jorm, 1979; Rayner, Murphy, Henderson, & Pollatsek, (1989) the most influential corresponds to the auditory versus visual dichotomy. This phonological/surface classification was first considered within the framework of the Dual Route Model and, subsequently, by connectionist theories (Ellis, 1984, 1993), although the following brief account focuses on perspectives relevant to the procedures of Castles and Coltheart (1993). Castles and Coltheart (1993) proposed that these phonological and surface subtypes of acquired dyslexia also existed within the developmental dyslexic population.

Castles and Coltheart (1993) tested a sample of 53 poor readers on their ability to read aloud sets of irregular words and nonwords. Based on their scores on these tasks, eight subjects were identified as pure developmental phonological dyslexics: Their nonword reading was poor, compared with chronological age- matched controls, but their exception word reading was within normal range. Another 10 subjects were classified as pure developmental surface dyslexics: Their exception word reading was poor but their nonword reading fell within normal range. A further 27 subjects were poor on both tasks and were therefore not classified as “pure” cases, but nevertheless showed a significant discrepancy between their scores on the exception word and nonword tasks. Castles and Coltheart (1993) concluded that these results were best interpreted in terms of a dual route model, with the subtype profiles representing different levels of development of the lexical and nonlexical procedures.

A break within the sublexical route results in the subtype of acquired dyslexia referred to as phonological dyslexia. Individuals who have acquired phonological dyslexia experience difficulties decoding unfamiliar words since the only way to read a novel letter string that is not represented in sight vocabulary is to implement some process of decoding (Funnell, 1983). The symptom most often associated with phonological dyslexia is, therefore, a difficulty with the reading of non-words or nonsense words like 'latsar' or'polmex'.

The second pathway for accessing pronunciation (the lexical procedure) treats written words as whole units. The visual or orthographic representation of a word is used to recover the connected pronunciation stored in the mental lexicon. This pathway represents the mechanism by which the sight vocabulary is accessed. Through this route, individuals are able to recognize words they have seen before and pronounce them without having to decode them. A break within the lexical procedure results in a subtype of acquired dyslexia referred to as surface dyslexia (Behrmann & Bub, 1992; McCarthy & Warrington, 1986).

Surface dyslexics, therefore, have difficulty accessing their sight vocabulary and have to rely on sublexical procedures to recover the pronunciation of a word. However, there are a sizeable number of phonetically irregular words within the English language that cannot be accurately pronounced via this sublexical route. For example, attempts to decode the irregular words 'pint',' have' and 'yatch' via grapheme–phoneme correspondence rules would result in pronunciations that rhyme with 'mint', 'save' and 'patch'. Such irregular words can only be read correctly by the lexical route. The defining characteristic of surface dyslexia is, therefore, a difficulty with reading irregular words. Previous research has identified two prominent subtypes of dyslexics who have relatively selective deficits when reading irregular words and nonwords (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, &

Petersen, 1996; Griffiths & Snowling, 2002; Ziegler, Castel, George& Perry, 2008). In particular, surface dyslexics are poor at irregular word but relatively normal at non word reading. In contrast, phonological dyslexics are poor at nonword but relatively normal at irregular word reading.

Coltheart, Besner, Jonasson and Davelaar (1979) found that the lexical decision response time was the same for regular and irregular words, suggesting that words are always read via the direct route. There are 2 possible explanations for this: The phonological recoding of the GPC route could be much slower than the direct access route, such that direct access will always win. Perhaps, words are read by the direct route and Nonwords by the GPC route.

This is only plausible if we assume in the first instance that everything we come across is a word until we try to read it lexically. If we fail to find a matching lexical item then we use the non-lexical route. No current model of reading has proposed this approach, so it is probable that the GPC recoding route is just relatively slow.

2.2.2 Phonological processing problems in developmental dyslexics

a. Phonological awareness

According to the phonological deficit hypothesis, developmental dyslexia is a language-specific disorder stemming from impairment in the speech processing system (Frith, 1985; Snowling, 2000).It is hypothesized that dyslexics' representations of speech sounds (phonological representations) are coarsely coded, under-specified or noisy (Elbro, 1996; Snowling, 2000). These inaccurate representations in turn would cause reading and writing difficulties as well as the more direct phonological symptoms of dyslexia.

Symptoms of the deficit are highlighted by three main types of tasks. Firstly, dyslexics perform poorly on tasks which require phonological awareness, for instance paying attention to and manipulating individual speech sounds (Snowling, 2000). Secondly, they are ill-at-ease when required to name series of objects (rapid automatic naming) rapidly. Thirdly, their verbal short-term memory is reported to be deficient compared to controls: This is manifested by a lower memory span and poor nonword repetition, and impacts negatively on list learning, story recall, paired-associate learning, and the more complex phonological awareness tasks such as spoonerisms (Blomert & Mitterer, 2004; Tijms, 2004).

Children with phonological processing deficits, called dysphonetics or phonological dyslexics (Milne, Hamm, Kirk, & Corballis, 2003; Vila Abad & Babero Garcia, 2002), or with a visual deficit slowing direct access to the lexicon, called dyseidetics (Milne et al., 2003). The mixed group, dysphoneidetics (Boder, 1970), is assumed to be affected by both deficits. Coltheart and Castles (1993) have compared two children who displayed a phonological dyslexic style of reading (in reading words significantly better than non words), with two children who resembled surface dyslexia (in reading irregular words significantly less than regular words). The two children who showed a phonological dyslexic profile had more difficulty with phonological processing than the two who showed a surface dyslexia profile as measured by tests of rhyme, non-word repetition and spelling. However even the surface dyslexics were worse on the phonological tasks than normal readers of the same age. These findings are in line with the hypothesis that dyslexic reading difficulties stem from phonological processing problems. However, they suggest that the severity of children's phonological difficulties can affect the way in which their reading system becomes set up- and whether they look like phonological or surface dyslexics.

Investigations of acquired dyslexia suggested that word reading is based on a Dual Route System; one of which, for high-frequency words, is a direct route from the visual word form to the word's phonology and meaning, whereas for low-frequency words a second route to the lexicon proceeds via a grapheme-to-phoneme conversion rule in which individual letters are mapped onto phonological units before these are assembled into a phonological word form (Coltheart , Curtis , Atkins, & Haller, 1993; Coltheart & Rastle, 1994; Ellis, 1984; Joubert & Lecours, 2000). The latter system has to be activated during non-word reading. In reading meaningful text it is likely that both routes are always - more or less - activated (Booth, Perfetti & MacWhinney, 1999; Friederici & Lachmann, 2002).Nevertheless, it was concluded that problems in one or the other processing route may cause different reading failures. Thus, the performance in non-word reading vs. frequent word reading was suggested as a tool to differentiate between these groups (Coltheart, 1996; Stein, 2002).

A specific deficit in phonological awareness and more specifically phonemic awareness is expected for phonological dyslexics, task involving deleting the first or the last segment of the word, either a syllable or phoneme, was used in a study by Stanovich, Siegel and Gottardo (1997).Whereas, the scores of the phonological and mixed profile dyslexics were found to lag behind those of the reading level controls, those of the surface dyslexics were comparable to the scores of the reading level controls. A similar result were observed in a study by Manis, Seidenberg, Doi, McBride-Chang and Petersen (1996) for phonemic awareness task where the scores of the phonological dyslexics were consistently lower than those of the reading level controls where those of the surface dyslexics were not.

Manis, Seidenberg and Doi (1999) showed that their two groups of surface and phonological dyslexics had comparable low scores on the print exposure measure they used. They suggested that low print exposure would result in a phonological dyslexic pattern in poor readers with a severe phonological deficit but in surface dyslexia pattern in children with milder phonological pattern. Phonological discrimination is known to be an indicator for the quality of phonological coding/ decoding (Cornelissen, Richardson ,Mason, Fowler, & Stein, 1996;; Fuchs & Lachmann, 2003;Manis et al., 1997). However, there is a serious discourse about whether phonological deficits are due to a more general, that is, a non-linguistic, auditory low-level dysfunction, such as a temporal processing deficit, either of general nature (Facoetti, Lorusso, Paganoni , Umilta & Mascetti, 2003 ; Klein, 2002; Stein, 2002;) or specific to the auditory domain(Kujala, 2002; Rey, De Martino, Espesser & Habib., 2002; Tallal, 1980,). According to a number of authors (Farmer & Klein, 1995; Helenius, Utela, & Hari, 1999; Tallal, 1980), low-level processing deficits cause problems in discriminating rapid temporal changes (as are typical of speech), and thus, disturb the adequate development of phonological codes from an early age in childhood. Other authors failed to find low-level auditory deficits in dyslexics (Chiappe, Stringer, Siegel, &Stanovich, 2002).

Zabel and Everatt (2002) found that phonological dyslexics behave in a same way as surface dyslexics on four tasks requiring phonological processing(pseudo-word reading task, a spoonerism task, an alliteration task, and a rhyme fluency task),both in accuracy and speed. Furthermore, no statistical differences between phonological and surface dyslexics were found in the rapid naming of pictures or digits, again, no matter what measure used (accuracy and speed).Jimenez-Gonzalez and Ramirez-Santana (2002) also found there was no difference between phonological and surface dyslexics in phonological awareness.

Several Investigators (Werker & Tees, 1987; Reed, 1989; Mody, Studdert-Kennedy, & Brady, 1997) have contributed to the evidence that dyslexia is associated with auditory perceptual problems. Dyslexic children have repeatedly shown less consistent identification of consonant-vowel pairs ([ba]-[da], [sa]-[sta], [da]-[ga]) at a synthetic continuum, even at the extreme ends of the continua. The nature of the auditory problems is up to present date a hotly debated issue. Many claims have been made on the specificity of the sounds (speech versus non-speech sounds) and the properties of sounds (influence of duration, loudness) that are supposed to play a role in the perceptual problems of dyslexic children. Abstracting away from the controversy around the nature of the deficit, ample evidence has been brought out over the years that speech perception is affected in developmental dyslexia.

b. Nonword reading

Siegel (1993) Pseudoword reading is the golden standard for assessing the deficits of dyslexics phonological reading route. This pseudoword reading has 100% reliability when measured by either response accuracy or latency.

Rack, Snowling and Olson (1992) reviewed a number studies on nonword reading in developmental dyslexia in English ,they found nonword reading deficits in dyslexic children compared to reading level matched children. Error rates were high typically between 40% to 60%. Rack et al., (1992) noted that English studies which did not find a nonword reading deficits in dyslexic children in comparison with reading level match typically used young readers (7years) as controls and used nonwords with relatively similar orthographic patterns.(e.g. loast-[toast]).They argued that young English readers are relatively poor at nonword reading and they concluded that nonwords with familiar nonword analogies(like –oast in loast) are not the best test of phoneme-grapheme recoding skills.

Landerl , Wimmer and Firth (1997) studied nonword reading in 12years old English dyslexic children and8 years reading level matched controls and the nonwords were of 1,2 and 3 syllables in length. The authors found that dyslexic children performed poorer in nonword reading than the reading level matched controls. These difficulties were found at all syllable lengths, both groups performed poorly with the difficult 3-syllable words. For these words dyslexic children performed about 30% correct and reading level controls performed 40% correct.

In phonological dyslexia, non-word reading shows a deficit while word reading remains intact (Cestnick & Coltheart, 1999; Southwood & Chatterjee, 2001). In another study, Ferrand (2000) found longer latency for naming multi-syllabic low frequency words and non-words in French than naming their monosyllabic counterpart but no such effect is found in high frequency words. Taken the arguments from the two studies together, the lexicalization of high frequency words depends largely on the lexical route while that of low frequency words and non-words depends largely on the sublexical route.

c. Rapid picture naming

Speeded naming of pictures, colours or letters has been found to be a predictor of reading ability (De Jong & Van der Leij, 1999; Wolf et al., 2002). Whereas some researchers view rapid naming ability to be a reflection of general phonological ability (Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997), Wolf and co-workers (Wolf & Bowers, 1999; Wolf et al., 2002) argue that deficits in rapid naming are a separate source for reading difficulties, independent from phonological deficits. The ‘double deficit hypothesis’ assumes that children with reading disability may either suffer from a phonological deficit, a naming speed deficit, or from both deficits. Empirical evidence comes from Wolf et al. (2002) who found that in a sample of reading disabled children, 60% of the children were found to be impaired in both rapid naming and in phonological awareness, 15% of the children were selectively impaired in rapid naming and that 19% of the children only had deficits in phonological awareness.

Here a phonological representation needs to be retrieved from the lexicon and needs to be matched to a symbol that is visually perceived. As naming of colours (and objects) precedes reading, the idea was that this may be a predictor of reading (Geschwind, 1965). Denckla and Rudel (1974) discovered that is was not so much the accuracy of colour and object naming itself, but the naming speed that differentiated between children with dyslexia and normally reading children. A naming speed deficits was found to persist over 9years in at least some of the dyslexic individuals studied by Korhonen (1995) and it is likely that difficulty in rapid naming is a unremitting problem in dyslexic children (Felton, Naylor, &Wood, 1990).

Denkla and Rudel (1976) dyslexics for the rapid serial naming of objects performed slower not only than controls who read at an age appropriate level but also other learning disabled children matched for reading age. Guy, Griffin and Hynd (2000) also reported that young reading disabled children(less than 12.3 yrs old) were slower and more error prone in naming series of letters, digits and objects than both control readers of the same age and children with the diagnosis of attention deficit hyperactive disorder. Ahissar (2007) also stated that the perceptual anchor theory can account for deficits in RAN according to which if a smaller number of stimulus items are presented repeatedly the deficits were stronger in CWD.

2.2.3 Letter recognition and orientation problems in dyslexia

In the earliest stages of exposure to print, visual (surface) dyslexics have great difficulty recognizing numbers and letters, and even after they can read quite well, they still have a serious problem recalling how words look (Willows & Terepocki, 1993). It is necessary to draw on stored orthographic images for reading of irregular words. Insufficient attention to individual letters would seem to lead to inaccurate orthographic representations (Foorman, 1994). Even for skilled readers, visual processing of individual letters in words is important (Adams & Bruck, 1993). Further, if orthographic imagery for single letters is unstable, establishing automatic orthographic-phonological connections will be impeded. Detailed visual information, including the orientation of letters, influences the whole process of phonological and semantic decoding (Lachmann, 2002).

Terepocki, Kruk, and Willows (2002) compared 10-year-old average readers and children with reading disability. The children with reading disability made more orientation errors than average readers on computer-based reversal detection tasks (numbers, letters, letter strings, words), and more reversal errors on controlled writing tasks. The two groups did not differ on attention control tasks, however. The authors suggest that the reading disabled group's difficulties in discriminating similar looking items could be due to poorly specified representations of letters. They concluded that although reversal errors are likely to disappear in children with reading disability as their reading and writing skills improve, the consequences of early letter orientation errors need further study.

2.2.4 Orthographical processing in developmental dyslexics

The word superiority effect (WSE) was first established as a basic phenomenon related to reading ability in the work of Cattell (1886). Cattell showed that people could recall more letters from briefly presented words than briefly presented meaningless strings of letters. Henderson (1982) interpreted this finding as ruling out a letter based account of visual word recognition.

The word superiority effect refers to better identification of a target letter when it is embedded in real words than when it is embedded in nonwords (Reicher, 1969). Investigators (Ziegler & Jacobs, 1995; Ziegler, Van Orden, & Jacobs, 1997) studied the position-specific letter processing and the functioning of the ortho-graphic lexicon, they used a letter search task, in which participants had to identify whether a pre-specified target letter was present in an unpronounceable consonant string (e.g., FXVRN) or a word Looking at letter search performance in unpronounceable consonants allows us to test the efficiency of letter processing without any lexical activation. To investigate the functioning of the orthographic lexicon, they used the word superiority effect.

In classic word recognition models, the word superiority effect is modeled by assuming either feedback from the orthographic lexicon (McClelland & Rumelhart, 1981) or the joint integration of letter-level and word-level orthographic information (Grainger & Jacobs, 1994). In both cases, the existence of a word superiority effect necessitates relatively efficient access to the orthographic lexicon. Indeed, previous work has shown that dyslexic children with severe phonological problems can show a normal word superiority effect (Grainger, Bouttevin, Truc, Bastien, & Ziegler, 2003), which suggests that orthographic access is possible even when phonological processing is impaired.

In a classical dual-route model (Coltheart, 1980), orthography feeds forward to phonology, which feeds forward to semantics, and orthography may alternatively feed forward to semantics directly. On the other hand, in interactive activation a model, orthography does not just feed forward to phonology; rather, the connections between components are bidirectional, allowing for feedback between levels and complex interactions between different sources of information. Whatmough, Martin and Daniel (1999) conducted a cross-modal priming experiment and found that in addition to orthography activating phonology, phonological information appears to be able to activate orthographic representations. Thus, activation and suppression arising from ‘backward’ links between different levels should also be taken in consideration when analyzing psycholinguistic data.

2.2.5 Computational models of Reading

There are various models of reading proposed in the literature to explain development of reading in general and their application in children with dyslexia. Some of these models have been described in the following sections.

The Logogen Model

In this model, every word we know has simple feature counter called a logogen corresponding to it. A logogen accumulates evidence until its individual threshold level is reached. When this happens, the word is recognized. Lexical access is therefore direct and occurs simultaneously and in parallel for all words. Proposed by Morton (1969, 1970), it was related to the information processing ideas of features and demons. It was originally formulated to explain context effects in tachistoscopic recognition, but has been extended to account for many word recognition phenomena.

Each logogen unit has a resting level of energy called activation. As it receives corroborating evidence that it corresponds to the stimulus presented, its activation level increases. Hence, if a letter “t” is identified in the input, the activation levels of all logogens that corresponds to words containing a “t” will increase. If the activation level manages to pass a threshold, the logogen “fires” and the word is “recognized”. Both perceptual and contextual evidence will increase the activation level. That is, there is no distinction between evidence for a word form external and internal sources. Context increases a logogen’s activation level just as relevant sensory data do.

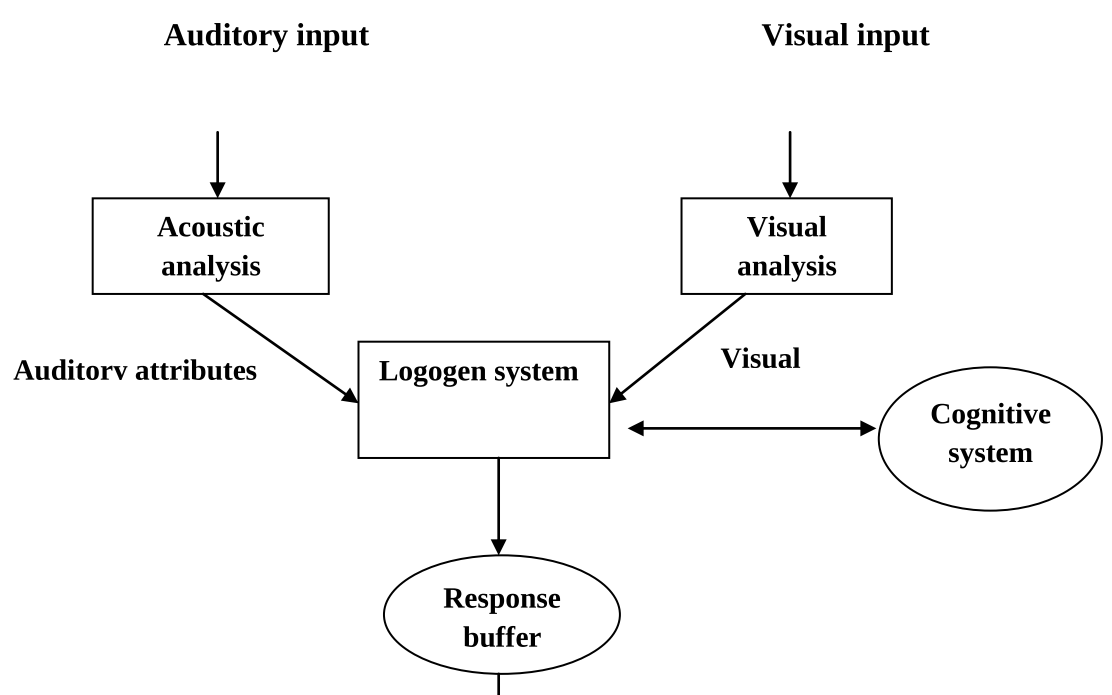


Figure 2: Logogen Model (Morton, 1979)

Any use of the logogen will give rise to subsequent facilitation by lowering the threshold of that logogen. More frequent items have lower thresholds. Nonwords will be rejected if no logogen has fired by the time a deadline has passed. Logogens compute phonological codes from auditory and visual word analysis and also pass input after detection to the cognitive system. The cognitive system does all the other work, such as using semantic information. The connections are bi-directional, as semantic and contextual information from the cognitive system can affect logogens.

Revised Logogen model

In the original logogen model, a single logogen carried out all language tasks for a particular word, regardless of modality. That is, the same logogen would be used for recognizing speech and visually presented words, and for speaking and for writing. The model predicts that the modality of source of activation of a logogen should not matter. For example, visual recognition of a word should be as equally facilitated by a spoken prime as by a visual prime. Subsequent experiments contradicted this prediction.

Winnick and Daniel (1970) showed that the prior reading aloud of a printed word. However, naming a picture or producing a word in response to a definition produced no subsequent facilitation of tachistoscopic recognition of those words. That is, different modalities produce different amounts of facilitation. Morton divided the word recognition system into different sets of logogens for different modalities (e.g.: input and output). Morton (1979) also showed that although modality of response appeared to be immaterial (reading or speaking a word in the training phase), the input modality did matter. The model was revised so that instead of one logogen word for each word, there were two modality specific ones. The consequence of this change ensured that only visual inputs could facilitate subsequent visual identification of words and that auditorily presented primes would not facilitate visually presented targets in tachistoscopic recognition subsequent evidence suggests that 4 logogen systems are necessary: one for reading, one for writing, one for listening and one for speaking.

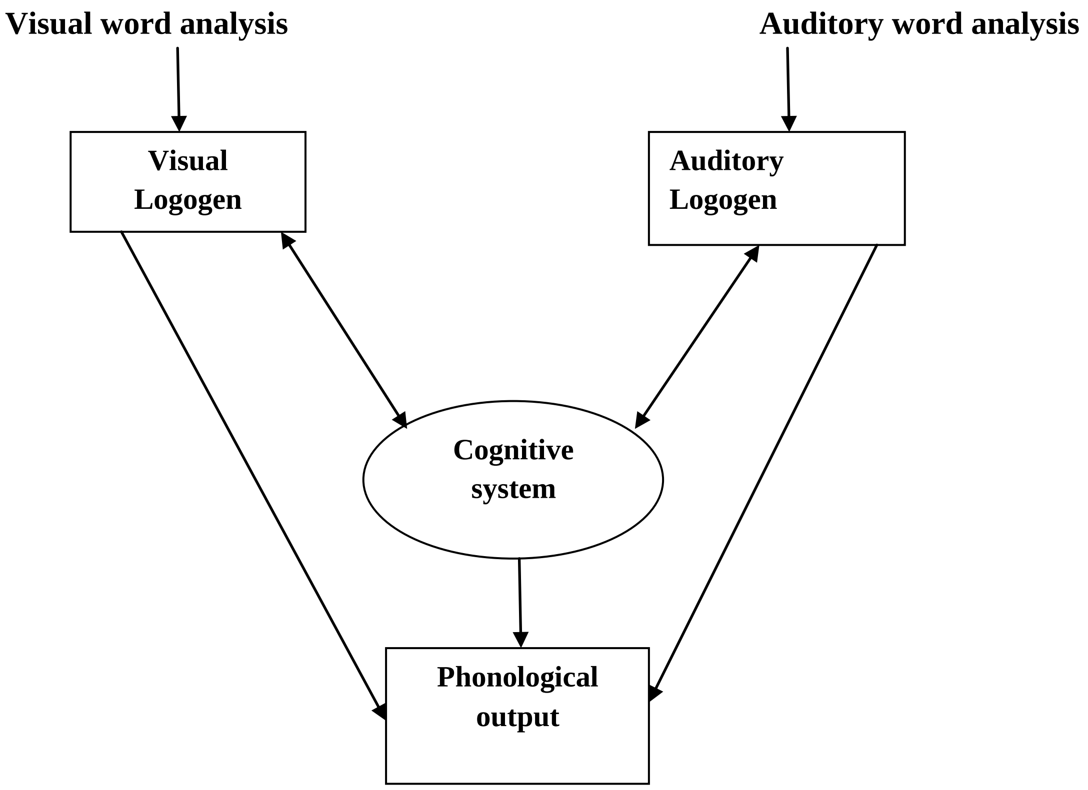


Figure 3. Revised logogen model

The Connectionist Model

This was developed to account for lexical decision tasks and word naming tasks by Seidenberg and McClelland (1989). There is no lexicon. It has distributed representations that do not have a single representation like a lexicon with lexemes that represents single words, for example, dog. There is no dog node; the word is recognized by it s unique pattern of orthographic activation distributed in the network.

The model is largely determined by the characteristics of orthography. The model tries to show how a lexical processing system develops when influenced by a spelling-to-sound learning regime. Regular and irregular words are learned through experience with spelling-sound correspondence. There is no mechanism which looks words, no lexicon and no set of phonological rules. The key feature is that there is a single procedure for computing phonological representations from orthographic representations that works for regular words, exceptional words, and non words.

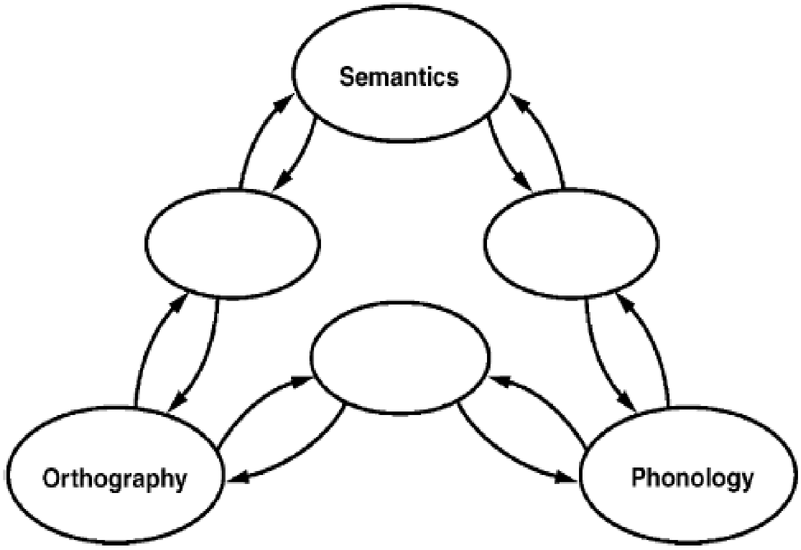


Figure 4. Theoretical framework (Seidenberg & McClelland, 1989).

The Seidenberg and McClelland (1989) model has a set of input units that translate the orthography of the stimulus along with a set of output units that represent the stimulus' phonology. The input units are connected to a group of hidden units. The hidden units' only inputs and outputs are within the system being modeled, and they are not connected by external systems. The hidden units are connected to the phonological output units. The weights (strength of association) connecting input and output are adjusted according to a back- propagation rule that is adjusted to reduce the difference between outputs units and "correct" pronunciation. Feedback (correction) adjusts the association between the outputs and correct target. There are no priority weights between the input and output units before learning begin. The weights are established by the feedback in the back propagation process. In the training phase of the model's development, The Seidenberg and McClelland fed the model 2,897 monosyllabic English words at a rate that reflected their frequency of usage in the language. The model produced phonology that corresponded to regular words high frequency exception words (e.g. have) and novel non words.

In an important way, this model captures the frequency-by-regularity interaction in lexical research. This interaction indicates that for high-frequency words, the correspondence between orthography and phonology is of little importance However, for low-frequency words, the impact of spelling-to-sound correspondence is large. The dual-route model of lexical access accommodates this interaction, as summing that the direct part rather than the indirect part accesses high-frequency words (Monsell, Patterson, Graham, Hughes, and Milroy, 1992; Paap and Noel, 1991). That the word is not pronounced according to regular phonological rules over rides inconsistent correspondence between orthography and sound. For e.g., 'have' has such a high frequency of use that lexical access is achieved before incorrect pronunciation information ('should it sound like gave or wave?') is overridden. Conversely, a low frequency word slows up the lexical path and allows for interference from phonological mediation. The critical point for the dual route model is that the output of low frequency mediated responses can be overridden by the availability of phonological information produced by the indirect route.

In comparison, the Seidenberg and McClelland model does not assume separate (dual) paths to a lexicon or even the existence of a lexicon to account for the frequency-by-regularity interaction. The frequency-regularity relationship is produced by the correspondences between frequency and spelling to sound correspondence in the alphabetic system with continued practice, the difference between target activation ('right pronunciation') and the actual activation computed by the network get smaller and smaller. The activation of phonological units approximate the target values more and more, regardless of whether the word has regular correspondence, (e.g. 'gave') or exceptional correspondence (e.g. have). For high frequency words, regular correspondence does not make a difference. However, for low frequency exceptional words, the magnitude of error between the target and the activated units is larger than it is for low-frequency regular words.

This model also accounts for some neighborhood effects on pronunciation. The consistency of spelling-to-sound correspondence in English is influenced by word neighborhood, words that differ by one letter or one phoneme. Jared, McRae, and Seidenberg (1990) demonstrated that regular words show consistency effects, especially when high-frequency neighbors have consistent spelling-to-sound patterns (e.g. lint) more so than when neighbors have inconsistent spelling-to-sound patterns (e.g. pint). The neighborhood frequency effects are handled well by connectionist models which predict pronunciation on the basis of lexical frequency and correspondence.

Dual route models of reading

The dual-route conception of reading seems first to have been enunciated by de Saussure (1922). However, it was not until the 1970s that this conception achieved wide currency. A clear and explicit expression of the dual-route idea was offered by Forster and Chambers (1973). Marshall and Newcombe (1973) advanced a similar idea within a box-and arrow diagram. The text of their paper indicates that one of the routes in that model consists of reading “via putative grapheme–phoneme correspondence rules” (Marshall & Newcombe, 1973).

Since the other route in the model they proposed involves reading via semantics, and is thus available only for familiar words, their conception would seem to have been exactly the same as that of Forster and Chambers (1973) In these first explications of the dual route idea, a contrast was typically drawn between words (which can be read by the lexical route) and nonwords (which cannot, and so require the nonlexical route).

Baron (1977) was the first to express these ideas in a completely explicit box-and-arrow model of reading, which is shown in figure 1.1.

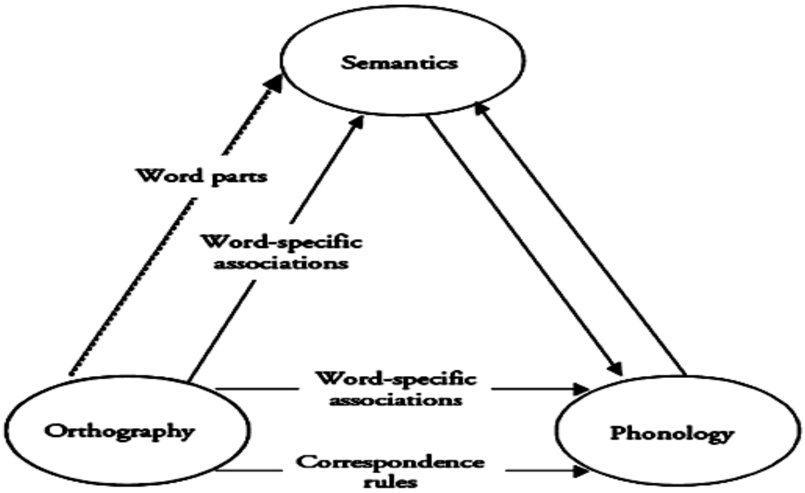


*Figure 5***.** An architecture of reading system (Baron, 1977).

This model has some remarkably modern features: for example, it has a lexical-non semantic route for reading aloud (a route that is available only for words yet does not proceed via the semantic system) and it envisages the possibility of a route from orthography to semantics that uses word parts (Baron had in mind prefixes and suffixes here) as well as one that uses whole words. Even more importantly, the diagram in figure 6 involves two different uses of the dual-route conception. The work previously cited is all concerned a dual route account of reading aloud; but Baron’s model also offered a dual-route account of reading comprehension.

The use of the terms “lexical” and “nonlexical” for referring to the two reading routes seems to have originated with Coltheart (1980). Reading via the lexical route involves looking up a word in a mental lexicon containing knowledge about the spellings and pronunciations of letter strings that are real words (and so are present in the lexicon); reading via the nonlexical route makes no reference to this lexicon, but instead involves making use of rules relating segments of orthography to segments of phonology.

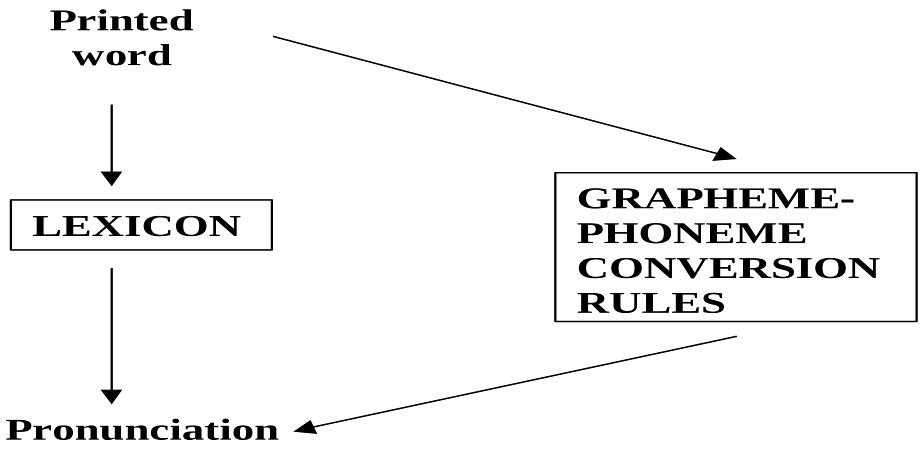


Figure 6. Dual route Conception.

De Saussure (1922) suggested that the orthographic segments used by the nonlexical route are single letters, but, as discussed by Coltheart (1978) that cannot be right, since in most alphabetically written languages single phonemes are frequently represented by sequences of letters rather than single letters. Coltheart (1978) used the term “grapheme” to refer to any letter or letter sequence that represents a single phoneme, so that TH and IGH are the two graphemes of the two-phoneme word THIGH. He suggested that the rules used by the nonlexical reading route are, specifically, grapheme–phoneme correspondence rules such as TH Æ /q/ and IGH Æ /ai/.

Evidence for this lexical reading route came from the examination of individuals who acquired reading deficits following some form of brain injury (Shallice & Warrington, 1980; Marshall & Newcombe, 1973; Patterson, Marshall, & Coltheart, 14 1985). And the evidence for the nonlexical route comes from individuals with an acquired selective deficit in reading pseudowords or novel real words (Funnell, 1983; Shallice & Warrington, 1980).

Dual route cascaded model (DRC model)

Of all cognitive domains, reading is the one in which computational modeling has been most intensively employed. This began with the interactive activation and competition (IAC) model of McClelland and Rumelhart (1981) and Rumelhart and McClelland (1982). This was a model just of visual word recognition, not concerned with semantics or phonology. The latter domains were introduced in the much more extensive computational model developed in a seminal paper by Seidenberg and McClelland (1989). One influence their paper had was to prompt the development of a computational version of the dual-route model: the DRC ("dual-route cascaded") model (Coltheart et al., 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Dual Route Cascaded model (DRC) has two core assumptions. First, processing throughout the model is cascaded. That is, any activation in earlier modules starts flowing to later modules immediately. Second, there are two routes for translating print into sound: a lexical route, which utilize word-specific knowledge, and a non-lexical Grapheme-to-Phoneme Conversion (GPC) route, which utilize a sub-lexical spelling-sound correspondence rule system.

Another feature of DRC is that processing is done in parallel. For example, all features across the stimulus array are extracted in parallel. Similarly, all the letters units are activated in parallel. Indeed, processing occurs in parallel within all modules except the GPC module, where processing is serial. That is the pathway of the lexical route are represented as a double headed arrows because activation in this route flows in both the directions, so processing is parallel and in non lexical route there is one way activation only from top-down so processing here is serial. Within any set of letter units, every unit laterally inhibits every other; for example, within the orthographic lexicon, each word unit has an inhibitory connection to the other .these inhibitory connections help in suppressing the incorrect units from the correct units. Here in this model the letters and the phonemes has a positional encoding, so that it can able to discriminate between words which are made up of the same letters in different positions(anagrams such as rat, art, tar).At present, the DRC model deals only with monosyllabic words, because it is currently unknown how GPC works for polysyllabic words. Its lexicon contain orthographic and phonological units for almost all the monosyllabic words in English (7,500 words).

Coltheart et al. (2001) argue the non-word letter length effect produced by DRC is a direct consequence of serial processing in the GPC module. That is, because GPC processes letters serially, the time to name a non-word increases as the length of non-word increases. This phenomenon parallels the *letter length effect* in human performance (Weekes, 1997).

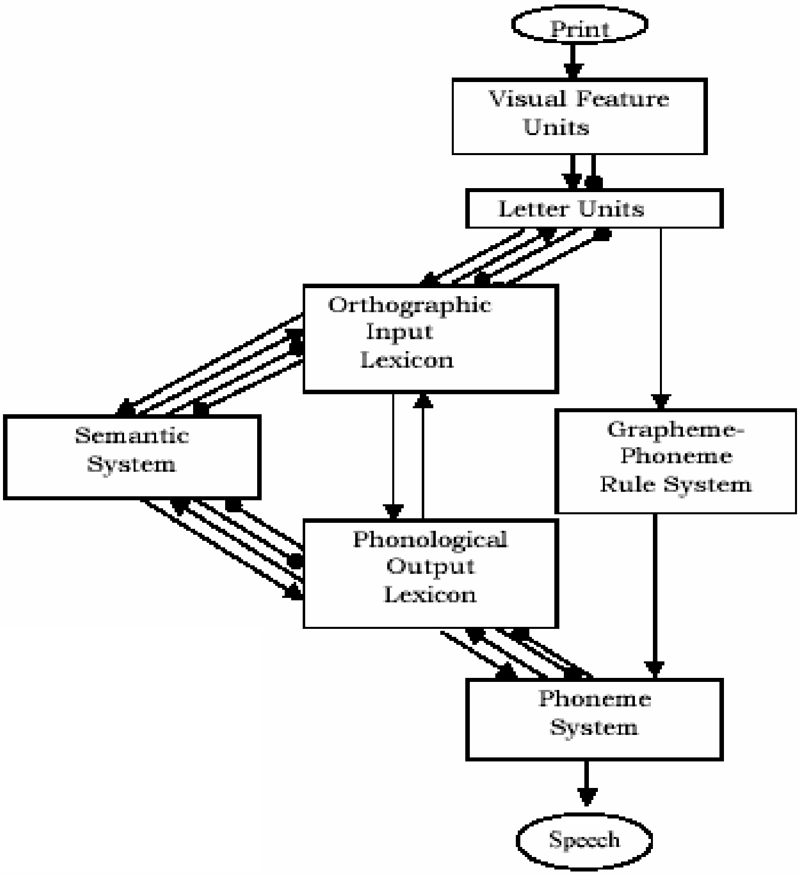


Figure 7: DRC model of Visual word Recognition (Coltheart et.al. 2001).

There are comparatively very few studies that have investigated the relative importance of different or multiple components of reading and its deficits in children (Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003; White, Milne, Rosen, Hansen, Swettenham, Frith, & Ramus, 2006). So, each component of reading has to be investigated for the deficits at different levels of processing. This has been studied extensively using the DRC model Coltheart et al., (2001). However, its application to clinical population is limited. There are few research studies who have adopted this psycholinguistic model of reading in Indian population (Shanbal & Prema, 2003) and further research has to be focused on how the various levels of processing in DRC model will help in developing various assessment tools and intervention strategies for the disordered population in India. Hence, there is a need to study the DRC model and its application to developmental dyslexia in Indian children. There are two subtypes of developmental dyslexia found in previous research, as phonological and surface dyslexias, based on reading irregular words and non-words tasks (Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Spreng-er-Charolles, Cole, Lacert, & Serniclaes, 2000, Griffiths & Snowling, 2002). There are few studies involved in interpreting the subtypes of developmental dyslexia whether it involves single dissociation deficits or double dissociation deficits based on dual route model (Ziegler, 2008).

CHAPTER 3

Method

3.1 Participants

Subjects consist of an experimental group and a control group. The experimental group consists of 16 dyslexic children (8-12yrs). And the control group consists of 40 age matched normal children and they were 10 children in each grade from III, IV, V and VI with equal number of males and females. And none of the children in both the groups had any known or reported hearing, neurological, developmental or emotional problems. And the subject selection criteria include the following,

Subject selection criteria

- Age range of both Experimental and Control group was 8-12yrs.
- Native language of both Experimental and Control group was Kannada and studied English as the medium of instruction.
- A WHO Ten –Question Disability Screening Checklist (cited in Singhi, Kumar, Prabhjot & Kumar, 2007) and Developmental Screening Test (Bharath Raj, 1972), was used to screen both the groups in terms of hearing, intelligence, motor and other factors like school performance, emotional or behavioral factors.
- Early reading skills (Loomba, 1995) was used in the selection of dyslexic children.
- Cognitive Linguistic Assessment Program for Children (Anitha, 2004).for

screening children for language abilities.

- All the children with dyslexia were assessed by a clinical psychologist for their intelligence quotient (IQ), and was reported to be average or above average.

The following ethical standards were followed during the study

This study was conducted with the understanding and consent of the participants and their parents. They were provided information in the language he/she was capable of understanding and were explained about the aims, method of the research and approximate duration of testing.

3.2 Test Materials

Stimuli included 50 regular words and 50 irregular words taken from the class books of grade III to VI. Pictures included 100 common line drawings taken from UNICEF picture cards and from hundred picture naming test. For the familiarity check, from these groups of pictures and words, 10 most familiar regular and irregular words which were matched in length were taken for the present study. Twenty pronounceable pseudowords were also taken for the present study and these selected words were presented through DMDX software for about 250 ms (see Appendix A for test stimuli).

Tools

- Compaq Presario C700 laptop with 15 - inch screen and microphone with flat frequency response was used.
- DMDX software version 3.13.0 (Forster & Forster, 2003) was used for calculating latency and accuracy in the reading tasks and DRC model's component tasks.

3.3 Procedure

- The participants were seated in a comfortable position facing the 15-inch screen of the laptop in a quiet room.
- The responses were recorded through a high quality microphone placed at a distance of 10 cm from the participant's mouth.
- Testing was carried out in an allay environment

The following tasks were carried out in the present study:

1. Reading task

The participants were instructed to read the stimuli aloud. The stimuli include 20 nonwords, 10 regular words, and 10 irregular words .Regular and irregular words (See Appendix 1) were matched in terms of length and word familiarity. Non-words were created by changing the onset, the vowel or the coda of an existing word that was matched in terms of frequency and length to the regular and irregular words. The items were presented at the centre of the computer screen. DMDX experimental software version 3.1.3.0 (Forster & Forster, 2003) was used for the experiment. Participants' responses were recorded with a voice key and saved as separate wave files. These files were used for error coding and latency measures. Latency was measured from the appearance of the stimulus on the screen until the participant begins to utter the response and in error coding the positive or correct responses were coded as ''1" and negative or incorrect responses were coded as ''0". Reading speed and accuracy were assessed on a reading task.

2. Letter search task

The task was to search for a target letter embedded in a letter string. Following an initial fixation point, a target letter (e.g., ‘‘A’’) which will appear on the computer screen for 500 ms (milliseconds) followed by the stimulus (word or unpronounceable letter string), which stays on the screen until the participant presses one of the two response buttons to indicate whether the target letter was present or not in the stimulus. The stimuli include 20 five-letter words and 20 five-letter nonwords (i.e., unpronounceable letter strings). Identity and position of the target letter were matched across words and nonwords (e.g., ‘‘R’’ in ‘‘boire’’ versus ‘‘ghyrc’’). To avoid visual matching strategies, target letters were presented in upper case and letter strings were presented in lower case. The dependent variables were analyzed for errors and latency using DMDX experimental software .Latency was measured from the appearance of the stimulus on the screen until the participant begins to utter the response and in error coding the positive or correct responses were coded as ‘‘1” and negative or incorrect responses were coded as ‘‘0

3. Picture naming task

Two sets of five line drawings of familiar objects were selected from UNICEF picture cards a database for picture naming. All pictures names had a consonant-vowel-consonant (CVC) structure. There was no phonological overlap between them. The pictures were checked for familiarity and name agreement.

The objects were displayed in the centre of the computer screen one per trial. The participant’s task was to name the object as quickly as possible. The two lists of five objects were repeated in pseudo-random order 10 times each (i.e., a total of 50 naming responses per list). During training, participants were, first presented with a sheet that contained the five objects in an unspeeded naming task. This initial training allowed us to make sure that the participant was familiar with the objects and that they provided the correct name. After that, participants were trained twice in the speeded computer-based version of the task on a subset of 10 items. Following training, participants were asked to perform the picture naming task twice, once using the items of list 1 and once using the items of list 2 (counterbalanced across participants). During the test, participants' responses were recorded with a voice key. Each response was saved as a sound file. The sound files were used for off- line error coding and for the measurement of reaction times. The dependent variables were analyzed for errors and latency using DMDX experimental software. Latency was measured from the appearance of the stimulus on the screen until the participant begins to utter the response and in error coding the positive or correct responses were coded as ''1'' and negative or incorrect responses were coded as ''0''.

4. Phoneme matching

Participants were asked to assess the phonological similarity of spoken words either for the initial or the final phoneme. On each trial, three spoken CVC words were presented. Two of them shared either the initial or the final phoneme. The participants' task was to indicate which item did not share the initial or the final phoneme. To facilitate the task, phoneme position was blocked (first position block versus final position block). The order of blocks was counterbalanced across participants. The dependent variable was analyzed for error rate using DMDX experimental software and the positive or correct responses were coded as ''1'' and negative or incorrect responses were coded as ''0''.

The data was then subjected to statistical analysis and the results are presented in the following sections.

CHAPTER 4

Results

The aims of the present study were

1. To assess each representational level of the dual route cascaded model in reading- letter level, orthographic lexicon, phonological lexicon and the phoneme system.

2. To investigate on the subtypes of developmental dyslexia which could be given a conceptual interpretation i.e. dyslexia as a unitary disorder or of heterogeneous type based on dual route model.

The participants considered for the study included normal children and children with dyslexia. Stimulus was presented through the DMDX experimental software (Foster & Foster, 2003). Tasks included letter search task (for words and nonwords), picture naming, phoneme matching, reading [regular words (RW), irregular words (IW) and nonwords (NW).]

Broadly the results were analyzed for accuracy and reaction time (RT) measurements for performance of normal children and children with dyslexia on all the tasks. The results are described below in the following sections,

4.1 Comparison of performance of normal children and children with dyslexia (CWD) on reading tasks [regular words (RW), irregular words (IW) and non-words (NW)].

4.2 Comparison of performance of normal children and children with dyslexia on different components of the DRC model.

4.3 Subtypes of dyslexia derived from the DRC model.

The statistical methods used were as follows.

- Mixed ANOVA and one way ANOVA were used for comparing the normal children across grades in each task.
- Repeated measures ANOVA was used to compare normal children within grades.
- Wilcoxon signed rank test was used to compare children with dyslexia children within grades.
- Mann-Whitney test was done to compare the reading and the DRC models component tasks across groups.
- Bonferroni test was carried out to explore which of all the tasks were significantly different across grades in both CWD and normal children.
- Hierarchical cluster analysis was done on CWD group to explore the different clusters based on homogeneity among subjects,

The results are described in the following sections.

4.1 Comparison of performance of normal children and children with dyslexia (CWD) on reading tasks.

The results of performance of children on reading regular, irregular and nonwords were analyzed for accuracy and reaction time (RT) measurements. The raw scores were converted as percentage scores for the accuracy measures. As there were unequal number of subjects in both the groups, parametric tests were done for normal children and nonparametric tests for children with dyslexia. The results are shown in the following tables for both normal children and children with dyslexia.

4.1.1 Accuracy measurements

Table 1 shows mean and standard deviation (SD) for accuracy measures in normal children and children with dyslexia across all the reading tasks (RW, IW, NW) for each grade (III, IV, V, VI).

The mean accuracy for normal children on reading tasks is shown in the Table 1. The Table 1 shows that the overall mean accuracy for reading performance in normal children for each task was better for reading regular words (97.5 %) and reading irregular words (92%) compared to reading nonwords (66%). When we consider each of the grades for reading regular words, irregular words and non words, it was observed that the mean accuracy increased with increase in grade level, i.e., normal children in the higher grades performed better than children in the lower grades indicating a developmental trend across all the tasks .The same has been depicted in the Figure 1.

Table1. *Overall Mean Accuracy and S.D for all the reading tasks across groups.*

Grades	Reading Tasks	Groups			
		Normals		CWD	
		Mean (%)	S.D	Mean (%)	S.D
III	RW	100.00	.00	50.00	16.33
	IW	88.00	14.76	25.00	17.32
	NW	64.50	14.80	7.50	9.57
	R	77.75	11.21	22.50	8.42
IV	RW	91.00	15.95	57.50	12.58
	IW	88.00	15.49	50.00	25.82
	NW	55.00	18.41	17.50	6.45
	R	71.75	14.34	35.63	7.74
V	RW	99.00	3.16	32.50	39.48
	IW	95.00	12.69	32.50	47.17
	NW	65.00	23.09	6.25	7.50
	R	81.50	13.80	19.38	25.03
VI	RW	99.00	3.16	32.50	39.48
	IW	95.00	12.69	32.50	47.17
	NW	65.00	23.09	6.25	7.50
	R	81.50	13.80	19.38	25.03
Total	RW	97.50	8.70	46.88	23.01
	IW	92.50	12.96	38.75	28.02
	NW	66.00	19.65	10.00	8.56
	R	79.69	13.12	26.41	14.29

[**RW**-Regular words, **IW**-Irregular words, **NW**-non-words, **R**-Reading]

Mixed ANOVA was carried out across grades in normal children and the results showed an overall significant main effect on reading tasks across grades i.e., F (2, 72) = 93.22, $p<0.001$.The results also revealed that there is no significant interaction effect across tasks and grades. Boneferroni test was computed to see the pair wise differences in each of the three reading tasks (RW, IW, and NW) across the grades.

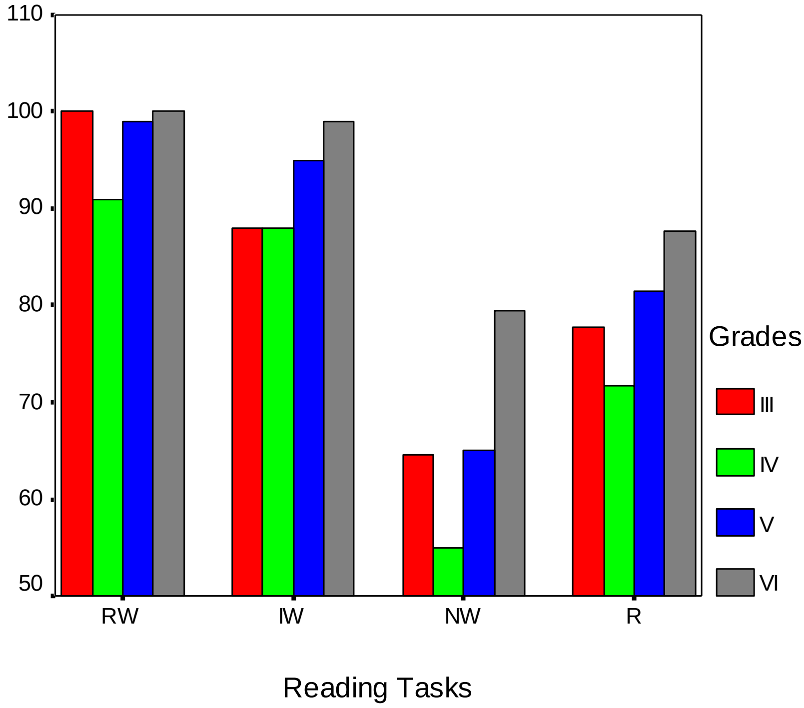


Figure 8. Comparison of mean accuracy of reading tasks across grades in normal children.

The results showed that the performance for each of the reading tasks were significantly different from each other across grades. Post-Hoc Duncan test results revealed a significant difference between grade III and grade IV, grade IV and grade V in normal children. One- way ANOVA was carried out for accuracy measures for reading tasks (RW, IW and NW) across grades. The results revealed that there was a significant difference in reading RW, $F(3, 36) = 2.874$, $p< 0.05$, reading NW, $F(3, 36) = 3.06$, $p< 0.05$ in normal children and overall reading performance $F(3, 36) = 3.021$, $p< 0.05$. Post-Hoc Duncan Test results showed that for both RW and NW performance of normal children on reading tasks showed a significant difference across grade VI and other grades.

Further analysis revealed mean accuracy for CWD on reading tasks as shown in Table1. The Table1.shows that the overall mean accuracy for reading performance in children with dyslexia for tasks was higher for reading RW (46.88 %), reading IW (38.75%), and lower for reading NW (10%). The same has been depicted in the Figure 9.

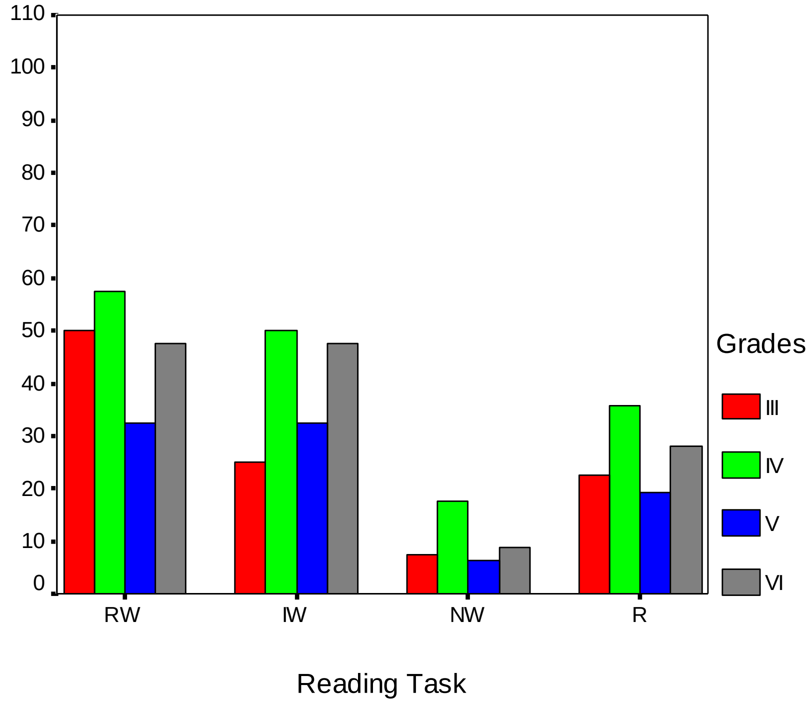


Figure 9. Comparison of mean accuracy for reading tasks across grades in children with dyslexia.

The mean accuracy for different reading tasks represented in the Table1 shows that the mean accuracy was lesser in children with dyslexia (26.41%) compared to normal children (79.69%). Mann- Whitney test revealed that this was statistically significant across groups and across tasks (RW, IW & NW).The results showed that there was a significant difference between CWD and normal children.

The mean accuracy for normal children within grades for different reading tasks is shown in the Table1. The table showed that, in all the grades (III, IV, V, and VI) the mean accuracy was greater for reading NW and lesser for reading

RW.Repeated measures ANOVA was computed for within subject effects on each grade separately for accuracy measures of reading Tasks in normal children. In grade III, there was an overall significant main effect on reading tasks i.e., $F(2, 18) = 22.22$, $p < 0.001$. Boneferroni test was computed to see performance of normal children in each of the three reading Tasks in grade III**.** The results showed that each of the reading Tasks was significantly different from each other in the accuracy measures. In grade IV, Repeated measures ANOVA showed there was an overall significant main effect on reading tasks i.e., $F(2, 18) = 17.96$, $p<0.001$. Boneferroni test, results revealed that NW reading was significantly different from reading RW and IW. In grade V, Repeated measures ANOVA showed there was an overall significant main effect on reading tasks i.e., $F(2, 18) = 10.07$, $p<0.05$. Boneferroni test results revealed that reading RW was significantly different from reading IW and NW in the accuracy measures. In grade VI, Repeated measures ANOVA results showed there was an overall significant main effect on reading tasks i.e., $F(2, 18) = 15.7$, $p<0.001$. Boneferroni test results revealed that reading NW was significantly different from reading RW and IW.

The mean accuracy for CWD within grades for different reading tasks shows that, in all the grades (III, IV.V and VI) the mean accuracy was greater for RW and least for reading NW. Comparing this with the normal children, CWD have lower accuracy score than normal children (see Table 1). For analyzing the accuracy measures in CWD of reading tasks within grades Wilcoxon singed rank test was done. The results revealed that there was a significant difference found for reading RW and NW and for reading IW and NW at 0.05 levels. Mann- Whitney test revealed that there was any significant difference on accuracy measures of reading tasks within each grade for normal children and children with dyslexia. The results showed that there was a significant difference between the tasks in each grades (III, IV, V, VI).

4.1.2 Reaction Time measurements

Table 2 shows mean and standard deviation (SD) for the reaction time(RT) measures for normal children and children with dyslexia across all the reading tasks (RW, IW, NW) for each grade (III, IV, V, VI).

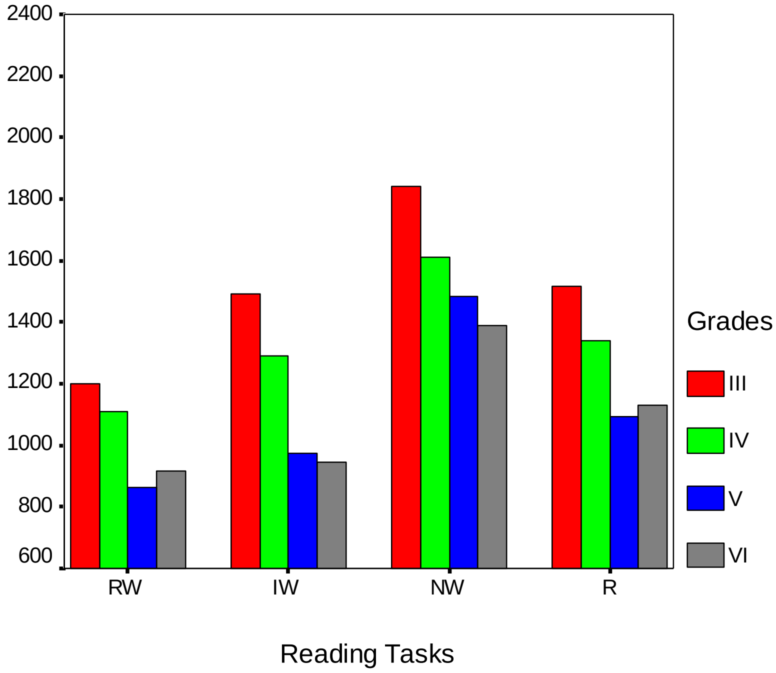
The mean reaction time (RT) for normal children on reading tasks are shown in Table2.Theresults revealed that the overall mean RT for performance of reading in normal children for each task was longer for reading NW, then for reading IW, and shorter for RW. When we consider each of the grades for reading IW, reading NW, it was observed that the mean RT decreased with increase in grade level but for reading regular words this trend doesn’t follow because grade V performed poorer than grade VI. The same has been depicted in the Figure 10.

Table 2. *Overall Mean Reaction time (RT) and S.D for all the reading tasks across groups*

Grades	Reading Tasks	Groups			
		Normals		Dyslexics	
		Mean (in ms)	S.D	Mean(in ms)	S.D
III	RW	1201.37	246.34	2316.99	353.92
	IW	1491.19	350.90	1763.28	89.60
	NW	1840.58	467.99	2042.81	799.40
	R	1515.00	304.20	2322.47	465.19
IV	RW	1109.72	373.22	1548.83	316.60
	IW	1290.42	439.80	1828.00	411.14
	NW	1610.65	482.75	1820.00	314.27
	R	1339.95	417.63	1733.55	232.30
V	RW	862.58	283.92	1656.38	81.86
	IW	974.19	333.00	1616.19	86.70
	NW	1484.07	658.08	2062.05	182.50
	R	1093.90	333.75	1780.62	104.84
VI	RW	915.77	272.99	1317.80	531.02
	IW	944.71	450.33	1456.70	527.41
	NW	1390.40	560.86	1766.74	758.81
	R	1128.28	423.73	1485.26	504.65
Total	RW	1022.36	318.72	1717.66	535.43
	IW	1175.13	445.45	1666.23	374.02
	NW	1581.43	553.24	1889.99	478.67
	R	1269.28	398.11	1837.60	486.18

[**RW**-Regular words, **IW**-Irregular words, **NW**-non-words, **R**-Reading.]

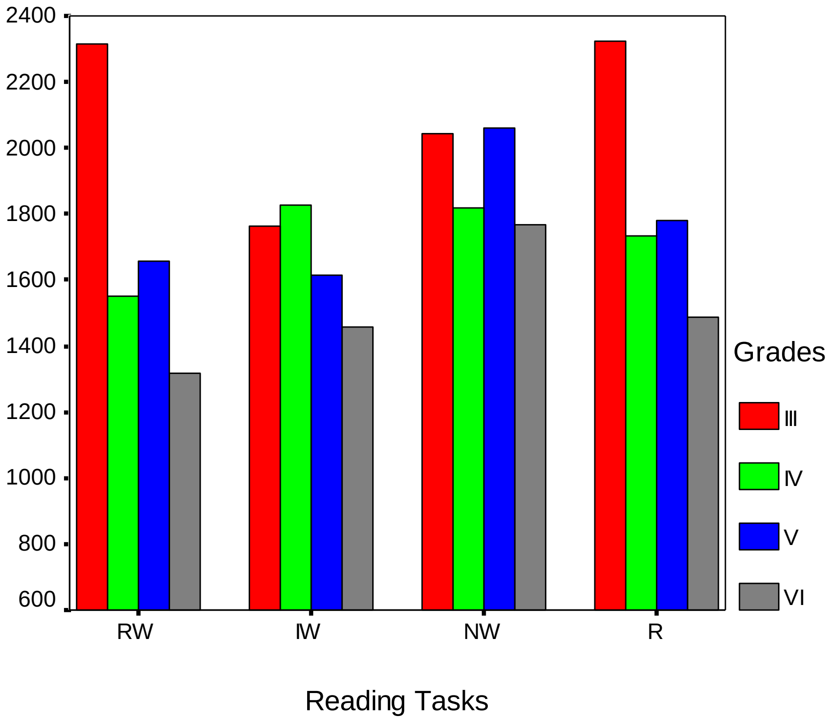
Mixed ANOVA was carried out across grades in normal children. The statistical results showed an overall significant main effect in the reading tasks across grades i.e., $F(2, 72) = 56.61$, $p<0.001$.The results also revealed that there is no significant interaction effect across tasks and grades. Boneferroni test across the grades showed that each of the reading tasks was significantly different from each other in the reaction time measures across the grades. Further Post-Hoc Duncan test revealed a statistically significant difference between children of grade III and grade VI, grade VI and grade VI. The results of one-way ANOVA for RT on reading tasks across grades revealed that there was a significant difference in reading RW, $F(3, 36) = 2.87$, $p<0.05$ and reading IW, $F(3, 36) = 2.77$, $p<0.05$ in normal children. And within each of the reading tasks Post Hoc-Duncan results showed that for RW and IW reading tasks there was a significant difference across grade III and grade VI, grade IV and grade VI children.



[**RW**-Regular words, **IW**-Irregular words, **NW**-non-words, **R**-Reading]

*Figure 10.*Comparison of mean reaction time for reading tasks across grades in Normal children.

The mean reaction time (RT) for children with dyslexia on reading tasks are shown in the Table2. It shows that overall mean RT for reading performance in CWD for each task was longer for reading NW, then for reading RW, and shorter IW. Mann- Whitney test results showed that there was a significant difference for reading RW, IW and for the overall reading performance between CWD and normal children. But there was no significant difference for reading NW between the groups.



[**RW**-Regular words, **IW**-Irregular words, **NW**-non-words, **R**-Reading]

Figure 11. Comparison of mean reaction time for reading tasks across grades in children with dyslexia.

The mean reaction time (RT) for the normal children within grades for different reading tasks represented in the Table2 showed that, in all the grades (III, IV, V, VI) the mean RT was longer for reading NW and shorter for reading RW. Repeated measures ANOVA was computed for within subject effects on each grade separately for reaction time measures of reading Tasks. In IIIrd grade, there was an overall significant main effect on reading tasks i.e., F (2, 18) = 22.22, p<0.001. Boneferroni test results showed that each of the reading tasks was significantly different from each other in the reaction time measures. In grade IV, Repeated measures ANOVA results showed there was an overall significant main effect on reading tasks i.e., F (2, 18) = 17.96, p<0.001. Boneferroni test, results revealed that NW reading was significantly different from reading RW and IR. In grade V, Repeated measures ANOVA results showed there was an overall significant main effect on reading tasks i.e., $F (2, 18) = 10.07, p<0.05$. Boneferroni test results revealed that reading RW was significantly different from reading IW and NW in the reaction time measures. In grade VI, Repeated measures ANOVA results showed there was an overall significant main effect on reading tasks i.e., $F (2, 18) = 15.7, p< 0.001$. Boneferroni test results revealed that reading NW was significantly different from reading RW and IW. The mean RT for CWD within grades for different reading tasks represented in the Table 2 showed that, in CWD grade III, mean reaction time was longer for reading words than reading irregular and nonwords. In grade IV, RT was longer for reading irregular words and shorter for reading regular words. In grade V, RT was greater for reading non words and shorter for reading irregular words. In grade VI, the reading nonwords had longer RT and shorter for regular words.

4.2 Comparison of performance of normal children and children with dyslexia on different components of the DRC model.

The results of performance of children on component tasks of dual route cascaded model (DRC) [(letter search words (LSW), letter search nonwords (LSNW), picture naming (PN), phoneme matching (PM)] were analyzed for accuracy and reaction time (RT) measurements. As there were unequal numbers of subjects in both the groups, parametric tests were done for normal children and nonparametric tests for children with dyslexia.

4.2.1 Accuracy measurements for DRC

Table 3 shows mean and standard deviation (SD) for the accuracy measures in normal children and children with dyslexia across all the DRC components tasks (LSW, LSNW, PN, PM) in each grade (III, IV, V, VI).

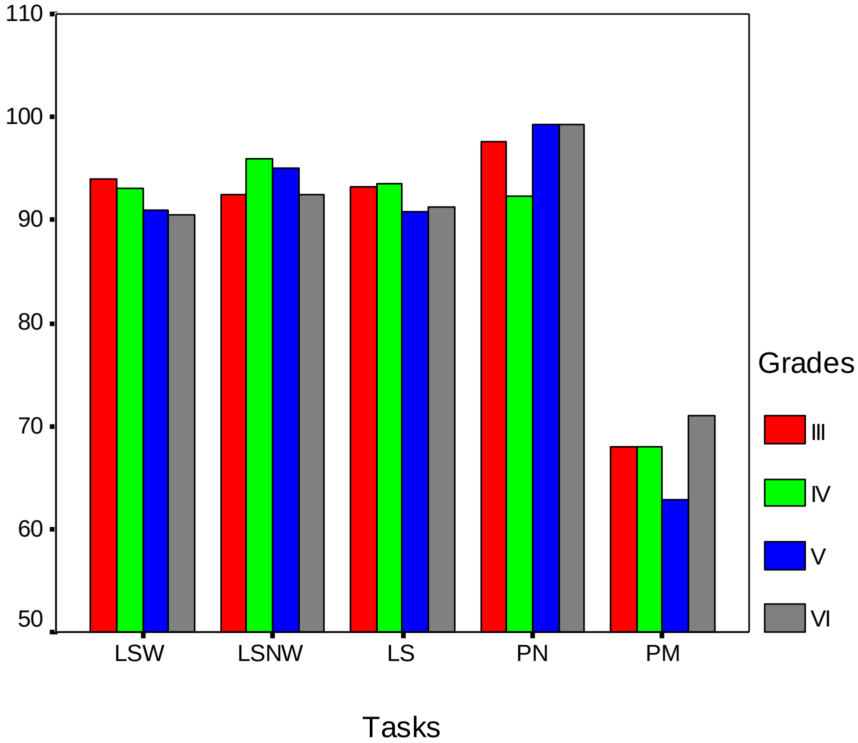
Table 3. *Overall Mean Accuracy and S.D for all the DRC components tasks across groups*

Grades	Component Tasks	Groups			
		Normals		Dyslexics	
		Mean (%)	S.D	Mean (%)	S.D
III	LSW	94.00	7.38	77.50	23.63
	LSNW	92.50	10.87	72.50	15.55
	LS	93.25	8.90	75.63	20.14
	PN	97.67	4.17	59.33	33.04
	PM	68.00	21.50	55.00	23.80
IV	LSW	93.00	93.00	76.25	18.87
	LSNW	96.00	4.59	72.50	20.62
	LS	93.50	4.59	71.88	17.00
	PN	92.35	8.17	79.16	14.75
	PM	68.00	16.87	45.00	31.09
V	LSW	91.00	91.00	66.25	18.87
	LSNW	95.00	5.77	68.75	17.50
	LS	90.75	8.42	67.50	17.44
	PN	99.34	1.39	79.82	8.88
	PM	62.90	20.32	32.50	12.58
VI	LSW	90.50	11.89	62.50	26.30
	LSNW	92.50	9.50	67.50	21.79
	LS	91.25	8.19	65.00	23.72
	PN	99.30	1.48	65.33	14.18
	PM	71.00	22.34	22.50	9.57
Total	LSW	92.13	8.39	70.63	20.89
	LSNW	94.00	7.94	70.31	17.17
	LS	92.19	7.51	70.00	18.17
	PN	97.17	5.36	70.91	20.03
	PM	67.47	19.78	38.75	22.77

[**LSW-** Letter search word**, LSNW-** Letter search nonwords,

LS-letter search overall **PN** –Picture naming, **PM-**Phoneme matching]

The mean accuracy scores for normal children on DRC component tasks are shown in the Table 3. The results revealed that the overall mean accuracy for the component performance in normal children for each task was higher for PN (97.17%), LSNW (94%), LS (92.19%), LSW (92.13%) and least for PM (67.47%).When we consider each of the above tasks across grades there was no trend observed in mean accuracy on DRC component tasks. The same have been depicted in Figure 12.



[LSW- Letter search word**, LSNW-** Letter search nonwords, **LS**-letter search overall **PN** – Picture naming, **PM-**Phoneme matching]

Figure 12. Comparison of mean accuracy of DRC component tasks across grades in normal children.

Mixed ANOVA was carried out across grades in normal children and the results showed an overall significant main effect in the DRC component tasks across grades i.e., $F(3, 108) = 52.43$, $p<0.001$.The results also revealed that there is no significant interaction effect across tasks and grades. Boneferroni test results showed that the performance on PM was significantly different from other tasks. And also PN was significantly different from LSW. Post-Hoc Duncan test results revealed that there was no significant difference across grades. One- way ANOVA was carried find out is there any significant difference in the performance of normal children in terms of accuracy measures of reading tasks across grades. The results revealed that there was a significant difference in PN, $F (3, 36)= 4.93$, $p<0.05$ and Post Hoc-Duncan Test results showed grade VI was significantly different from all other grades on PN task.

The mean accuracy for the DRC component tasks as shown in Table 3 revealed that the overall mean accuracy for the component performance in children with dyslexia for each task was higher for picture naming (70.91%), letter search words (70.6%), letter search nonwords(70.31%),over all letter search (70%) and least for phoneme matching (38.75%). Mann- Whitney test was done for analyzing the accuracy measures across groups. The results showed that there was a significant difference at 0.05 levels all the tasks which check the components of the model between dyslexic and normal children.

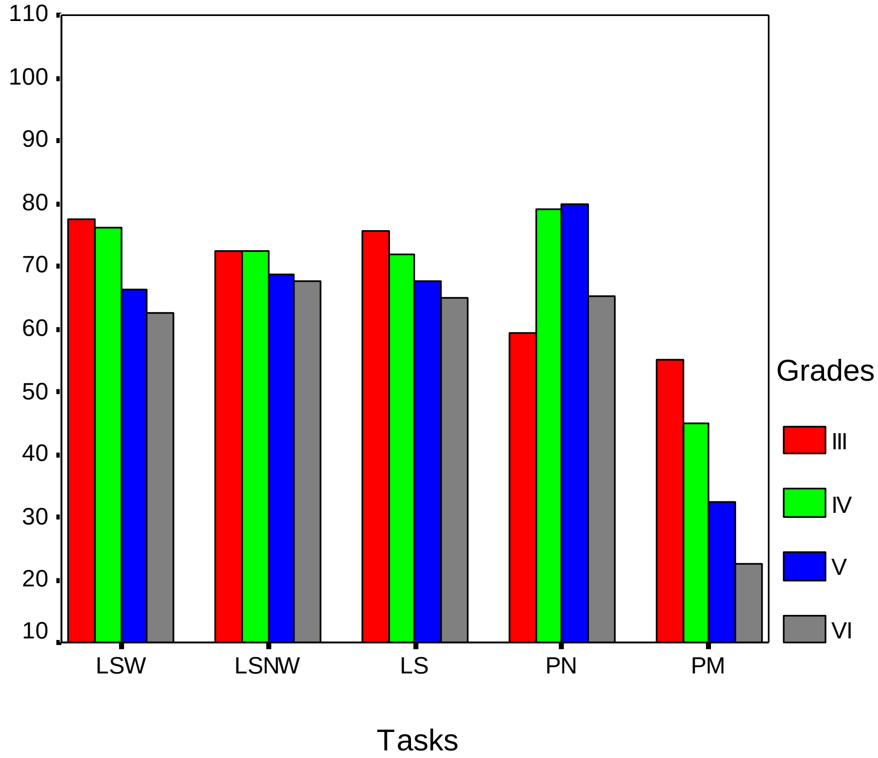


Figure 13. Comparison of mean accuracy of DRC component tasks across grades in children with dyslexia.

The mean accuracy for normal children within grades for different DRC component tasks showed that, in grades III, V and VI mean accuracy was greater for PN and least for PM. In grade IV, its greater for LSNW and least for PM. Repeated measures ANOVA showed that performance in terms of accuracy measures revealed that in grade III, there was an overall significant main effect on reading tasks i.e., F (3, 27) = 13.102, $p<0.001$. Boneferroni test results showed that performance of normal children in grade III on PM was significantly different from other tasks (LSW, LSNW, and PN). In grade IV, Repeated measures ANOVA results showed there was an overall significant main effect on reading tasks i.e., F (3, 27) = 14.766 $p<0.001$. Boneferroni test results revealed that PM was significantly different from other tasks (LSW, LSNW, and PN). In grade V, Repeated measures ANOVA results showed there was an overall significant main effect on reading tasks i.e., F (3, 27) = 19.439 p<0.05. Boneferroni test results revealed that PM was significantly different from other tasks (LSW, LSNW, and PN). In grade VI normal children, Repeated measures ANOVA results showed there was an overall significant main effect on reading tasks i.e., F (3, 27) = 8.486, p< 0.001. Boneferroni test results revealed that performance on phoneme matching tasks was significantly different from PN.

Table 3 also shows the mean accuracy for the CWD within grades for different DRC component tasks .As Table 3 shows that, in grade III, mean accuracy was greater for over all LS and least for PM .In grades IV and V, accuracy was greater for PN and least for PM .In grade VI, the LSNW had higher accuracy and least for PM.Wilcoxon singed rank test results revealed that there was a significant difference found for the PM and PN and for PM and LSW, PM and LSNW. Mann- Whitney test was done for each grade across both the groups. The results showed that in grade III, PN, LSNW and over all letter search showed a significant difference across groups (CWD and Normal children) at 0.05 levels. In grade VI, LSNW and over all LS showed a significant difference across groups at 0.05 levels. In grade V all the component tasks showed a significant difference across groups at 0.05 levels. In grade VI, PN, LSNW and PM tasks showed a significant difference across groups at 0.05 levels.

4.2.2 Reaction Time measurements of DRC component tasks

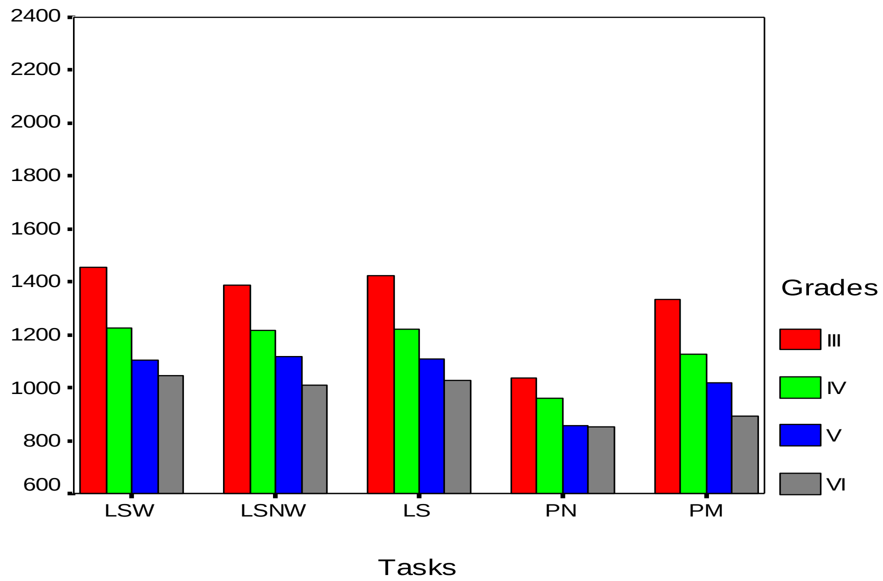
Table 4 shows mean and standard deviation (SD) for the reaction time (RT)measures for normal children and children with dyslexia across all the DRC components tasks (LSW, LSNW, PN, PM) for each grade (III, IV, V, VI).

Table 4. *Overall Mean Reaction time (RT) and S.D for all the DRC component tasks across groups*

Grades	Component Tasks	Groups			
		Normals		Dyslexics	
		Mean (ms)	S.D	Mean (ms)	S.D
III	LSW	1456.21	325.00	1755.26	239.54
	LSNW	1387.67	335.76	1656.83	336.94
	LS	1422.03	323.34	1672.12	255.80
	PN	1037.61	222.75	1152.55	218.23
	PM	1331.28	397.73	1613.79	304.42
IV	LSW	1226.73	191.74	1470.89	187.27
	LSNW	1215.16	174.68	1538.16	229.25
	LS	1219.79	172.41	1515.91	186.20
	PN	960.88	200.15	998.57	59.91
	PM	1125.69	492.99	1543.29	266.56
V	LSW	1103.19	186.92	1333.32	276.26
	LSNW	1119.45	164.67	1397.94	333.66
	LS	1110.21	163.87	1371.34	305.03
	PN	854.97	161.78	1235.92	312.05
	PM	1019.09	207.66	1131.73	295.44
VI	LSW	1043.67	289.18	1018.30	345.10
	LSNW	1009.37	254.82	1073.77	326.72
	LS	1025.28	265.76	1056.43	343.36
	PN	852.30	183.46	1766.74	758.81
	PM	891.93	326.73	1485.26	504.65
Total	LSW	1207.45	293.00	1394.44	364.10
	LSNW	1182.91	272.16	1416.68	357.20
	LS	1194.33	275.83	1403.95	342.37
	PN	926.44	201.73	1079.26	230.75
	PM	1092.00	392.14	1357.10	411.69

[**LSW-** Letter search word**, LSNW-** Letter search nonwords, **LS**-letter search overall **PN** –Picture naming, **PM-**Phoneme matching].

The mean reaction time (RT) for normal children on DRC component tasks are as shows in the Table 4. The table revealed that the overall mean RT for the performance on the tasks in normal children was longer for LSW, then for PM, LSNW and shorter for PN. When we consider each of the grade for all the tasks it was found that the RT was longer for grade III and shorter for grade VI for all the DRC component tasks. It was observed that the mean RT decreased with increase in grade level, i.e., normal children in the later grades performed better than children in the earlier grades indicating a developmental trend across all the tasks.



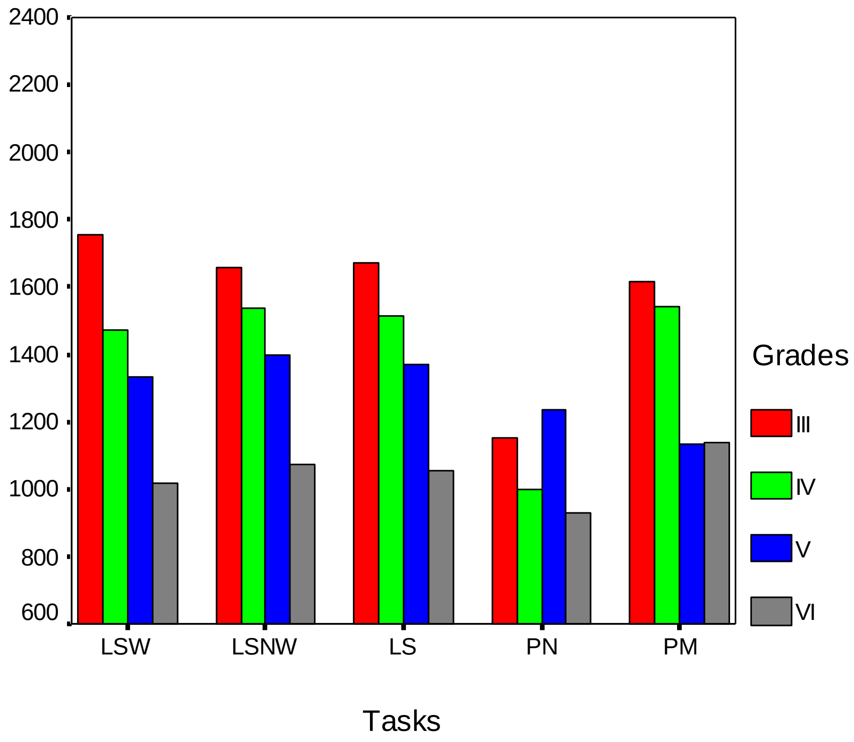
[LSW- Letter search word**, LSNW-** Letter search nonwords,

LS-letter search overall **PN** –Picture naming, **PM-**Phoneme matching]

Figure 14. Comparison of mean reaction time (RT) of DRC component tasks across grades in normal children.

Mixed ANOVA was carried out across grades in normal children, the results showed an overall significant main effect in the reading tasks across grades i.e., F (3, 108) = 10.71, p<0.001.the results also revealed that there is no significant interaction effect across tasks and grades. Boneferroni test was computed to see the pairwise differences in each of the four DRC component Tasks (LSW, LSNW, PN, PM) across the grades. The results showed that picture naming was significantly different from each other component tasks in the reaction time measures across the grades at 0.05 levels. Post-Hoc Duncan test results across the grades revealed that normal children in grade III and grade VI, grade III and grade IV, grade III and grade V showed a significant difference within the grades. One- way ANOVA was carried out in normal children to find out is there any significant difference in the RT measures of component tasks across grades. The results revealed that there was a significant difference in letter search words, $F (3, 36) = 5.1$, $p< 0.05$, letter search nonwords words, $F (3, 36) = 4.36$, $p<0.05$ in normal children and overall letter search performance $(3, 36) = 5.07$,$p<0.05$ And within each of the component tasks which was found to have a significant difference those tasks were analyzed using Post-Hoc Duncan Test for any differences across grades for each of those tasks. The results showed that for the above significant tasks (LSW, LSNW, PN, PM) there was a significant difference across grade III and grade VI, grade III and grade V.

Further Table 4 also shows the mean reaction time (RT) for CWD on DRC component tasks which revealed that the overall mean RT for the component task performance in children with dyslexia for each task was longer for LSNW, then for over all LS performance, LSW ,PM and shorter for PN. When we consider each of the grades for LSW, LSNW and for overall LS, it was observed that the mean RT decreased with increase in grade level except for PN and PM tasks.



[LSW- Letter search word**, LSNW-** Letter search nonwords,

LS-letter search overall **PN** –Picture naming, **PM-**Phoneme matching]

Figure 15. Comparison of mean reaction time (RT) of DRC component tasks across grades in children with dyslexia**.**

The mean reaction time (RT) for the normal children within grades on different components tasks represented in the Table 4 showed that, for the grades (III, IV, and VI) the mean RT was longer for LSW and shorter for PN tasks. In grade V the mean RT was longer for LSNW and shorter for PN.

Repeated measures ANOVA was computed for within subject effects on each grade separately for RT measures in normal children on component Tasks. In grade III, there was an overall significant main effect on component tasks i.e., F (3, 27) = 3.58, $p < 0.05$. Boneferroni test results showed that, the PN task was significantly different from LSW and LSNW in the reaction time measures. In grade IV, Repeated measures ANOVA showed there was no overall significant main effect on component tasks i.e., F (3, 27) = 2.28, p> 0.05. In grade V normal children, Repeated measures ANOVA showed there was an overall significant main effect on reading tasks i.e., F (3, 27) = 5.02, p< 0.05. Boneferroni test results revealed that the PN task was significantly different from LSW and LSNW. In grade VI, Repeated measures ANOVA results showed there was no overall significant main effect on component tasks.

The mean RT for the CWD within grades for different component tasks is shown in Table 4. The table shows that mean RT performance of CWD in grade III, was longer for LSW and shorter for pN. In grade IV, it's longer for LSNW and shorter for PN. In grade V, RT was longer for LSNW and shorter for PM. In grade VI, PN had longer RT and shorter for LSW. In CWD for analyzing the reaction time measures of component tasks within grades Wilcoxon singed rank results revealed that there was a significant difference in performance for the pairs PN and PM, for PN and LSW, PN and LSNW at 0.05 levels. Mann- Whitney test was done for each grade across both the groups. The results showed that in grade III children; there was no significant difference in the RT measures of component tasks. In grade IV there was a significant difference for LSNW and overall performance on LS at 0.05 levels. For grader V, there was a significant difference for PN task at 0.05 levels and not for LSNW, LSW and PM tasks. In grade VI there was no significant difference in all the component tasks.

To summarize, the performance in terms of accuracy and RT measures in CWD was significantly poor in comparison with normal children on all the component tasks. CWD performed poorly on PM tasks compared to LSW and LSNW, PN tasks.

4.4 Subtypes of dyslexia derived from the DRC model.

Hierarchical cluster analysis was done for the purpose of subtyping children with developmental dyslexia. In this method the clusters were represented in dendrograms for the tasks which tests the component in the nonlexical route/sublexical route (phonological tasks) and also for the lexical route (non phonological tasks) in the dual route cascaded model (Coltheart et al., 2001)

4.3.1 Phonological Tasks

Figure 9 shows dendrogram representing hierarchical cluster analysis for phonological tasks in children with dyslexia. Cluster analysis on children with dyslexia revealed that for phonological tasks (letter search nonwords, phoneme matching, reading nonwords) the groups can be grouped into two main groups, the larger group and a smaller group within the larger group.

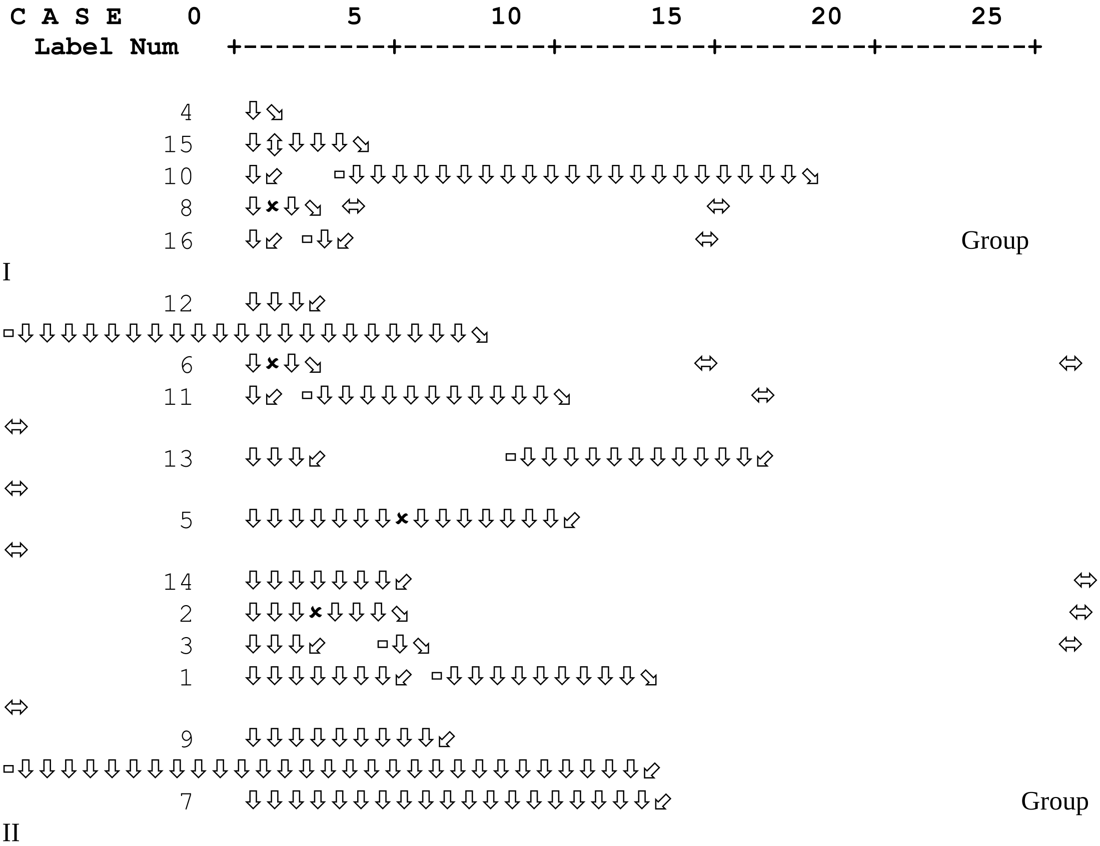


Figure 16. Dendrogram representing hierarchical cluster analysis for phonological tasks in children with dyslexia.

Analysis revealed that subjects {4, 15, and 10} performed similarly there by forming a cluster (Cluster I) themselves. On qualitative analysis of individual data, it was found that these children with dyslexia showed, poor performance on phoneme matching and reading non words task. Subjects {8, 16, and 12} performed similarly forming another cluster (Cluster II). On qualitative analysis of these individual data, it was found that these children with dyslexia showed poor performance on phoneme matching and reading nonwords. They performed better on letter search for nonwords task. Subject 13 (IIa) joins the cluster II at a later stage as it fell slightly apart in the mean accuracy .The difference between cluster I and II one is in terms of mean accuracy for PM and NW reading. The cluster I had a mean accuracy of about 30% but for the cluster II it was about 15%. Even though there were two different regions where in these six subjects fell, they did share many more features which are common to all the six subjects, so in the dendrogram all the six subjects merge at a later stage (See Figure 16).

Subjects {6, 11} formed the cluster III by their similar performances. On quantitative analysis the common features of the subjects in this cluster were same as above two clusters but the mean accuracy for their performance on PM and NW reading in this cluster was25%. Subjects {5, 14} formed the cluster IV at a longer distance when compared to other clusters so far, and they are of similar performances as of above clusters with a mean accuracy of 45%. And these clusters III and IV merge at the later stage of the dendrogram, and finally all the four clusters form a large group (Group I) because all the subjects in these four clusters share the common performance on phoneme matching and reading nonwords. There was another interesting cluster formed by subjects {2, 3} (Cluster V) which has a similar characteristics as poor performance in reading nonwords (5%).which was later joined by subject 1 (V a) and later by subject 9 (Vb) which differ slightly in the mean accuracy but all these subjects had poor performance on reading nonwords.

Subject 7 formed a separate cluster (Cluster VI) which later joins the cluster V because of the poor performance on reading nonwords (15%). These clusters V and VI form a smaller group (II) because of its similarities and this small group II joins the Large group (clusters I, II, III, IV) because all the subjects were tested under a common tasks (Phonological tasks).

To summarize, clusters which formed the phonological group included, cluster I {4, 15, 10} performed poorly on phoneme matching and reading nonwords, cluster II {8, 16, and 12} also showed poor performance in phoneme matching and nonword reading and cluster III{6, 11}and IV {5, 14} also showed poor performance on the above same tasks. Cluster V {2, 3} and cluster VI {7} showed poor performance only on nonword reading and these cluster was later joined by subjects 1 and 9. And this cluster V was less severe when compared to the above four clusters (I, II, III, IV) on phonological tasks.

4.3.2 Non-Phonological Tasks

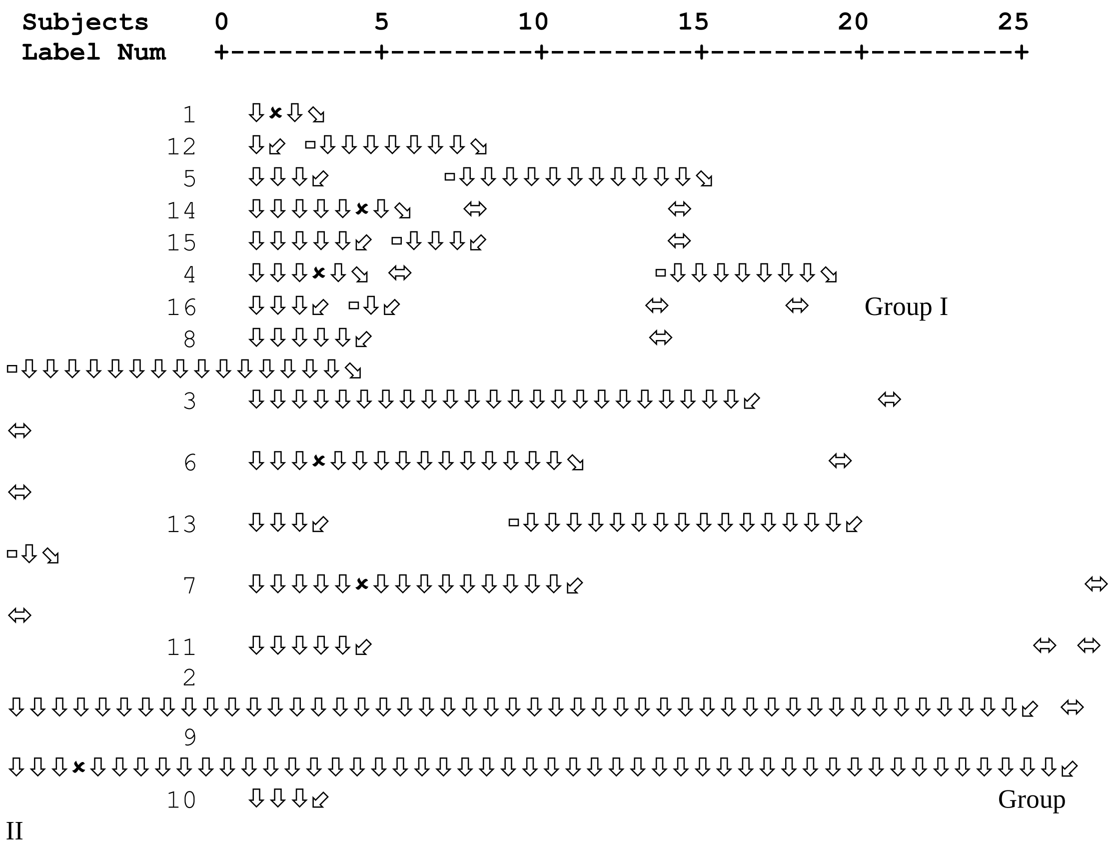


Figure17. Dendrogram representing hierarchical cluster analysis for non phonological tasks in children with dyslexia.

Figure 17 shows dendrogram representing hierarchical cluster analysis for phonological tasks in CWD. The cluster analysis revealed that for non-phonological tasks (letter search words, picture naming, reading regular words, and reading Irregular words) the dendrogram shown in figure 10 is divided into two main groups the larger groups and a smaller one.

In the larger group (Group I),

The analysis revealed that subjects {1, 12} performed similarly there by forming a cluster (Cluster I) both have the common characteristics such as the poor performance on reading IW which has a mean accuracy of about 40%. Subject 5 joins the cluster I (Ia) at a later distance as it is felt slightly apart in mean accuracy and it has also same poor reading irregular word performance (35%). Subjects {14, 15} performed similarly forming a cluster (Cluster II) which has the common features such as poor performance on reading IW and LSW which has the mean accuracy of 40%. Subjects{ 4, 16} performed similarly forming a cluster III which has a common feature such as poor performance in reading irregular words and letter search words with a mean accuracy of 35%. Subject 8 joins the cluster III (III a) at a later distance as it is felt slightly apart in mean accuracy and has the same deficits of cluster II. Later clusters II and III merge at a distance greater than those of the individual ones. And this merges with cluster I because all the clusters has similar poor performance in reading irregular words.

Subject 3 forms a separate cluster IV where there is a poor performance in reading irregular words (0% accuracy).This cluster joins with the above three clusters because of their similarity in their performance. Subjects {6, 13} form a cluster V as there was a common feature of poor performance in reading regular words (40%). Subjects {7, 11} forms a cluster VI because of their similarities in their tasks and this cluster merged with cluster V. The final large group (I) is formed when these six clusters merged at different distance levels and they all have the similar feature as poor performance in reading regular words, reading irregular words.

The smaller group (II) is formed by different clusters which later join to the group I. subject 2 forms the separate cluster VII and they have poor performance in reading regular words, reading irregular words, picture naming. Subject{ 9,10} forms the separate cluster VIII which shares the similar features such as poor performance in letter search words, reading regular words, reading irregular words

To summarize, clusters which formed the non- phonological group included, cluster I {1, 12} and cluster IV {3} which had poor performance in reading irregular words and V {6, 13} had poor performance in reading irregular words only. Cluster II {14, 15} had poor performance in letter search words and reading regular words. Cluster III {4, 16} both had the poor performance in letter search words and reading irregular words. Here clusters (I, IV, V) are very less severe than cluster II and III because they had poor performance in only one task (reading irregular words). Clusters VII {2} and VIII {9, 10} had poor performance in all of the non-phonological tasks and so they are more severe in type than the other clusters.

Table 5. *Subtyping of children with dyslexia based on phonological and non-phonological tasks.*

subjects (CWD)	Phonological tasks accuracy (%)	Non-phonological tasks accuracy (%)	subtypes of dyslexia
1	RNW (20%)	RIW (40%)	Mixed
2	RNW (10%)	RRW (30%), RIW (30%), PN (13%)	Mixed
3	RNW (0%)	RIW (0%)	Mixed
4	PM (20%), RNW (0%)	LSW (45%), RIW (30%)	Mixed
5	PM (40 %), RNW (25%)	RIW (30%)	Mixed
6	PM (30 %), RNW (20%)	RRW (40%)	Mixed
7	RNW (15%)	-	Phonological
8	PM (20 %), RNW 10%)	RIW (20%)	Mixed
9	RNW (0%)	RRW (0%), RIW (0%)	Mixed
10	PM (30 %), RNW (0%)	LSW (45%), RRW (0%), RIW (0%),	Mixed
11	PM (30 %), RNW (15%)	-	Phonological
12	PM (20 %), RNW (10%)	RIW (30%)	Mixed
13	PM (30 %), RNW (5%)	RRW (40%)	Mixed
14	PM (30 %), RNW (20%)	RRW (50%)	Mixed
15	PM (40 %), RNW (25%)	LSW (30%), RRW (30%),	Mixed
16	PM (10 %), RNW (10%)	-	Phonological

Table 5 summarizes the Subtypes of children with developmental dyslexia based on the lexical and nonlexical route; this table revealed that subjects {7, 11, and 16} are purely phonological dyslexics because they performed poorly on phonological tasks and better on non-phonological tasks. And all other subjects performed poorly on both the phonological and non-phonological tasks so they are grouped into mixed dyslexics {1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 14, 15}. There were no pure surface dyslexics found in the present study.

CHAPTER 5

Discussion

The results and the findings of the present study are discussed below in the following sections,

5.1 Performance of normal children and children with dyslexia (CWD) on reading tasks [regular words (RW), irregular words (IRW) and non-words (NW)].

5.2 Performance of normal children and children with dyslexia on different components of the DRC model.

5.3 Subtypes of dyslexia derived from the DRC model.

5.1 Performance of normal children and CWD on reading tasks

The aim of the present study was to find the reading performance on tasks such as regular words (RW), irregular words (IRW) and non-words (NW) reading in normal children and children with dyslexia (CWD). .The performance of normal children on accuracy measures improved from lower grades to higher grades thus indicating a developmental trend on irregular word reading tasks and on reaction time measures this trend was found on reading irregular words and nonwords but not for regular words. This developmental trend could be explained using dual route cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). For regular word processing, the lexical semantic route gets activated, which has connection between the orthographic lexicon to the phonological lexicon through a semantic system (see

Figure 7). The information stored in the semantic system plays a major role in the reading regular words. In children in the lower grades, this semantic system is still in the developmental stage so children might take longer time to process and make more errors in reading compared to older grade children. For e.g. in the present study, a regular word 'sand' (/sænd/) has each of the letters 's', 'a', 'n' and 'd'. This word activates its phonological representation for's', 'a', 'n' and'd' through the help of the semantic system. For irregular word processing, the lexical nonsemantic route gets activated which has a direct connection between orthographic lexicon to the phonological lexicon without involvement of semantic system. For e.g. consider an irregular word 'shoe' (/ʃu /). Here the letter units in the word have to activate its phonological representation as there is no involvement of the semantic system in processing this irregular form. With increase in grade levels, the performance was found to be improving in terms of accuracy measures. This could be because the children become more familiar of the letter combinations with development from lower to higher grades. Similarly, in the present study it was found that children in the lower grades took longer time (RT) to read irregular words in comparison to higher grades. This again is indicative of longer processing time in children in the lower grades as they are still developing the component processes that are required for reading irregular words. Thus, the present study supports various developmental stage models of reading like the DRC model (Coltheart et.al, 2001) which discuss the development of lexical route for processing irregular words.

For nonword processing, the sublexical route gets activated i.e. the route which follows the grapheme-phoneme correspondence rules. These set of rules are encapsulated in a GPC (grapheme to phoneme correspondence) module (Coltheart et.al, 2001). For e.g. consider a nonword ‘Mave’ (/mæv/) and the processing in this module is serial the corresponding translation would be: M -> /m/, A -> /æ/, V-> /v/, and E -> /i/. In young graders as the rules for the GPC module is not yet acquired there is a delay and they make more errors in reading nonwords than older graders (see Figure 7). If the GPC module is not developed, then children in lower grades will not be able to associate the grapheme ‘M’ with the phoneme /m/, ‘A’ with /a/ and so on. Hence younger children may find it difficult to read these non words in the absence of such a conversion system. In this process, children in lower grades may make more mistakes in an attempt to associate the graphemes to their phonemes or might take longer time in processing them. Whereas, in older children this system is developed and enough representations in GPC module will enable them to convert the letter strings into sounds and be able to read out the non words.

There was a significant difference across the tasks [regular words (RW), irregular words (IRW) and non-words (NW)]. Among the reading tasks, accuracy and reaction time measures was poorer on nonword reading task compared to irregular and regular words in normal children. This poor performance on non-word reading task in normal children could be explained using DRC model (Coltheart et.al, 2001). Nonwords are read through the sublexical route of the model, where it employs the spelling-sound correspondence rules. These set of rules are encapsulated in a GPC (grapheme to phoneme correspondence) module (see Figure 7). The GPC module applies rules serially left to right to a letter. That is, letters activate phonemes in a serial, left to right fashion. Activation of the second phoneme does not start until a constant number of cycles after the start of activation of the first letter. For e.g. consider a nonword ‘Mave’ (/Mǽv/) and the processing in this module is serial the corresponding translation would be: M -> /m/, A -> / ǽ /, V-> /v/. As the processing is serial it takes a longer time to process the nonwords where as for words the processing which takes place through the lexical route is parallel. These results are in consonance with the study by Burani et al., (2002) who derived reaction times (RTs) for naming non-words in third- to fifth-grade children. They attributed the difference in performance effect of younger graders to the older one due to morphological structure ,that nonwords made up of roots and derivational suffixes which looks similar to words are read quickly than the nonwords no morphological constituency. And the reaction time for naming reduced as the grade levels increased.

Poor performance on non-word reading task for accuracy and reaction time measures in normal children could also be explained using the lexicality effect (i.e., advantage of words over non-words). This refers to the difference in reading strings of letters that represent items from the lexicon, i.e., words, and strings that can be pronounced but do not have entries in the lexicon i.e. non-words. One well-known theoretical framework proposes that, since non-words cannot be read by means of the lexicon they constitute a specific way to evaluate efficiency in the use of the grapheme-to-phoneme rules, or the non-lexical routine in reading (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). And this lexicality effect was supported by studies on normal children by Tressoldi (1996). He reported data on the reading of lists of words and non-words in second to eighth graders. He found a clear effect of lexicality for both reading speed and reading accuracy in all groups of children.

The results also revealed that irregular word reading was significantly different from the other reading tasks on accuracy and reaction time measures in normal children. This could be explained by DRC model (Coltheart et.al, 2001), here the lexical nonsemantic route gets activated which has a direct connection between orthographic lexicon to the phonological lexicon without involvement of semantic system. For e.g. consider an irregular word /shoe/ here the letter units of the word in has to activates its phonological representation here as there was no involvement of the semantic system the processing time was slower and some of the regularization errors were seen in the younger grade children e.g. /shoe/ read as /ʃo: i/ and this may be attributed to the development of the phonological lexicon in the lexical semantic route of the DRC model.

In the present study, children with dyslexia (CWD) performed poorly on all reading tasks compared to normal children on both accuracy and reaction time measures. On nonword reading task CWD performed poorly compared to irregular and regular word reading. This poorer performance on nonword reading in CWD could be explained using the DRC model (Coltheart et.al, 2001). When there is a problem in the GPC module and proper phoneme to grapheme correspondence doesn't take place this leads to the impaired sublexical route, so more errors were seen in the nonword reading. For e.g. consider a nonword 'Mave' (/Mǽv /) the processing in this module is serial the corresponding translation would be: M -> /m/, A -> / ǽ/, V-> /v/. Normally the activation from one phoneme to the other has to be from left to right serially one after the other. If there is impairment in the serial processing then the word would be read as /Vǽm/ i.e. whichever phoneme is activated first will be read first which results in the impaired nonword reading (see Figure 7). These results are in consonance with the study by Landerl, Wimmer and Firth (1997) who studied nonword reading in 12 year old CWD and reading level matched normals. Their results revealed that CWD performed poorer on nonword reading compared to reading level matched controls and this was attributed to the lexicality effect. Several authors (e.g., Rack, Snowling, & Olson, 1992) reported that dyslexics selectively fail in reading non-words. A marked lexicality effect would indicate a phonological disturbance in dyslexia (for meta-analyses of this effect. (Rack et al., 1992; Van IJzendoorn & Bus, 1994).

Results also revealed that poorer performance on irregular word reading in CWD compared to normals and this could be explained using DRC model (Coltheart et.al 2001). For reading irregular words, there should be an intact lexical nonsemantic route which doesn't involve the semantic lexicon and there is a direct connection between the orthographic lexicon and phonological lexicon (see fig 8). For e.g. unit for word 'Shoe' (/ʃu: /) activates the phoneme for /ʃ/ and inhibits all the other phonemes and if this proper inhibition and excitation doesn't takes place it leads to error in irregular word reading. These results were in consonance with the study by Coltheart and Leahy **(**1996) who reported that learning to read in English is characterized by a slow increase in accuracy, although this is quite apparent for irregular words, many errors in reading regular words can still be expected even after several years of schooling.

5.2 Performance of normal children and CWD on different components of the DRC model.

Further, the results on different components of DRC model showed that in normal children, for accuracy measures there was no developmental trend as observed for reading tasks but for latency measures there was a developmental trend i.e. as the grade increases the reaction time was lesser. This was observed on all the component tasks of the present study. There was a significant difference across all component tasks [letter search words (LSW), letter search nonwords (LSNW), picture naming (PN), and phoneme matching (PM)]. In the present study children with dyslexia (CWD) exhibited clear deficits on all the three tasks that directly relate to processing levels in DRC, these included the letter search, picture naming and phoneme matching task compared to age matched normal children.

In the present study, poor performance on letter search task for nonwords were seen in normal children for both latency and accuracy measures. This could be explained through DRC model (Coltheart et.al, 2001) (see Figure 7). According to this model, the letter search task involves letter processing i.e. the letter unit component of the model (Ziegler & Jacobs, 1995; Ziegler, Van Orden, &Jacobs, 1997), where each letter in the word is processed visually and sent to the orthographic lexicon. If there is a problem in the letter unit processing it can lead to delay in the letter search task or can indicate reduced accuracy and latency measures. For e.g. consider a nonword letter strings (RQUAL) here. In the lower graders, the activation of the letter strings takes a long time in processing these strings because the letter processing unit is still in the developmental period and instead of searching for the target letter they may search for similar letters that they are familiar with or often used one. And as the grade level increases these errors were found to be decreasing. The results also revealed that accuracy and reaction time measures on letter search words and nonwords were poorer compared to normal children. This poorer performance could be explained through the DRC model (Coltheart et.al, 2001). There may be impaired connection between the letter unit and the orthographic lexicon or problem at the level of letter unit processing. For e.g. in the above considered nonword string

(RQUAL) because of the problem at the level of letter units causes visual processing errors such as poor discrimination of similar looking letters (e.g., ‘b’ and ‘d’, ‘m’ and ‘n’, ‘p’ and ‘q’) . Such errors were reported in a number of recent studies as well (Bosse, Tainturier, & Valdois, 2007; Hawelka &Wimmer, 2005; Hawelka, Huber, & Wimmer, 2006). Present study showed longer RT for letter search task on nonwords compared to words. This could be because of the familiarity effect i.e. the most familiar letter units may be processed easily compared to the unfamiliar words and hence take lesser time on words than nonwords which seem unfamiliar. These findings are in consonance with the study by Krueger (1982) who demonstrated that subjects can search for target letters within words faster than they can search through in nonwords.

Our results support findings of Terepocki, Kruk and Willows (2002) who compared 10-year-old average readers and children with reading disability. The children with reading disability made more orientation errors than average readers on computer-based reversal detection tasks (numbers, letters, letter strings, words), and more reversal errors on controlled writing tasks. The authors suggest that the difficulties of reading disabled group in discriminating similar looking items (e.g. ‘b’ and ‘d’, ‘m’ and ‘n’, ‘p’ and ‘q’) could be due to poorly specified representations of letters in their lexicon. They concluded that although reversal errors are likely to disappear in children with reading disability as their reading and writing skills improve, the consequences of early letter orientation errors need further study.

On picture naming tasks (PN), the results of the present study showed that in normal children the performance was better in terms of both accuracy and reaction time measures. There was a developmental trend found in normal children on the reaction time measures of rapid picture naming task i.e. as the grade level increases the latency decreased and not for the accuracy measures. This could be explained taking support from the DRC model (Coltheart et al, 2001). Picture naming tasks are supposed to involve access to the phonological lexicon in the lexical route (Glaser, 1992; Swan & Goswami, 1997; Wolf & Bowers, 1999). For e.g. consider a picture 'fish'. Here there is no involvement of the letter units and orthographic lexicon because of no written form. So it directly accesses the phonological lexicon for naming the picture (see Figure 7). In younger grade children the phonological lexicon is still in the developmental stage wherein the phonological repertoire in the lexicon may not be complete. Hence, the errors in the young grade normal children may be mostly the related words to the target picture which may be some word associated with 'fish'. For e.g., 'fish' may be named as 'water'. This may be because the phonetic representation of the picture 'fish' may not have been stored in the phonological lexicon in the earlier grades. With development, i.e., as the grades increases the phonological lexicon may be well established and hence children in the higher grades may name the target picture accurately and also take lesser time to process as the phonological representation is already available in older children. Hence, the time taken to access and process the name of the target will be lesser compared to younger children.

The results also revealed that there was no significant difference in accuracy measures on rapid picture naming tasks for both normal and CWD group. However, there was a significant difference in the reaction time measures for phoneme matching tasks for both the groups. Longer reaction time in CWD may be due to the delayed processing that takes place in the phonological lexicon which results in the longer processing time. Wolf and Bowers (1999) opined that deficits in rapid naming are most strongly associated with deficits in the development of orthographic representations for words. They hypothesized that children with slow naming speed may be activating the visual and phonological codes for printed letters too slowly to allow efficient encoding of the specific letter combinations in words.

These results are in consonance with the study by Denckla and Rudel (1974) who believed that normal children and CWD may be able to correctly name the colors or pictures presented to them, however, they found that naming speed in CWD was much slower in comparison to normal children. Thus, they believed that it is the naming speed more than the accuracy which differentiated between children with dyslexia and normally reading children for color and object naming. This may be because generally it has been found that CWD take longer time to process any temporal based tasks and further take longer time to activate the visual and phonological codes for naming (Wolf & Bowers, 1999). A naming speed deficit was also found to persist over 9 years in at least some of the dyslexic individuals studied by Korhonen (1995). Denckla and Rudel (1976) also reported that on naming objects, CWD children performed slower than normal controls who read at an age appropriate level and also the reading age matched children. Ahissar (2007) stated that the perceptual anchor theory can account for deficits in RAN according to which if a smaller number of stimulus items are presented repeatedly the deficits were stronger in CWD.

On phoneme matching tasks, the results of the present study revealed that both normal children and CWD performed poorer on phoneme matching (PM) tasks. When compared to normal children, CWD performed poorer on this task. In normals there was no developmental trend for the accuracy measures but there was a developmental trend in the latency measures i.e. as the grade level increases the latency for the phoneme matching task decreases. The reason for the occurrence of this trend in normal children could be explained by DRC model (Coltheart et al, 2001). Phoneme matching task measures the capacity to detect and manipulate phonemes while not requiring orthographic or visual-attentional processes. Although phoneme matching does not directly measure the GPC procedure, the claim is that meta-linguistic awareness of individual phonemes is necessary to create grapheme–phoneme mappings (Hulme, Caravolas, Malkova, & Brigstocke, 2005).For e.g. In this task three words are presented auditorily (Top, Toy, Mat) and subject has to find out the word which does not have the common phoneme in a computerized experimental tasks. To complete this task successfully, the child should be aware of the phonemes in that language and this awareness of phonemes develops as the age increases. This phoneme matching task was poorer in CWD and may be explained by impaired meta-linguistic awareness of individual phonemes. These findings are in consonance with the study by Tallal (1980) who proposed that children with specific reading difficulties are deficient in processing brief and rapidly changing acoustic information. With respect to speech perception this means that formant transitions of speech sounds, which are very brief acoustic events, will be hard to recognize.

Therefore, discrimination of phonemes like stop consonants, which only contrast in their initial formant transitions, will be susceptible to impairment in contrast to vowels. Investigators (Werker & Tees, 1987; Reed, 1989; Mody et al., 1997) have contributed to the evidence that dyslexia is associated with auditory perceptual problems. Dyslexic children have repeatedly shown less consistent identification of consonant-vowel pairs ([ba]-[da], [sa]-[sta], [da]-[ga]) at a synthetic continuum, even at the extreme ends of the continua. Perceptual difficulties, as described above, could adversely interfere with building up and stabilizing phonological representations as the boundaries of two consonants (as these seem particularly affected) may become blurred or distorted. Such noisy phonological representations may well explain the delay that dyslexic individuals have with learning new words, as they may need more tokens of the same word to establish a phonological representation of a word. Furthermore, ‘fuzzy’ phonological representations also stand in the way of accurate segmentation and manipulation of sounds within a syllable, which, in turn, is a very important factor when learning to relate graphemes to phonemes (Baldeweg, Richardson, Watkins, Foale, & Gruzelier, 1999).

5.3 Subtypes of dyslexia derived from the DRC model.

The major aim of the present study was to derive the subtypes of children with dyslexia (CWD) from the components of DRC model. Here hierarchical cluster analysis was done and results showed that the performance of the children with dyslexia on reading tasks and tasks related to the components of the model did not find a convincing interpretation of the subtypes in terms of single dissociated deficits. Rather than having a single deficit on either the lexical or nonlexical route, surface and phonological dyslexics seem to have multiple deficits in both the lexical and sublexical route. The findings are in consonance with the study by Pennington (2006) who has discussed the existence of heterogeneity in developmental dyslexia. Thus, at first sight, the classification of dyslexic children into subtypes yields a relatively poor description of the dyslexic population (Griffiths & Snowling, 2002). From the cluster analysis and the qualitative analysis two major subtypes of dyslexia were derived which included *phonological* and *mixed subtypes.* Literature review suggests broadly three subtypes of developmental dyslexia- phonological, surface and mixed type or unclassified (Castles & Coltheart, 1993; Ziegler et, al, 2007; Manis, Seidenberg, Doi, McBride-Chang & Petersen, 1996). And some of the authors concentrated mainly on two subtypes of developmental dyslexia which included phonological and surface subtypes (Stanovich, Siegel & Gottardo, 1997; Valdois, 1996).

The existence of phonological and mixed subtypes of dyslexia in the present study can be explained taking support from the DRC model (Coltheart, Rastle & Perry, 2001). In the present study, three out of sixteen children were found to be *phonological subtype* {7, 11, and 16} of dyslexia (see Table). And these children have been found to perform poorly on phonological related tasks like nonword reading (NW), phoneme matching (PM) and letter search nonwords (LSNW). These results could be explained from the DRC model (Coltheart et al, 2001), on phonological related tasks the sublexical route is activated. If there is a delay or deficit in the sublexical processing which involves the GPC module results in the phonological subtype. And these subtypes show errors in the phonological related tasks. For e.g. in phonological subtype, on nonword reading(/Mave/) the GPC module which follows a set of phoneme grapheme rules is impaired so that nonwords reading will be affected, in phoneme matching task the phoneme system in the nonlexical route is activated and it is impaired in these phonological subtypes because of the poor phoneme discrimination ([ba]-[da], [sa]-[sta], [da]-[ga]) which only differed in finer aspects like voicing and aspiration and also auditory perceptual problems in CWD. On letter search nonwords task e.g. (RQUAL) the impaired activation of the letter processing units results in the phonological subtype of dyslexia. These results were in consonance with the study by Castles and Coltheart (1993) identified pure developmental phonological dyslexics among CWD and their nonword reading was found to be poor compared to chronological age- matched controls, but their exception word reading was within normal range. Castles and Coltheart (1993) concluded that these results were best interpreted in terms of a dual route model, with the subtype profiles representing different levels of development of the lexical and nonlexical procedures. Castles and Coltheart (1993) maintained that one in three children with reading problems could be expected to manifest either a phonological or surface pattern of difficulties. Manis, Seidenberg, Doi, McBride-Chang and Petersen (1996) also reported of pure phonological classification may represent phonological processing deficits.

The results of present study contradict a study by Snowling and Nation (1997) who found that irrespective of classification procedure, no differences were identified between the subtypes of CWD on the measures of phonological processing. Zabel and Everatt(2002) also found that phonological dyslexics behave in a same way as surface dyslexics on four tasks requiring phonological processing (pseudo-word reading task, a spoonerism task, an alliteration task, and a rhyme fluency task),both in accuracy and speed. Still other studies showed that surface dyslexics still also showed phonological deficits in favor of the idea that surface and phonological dyslexia lie on a phonological deficit continuum (Griffiths & Snowling, 2002; Harm & Seidenberg, 1999; Manis et al., 1996; Snowling, 2001).

Thirteen out of sixteen were found to be of *mixed subtype* {1,2,3,4,5,6,8,9,10,12,13,14,15} of dyslexia(see Table 5). And these children have been found to perform poorly on phonological tasks like nonword reading (NW), phoneme matching (PM) and letter search nonwords. (LSNW) and non-phonological related tasks like picture naming (PN), letter search words, reading regular (RW) and irregular words (IRW). These results could be explained using the DRC model (Coltheart et.al 2001). In this model there are three major routes that are described as lexical- semantic route; lexical-nonsemantic route and sublexical route (see Figure 7). The lexical semantic route has its connection between the orthographic lexicon to the phonological lexicon through the semantic system and this explains the process of reading regular words. For e.g.in a regular word /sand/ the letter units from the orthographic lexicon goes to the semantic system and then phonological lexicon if this route is affected this leads to impaired regular word reading. For lexical nonsemantic route there is a direct connection between the orthographic and phonological lexicon without any connection to the semantic system and this route explains the process of reading irregular words which doesn’t have spelling -sound correspondence (see Figure 7). For e.g. in a irregular word /phone/ if there is a impaired connection between orthographic and phonological lexicon leads to impaired irregular word reading. And the sublexical route involves the GPC module which explains the processing of reading nonwords. If this route is impaired then the subjects has difficulty in reading nonword letter strings e.g (RQUAL). When both the lexical route and sublexical route are affected, it may show up errors in both phonological tasks and non phonological tasks. Most of the errors that were seen when both the routes are affected are of irregular word and nonword reading tasks.

These results of the present study are in consonance with the study by Castles and Coltheart (1993) who also observed that many poor readers are impaired on both irregular word and nonword reading tasks. They hypothesized that the reason why a correlation between irregular and nonword reading performance might also be expected on a dual-route account is related to the structure of the model itself, as the computational Dual Route Cascaded (DRC) model of Coltheart and colleagues (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). As stated in the model itself, the lexical and nonlexical routes of the DRC are not completely independent, but have three components in common: visual feature detectors, abstract letter units, and the phoneme output system. Therefore, a deficit in any one of these components will lead to impairments in both irregular and nonword reading.

Present study also supports study by Share (1995) who also observed co-occurrence of deficits in irregular and nonword reading, although the orthographic lexicon and the GPC procedure in the DRC model operate independently. He explained his finding using self teaching hypothesis, i.e., each component might assist the learning of the other. According to this hypothesis, being able to recognize unfamiliar printed words auditorily by sounding them out using the GPC procedure assists the development of visual word recognition skills, i.e., the use of this procedure helps the orthographic lexicon to develop (Share, 1995). Irrespective of subtype, dyslexic readers showed significantly poorer performance than chronological-age matched controls for both irregular- and nonword reading (Castles &Coltheart, 1993; Castles, Datta, Gayan, & Olson, 1999; Curtin, Manis, & Seidenberg, 2001; Manis et al., 1996; Stanovich, Siegel, & Gottardo, 1997).

Summary and Conclusions

Reading is a complex cognitive process. It involves the co-ordination of a series of functions which include visual functions such as configurational (feature) and orthographic (word form) analyses and verbal or language functions such as phonological, semantic and syntactic coding and decoding and other cognitive functions like memory and attention and motor skills. Reading can be hindered by faulty mechanisms in any or several of these functions involved (Lachmann, 2001).

Thus, the present study aimed at investigating the subtypes of children with developmental dyslexia based on the dual route cascaded model and to assess each of representational level of the DRC model (Coltheart et.al 2001). Two groups i.e., age matched normal children (40) and children with dyslexia (16) from grades III to VI without any hearing, neurological, developmental or emotional problems were considered for the study. Subjects were tested on tasks such as reading regular words, irregular words and nonwords, picture naming, letter search task for words and nonwords and phoneme matching tasks. The details of the stimulus are given in Appendix-A.

The subjects were asked to read the words presented through the software for the reading tasks and to name the pictures for picture naming and to search for the target letter in the words displayed on the screen for letter search task and for phoneme matching task subject has to listen to the words and find out the odd one out of the stimulus. The latency and accuracy were calculated for all the tasks.

Results of the present study revealed that reading performance of the CWD was poorer compared to the normal children. For normal children as the grade level increases the accuracy increases and latency reduced but this developmental trend was not seen in the CWD. Both the groups performed poorer in the nonword reading compared to irregular words and regular words. this was explained using the DRC model(Coltheart et al, 2001)in which the nonword reading difficulty was due to impaired GPC module in the sublexical route and irregular words difficulty was due to impaired lexical nonsemantic route, In the component tasks of the DRC model the CWD performed poorer compared to normal children. Both groups performed poorer on the phoneme matching tasks which was most affected in the CWD group. The performance was better in picture naming task compared to all other tasks which access the representational levels of the model. The errors on phoneme matching was explained using the DRC model, that poor phonemic awareness and poor processing of brief and rapidly changing acoustic information leads to the poor processing of phoneme system of the model which results in the poor performance in the phoneme matching tasks. On Subtyping of CWD, there was no single isolation deficits observed and multiple deficits were observed based on DRC model. Out of 16 children with dyslexia considered in the study three were grouped into pure phonological dyslexics {7,11,16}and all others formed a heterogeneous group i.e. mixed dyslexics {1,2,3,4,5,6,8,9,10,12,13,14,15}. The occurrence of phonological subtype of dyslexics was explained by the DRC model, that only the sublexical route was impaired leading to poor performance on phonological tasks whereas for mixed types the both lexical and sublexical route was affected resulting in poor performance on both phonological and non-phonological tasks.

Thus, the present study explained development of various component processes of reading in normal children where these processes develop from lower grades to higher grades for different components of reading. Also, the study supports the existence of subtypes of dyslexia even in Indian children learning to read and write the alphabetic language, English.

Implications of the study:

- The present study has investigated individually the components of the DRC model. This gives us an idea at which representation level the individual is having problem or whether a single component is affected or multiple components are affected. This will further help the clinician to plan intervention on those levels or components which have deficits in children with dyslexia.

- Studying the subtypes of developmental dyslexia (surface or phonological or mixed) based on DRC model has made way for us to explore whether only lexical route is affected or only the non-lexical route is affected or both. This would aid us in understanding that subtypes could exist in developmental dyslexia and thus emphasize on the need to design an Individualized education program (IEP) for intervention depending on the subtypes of dyslexia.

- The present study is only an initial attempt to investigate the reading performance and subtypes of children with developmental dyslexia using DRC model. Future studies are warranted in Indian population to study processing in semisyllabic Indian languages (like Kannada, Hindi, etc.). Also, studies related to cross language influences is also warranted to see whether there is facilitation or interference of an alphabetic language with a non-alphabetic language can also be explored.

Limitations of the study:

- The number of subjects considered for each grade in the study is very limited and hence difficult to generalize to normal population or children with developmental dyslexia.
- The present study is only an initial attempt to investigate the reading performance and subtypes of children with developmental dyslexia using DRC model. Other factors like the influence of native language or mother tongue or socio –economic factors, literacy level of parents, etc. have not been explored and explained in the present study.

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APPENDIX –A

1. Reading Tasks

a) Regular and Irregular words reading task

S.No	Regular words	Irregular words
1	Class	People
2	Page	Work
3	Week	Picture
4	Write	Science
5	Lunch	Bread
6	Sand	Country
7	Drink	Shoe
8	Leaf	Break
9	Grape	Phone
10	Home	Christmas

b) Nonwords reading task

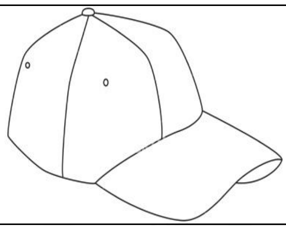
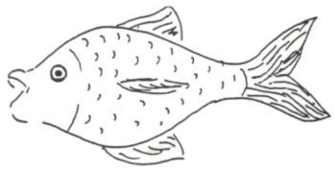
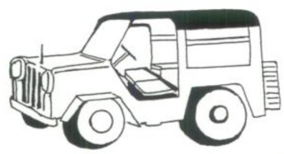
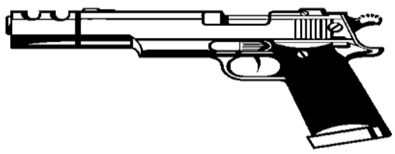
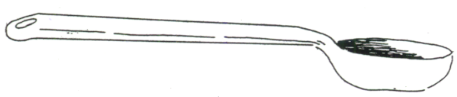
S.No	Non-words
1	Pocture
2	Wirld
3	Yaung
4	Droot
5	Mave
6	Wark
7	Pycle
8	Fyme
9	Burse
10	Chistle
11	Spock
12	Clider
13	Scain
14	Shace
15	Seather
16	Sibtle
17	Meople
18	Pown
19	Miver
20	Natch

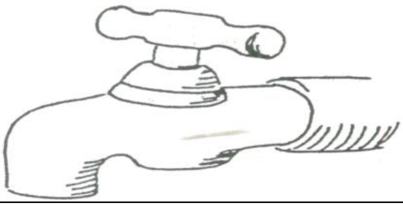
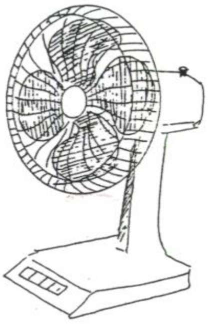
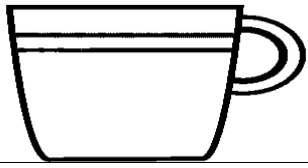
2. **DRC component Tasks**

a) **Letter search task**

S.No	Words(Target letter)	Nonwords(Target letter)
1	Power (A)	Chace (A)
2	Cobra (B)	Pock (B)
3	Spider (D)	Dreak (D)
4	Clock (E)	Spuak (E)
5	Swing (G)	Calse (G)
6	Horse (I)	Apris (I)
7	Object (J)	Natch (J)
8	Prize (K)	Piker (K)
9	False (L)	Rqual (L)
10	Woman (M)	Spuel (M)
11	Cloud (N)	Mifle (N)
12	Clean (P)	Pycle (P)
13	Equal (Q)	Couch (Q)
14	House(R)	Wirld (R)
15	Write (T)	Burse(T)
16	Smile (U)	Yaung (u)
17	White (V)	Miver (V)
18	Owner (W)	Awner (W)
19	Sixty (X)	Cobra (X)
20	Dozen (Z)	Pozen (Z)

b) Picture naming task.

S.NO	Name	Picture
1	**Bell**	
2	**Cap**	
3	**Fish**	
4	**Jeep**	
5	**Gun**	
6	**Rat**	
7	**Spoon**	

8	**Tap**	
9	Fan	
10	Cup	

c) Phoneme matching task

S.No	Word 1	Word 2	Word 3
1	Socks	Box	Gum
2	Top	Toy	Mat
3	Fog	Net	Dog
4	Bus	Web	Wet
5	Pen	Cap	Cat
6	Rat	Jug	Bat
7	Zip	Bat	Bag
8	Van	Jam	Can
9	May	Tap	Mat
10	Car	cat	Gap