PREVALENCE OF VISION CONDITIONS IN A SOUTH AFRICAN POPULATION OF AFRICAN DYSLEXIC CHILDREN.

by

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Submitted in partial fulfillment of the requirement

for the degree of **MASTER OF OPTOMETRY** in the

Discipline of Optometry in the Faculty of Health Sciences,

University of KwaZulu-Natal, Durban

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APRIL 2010

DECLARATION

I hereby declare that this thesis is my own original work. It is submitted to the University of KwaZulu-Natal in partial fulfilment for the degree of Master of Optometry.

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DATE: APRIL 2010

ACKNOWLEDGEMENTS

There are at times that this project seemed to be a 'never ending journey' and many people have encouraged me greatly. I wish to express my profound gratitude and acknowledgement of the contributions of the following people who have given me support in different ways:

- Professor Kovin Naidoo (my supervisor) for his guidance throughout the entire research process.
- The examiners for their critical evaluation of the study.
- My family for their patience throughout the time I was not there for them. Special thanks to my wife Joyce for all her encouragements right from the beginning of the project. To my parents, for giving me the discipline never to give up no matter how rough things may be.
- Carrin Martin for her invaluable support in editing this thesis. Members of staff of the International Center for Eye Care Education: Sandro Thaver for the statistical analysis, Mirashnee Rajah and Diane Wallace for their continued administrative and moral support.
- All members of staff of the Optometry Department University of Kwazulu Natal for their assistance in different ways.
- Celia G of ILAMO for assistance with referenced articles.
- Department of Education for granting permission to have access to the schools.
- The Principals, Parents and Learners of schools (Khulangolwazi special school and Addington Primary schools) Durban for their cooperation.
- Authors of the numerous studies I consulted whose studies upon which the foundation of this study was based.
- The University of KwaZulu-Natal for initial financial support.

Abstract

Dyslexia is a neurological disorder with genetic origin that affects a person's word processing ability, their spelling, writing, comprehension and reading, and results in poor academic performance. As a result, optometrists are consulted for assistance with the diagnosis and treatment of a possible vision condition. Optometrists are able to assist with treatment as part of a multidisciplinary management approach, where optometric support is necessary. International studies have indicated that up to 20% of Caucasian school children are affected by dyslexia, while there are no similar figures for African children. Studies have been done to assess the extent of visual defects among Caucasian dyslexics, but not among African dyslexic children. The aim of the study is therefore to determine the prevalence of vision conditions in an African South African population of dyslexic school children, and to investigate the relationship between dyslexia and vision.

The possible relationship between dyslexia and vision conditions has been recognized as an important area of study, resulting in research being conducted in many countries. Studies have been undertaken by optometrists and ophthalmologists, who differ in their approach and attitude on how vision conditions affect dyslexia. A review of the literature revealed three broad areas of vision that may impact on reading ability, these being acuity defects, binocular vision and ocular pathology. Acuity defects consist of visual acuity and refractive error. Areas of binocular vision evaluated in the literature include near point convergence, heterophoria, strabismus, accommodative functions, vergence facility and reserves. Hyperopia was the only vision variable that was found to be consistently associated with difficulties with reading, but not causally while findings on other variables were inconclusive. However, all the studies acknowledged the complexity of the condition, and the need for a comprehensive multidisciplinary management approach for its diagnosis and management.

The study was undertaken in the city of Durban, South Africa, using a case-control study of two groups of African school children between the ages of 10 and 15. Both study groups consisted of 31 children of normal intelligence, who were matched in gender, race and

socio-economic status. The case group attended a school for children with learning disabilities, while the control group attended a mainstream school. At the time of the study, only one school catered for African children with learning disabilities, and only 31 of its pupils were diagnosed with dyslexia. Ethical approval was obtained from the University of KwaZulu-Natal; permission to undertake the study in the identified schools was obtained from the Department of Education, and the school principals consented on behalf of the learners, as it was not always possible to reach the individual parent.

The researcher (an optometrist) visited both schools by appointment where rooms were made available to do the testing, and the tests were explained to all participants. The LogMar Acuity Charts were used to assess visual acuity, and static retinoscopy was used to assess refractive error. Binocular vision was tested using the cover test for ocular alignment, the Hirschberg test for strabismus, RAF rule for near point of convergence, ± 2 D flipper lenses for accommodation facilities, Donder's push up methods, using the RAF rule for amplitude of accommodation, plus and minus lenses for relative accommodation, monocular estimation technique for accommodation posture, and prism bars for vergence reserves. Ocular pathology was assessed using a direct ophthalmoscope.

The dyslexic group presented with the following: Refractive errors: hyperopia 6.5%, myopia 6.5%, astigmatism 10%, anisometropia 6.5%, remote near point of convergence 33%, esophoria at near 3%, exophoria at near 9.5%, accommodative infacility 54% and lag of accommodation 39.28%. The dyslexic group had relatively reduced fusional reserve compared to the control group.

The control group presented with the following: Refractive errors: hyperopia 3%, astigmatism 13%, anisometropia 6.5%, remote near point of convergence 48%, esophoria at near 0%, exophoria at near 0%, accommodative infacility 33% and lag of accommodation 41.93%.

The prevalence of a remote NPC was higher in the control group than in the dyslexic group and there was a statistically significant difference between the two groups: NPC break (*p=0.049*) and recovery (*p=0.046*). The prevalence of poor binocular accommodation facility at near was higher in the dyslexic group than in the control group and there was a statistically significant difference between the two groups (*p = 0.027*).

Vision defects such as hyperopia, astigmatism, accommodation lag, convergence insufficiency, poor near point of convergence and accommodative infacility were present in the dyslexic pupils, but they were no more at risk of any particular vision condition than the control group. This study provided the prevalence of vision conditions in a population of African dyslexic children in South Africa, the only vision variable that was significantly more prevalent in the dyslexic population being the binocular accommodation facility at near, although the study was unable to find a relationship between dyslexia and vision. The statistically significant difference may not imply clinical significance due to the small sample size. However, it is recommended that any vision defects detected should be appropriately compensated for as defective vision can make reading more difficult for the dyslexic child.

The sample size may have been a limitation; however, this was comparable with studies reviewed, most of which had sample sizes of less than 41. Due to the range of possible ocular conditions that could affect dyslexia, it is recommended that a larger sample size be used to ensure more conclusive results. Testing for relative accommodation with a phoropter would provide more accurate results, and accommodation facility and fusional reserves would be better assessed with suppression control. The study provides information and an indication of research needs regarding the prevalence of vision defects in an African South African population of dyslexic children.

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CHAPTER ONE: INTRODUCTION

1.1 Background and Rationale for the Study

Optometry has long been involved in the subject of vision and learning. As primary eye care practitioners, optometrists receive referrals from parents, teachers, psychologists and other professionals who usually seek the optometrist's advice about whether a child's vision problem may be contributing to or is responsible for poor academic performance.

According to Scheiman and Rouse[1], learning, which is the acquisition of knowledge or skill, can be achieved through study, experience or instruction and that between 75% and 90% of what a child learns is mediated through the visual pathways. As vision plays a major role in reading and the learning process any defects in the visual pathway disrupt the child's learning.

"The three interrelated areas of visual functions are: [1]

1. Visual pathway integrity, including eye health, visual acuity and refractive status.
2. Visual efficiency, including accommodation, binocular vision and eye movements.
3. Visual information processing including identification and discrimination, spatial awareness and integration with other senses".

Several studies[2-6] have been conducted to investigate the relationship between vision and dyslexia on Caucasian populations, while very few have been done on African subjects. Consequently, most inferences and conclusions on dyslexia are based on research conducted in Caucasian populations. Naidoo[7] reported that inferences drawn from studies in Caucasian populations may not be appropriate for the African population as the 'African Eye' differs from the Caucasian eye. For example, epidemiological studies have reported variations in refractive errors where the prevalence of myopia is higher among Caucasian persons than in African persons[8, 9], while African populations had higher open angle glaucoma prevalence than Caucasian persons[10].

This study attempts to contribute to the literature by examining the prevalence of a broader spectrum of vision variables in dyslexic school children in order to investigate a possible relationship between dyslexia and vision in African school children in South Africa. A search of the literature revealed that very little research has been conducted in Africa, the only one being conducted in 1997 by Raju[11]. Raju[11] investigated oculomotor functions in dyslexic school children in South Africa and reported that 65% of the normal readers exhibited normal oculomotor control as compared to 11% of the dyslexics. Furthermore, 54% of the dyslexic population exhibited deficiencies in both automaticity and oculomotor skills, while 12% of the controls displayed the same.

1.2 Aim

The aim of the study was to determine the prevalence of vision conditions in a South African population of African dyslexic children and to study the relationship between vision and dyslexia.

1.3 Objectives

1. To determine the distribution of visual acuity disorders among African dyslexic children.
2. To determine the distribution of refractive errors among dyslexic children.
3. To determine the distribution of phorias among dyslexic children.
4. To determine the distribution of strabismus among dyslexic children.
5. To determine the distribution of accommodation disorders among dyslexic children.
6. To determine the distribution of vergence disorders among dyslexic children.
7. To determine the distribution of ocular pathology among dyslexic population.
8. To compare these findings to a similar group of non-dyslexic children.

1.4 Research Questions

1. What is the prevalence of vision conditions among African dyslexic children of age range 10 and 15 years?

2. What is the relationship between dyslexia and vision?

1.5 Significance of the Study

The study will attempt to:

1. Identify high-risk ocular conditions among dyslexic children, which might influence the need for certain examinations or that could affect the child's ability to learn to read.
2. Relate findings of this research work to that of previous researchers.
3. Add to the knowledge base in the area of vision and dyslexia.

1.6 Goals of Study

1. To obtain quantitative information on the prevalence of visual conditions in dyslexic children in the African population.
2. To obtain information on the relationship between vision disorders and dyslexia.
3. To enable improvement of eye care for children with dyslexia.

1.7 Null Hypothesis

1. There will be no statistically significant difference between the mean visual acuity of the dyslexic group and of the control group.
2. There will be no statistically significant difference between the mean refractive errors of the dyslexic group and of the control group.
3. There will be no statistically significant difference between the mean phoria in the dyslexic group and of the control group.
4. There will be no statistically significant difference between the strabismic mean angle of deviation of the dyslexic group and of the control group.
5. There will be no statistically significant difference between the mean accommodation functions (amplitude, facility, posture) in the dyslexic group and of the control group.

6. There will be no statistically significant difference between the mean fusional vergence amplitude and reserves of the dyslexic group and of the control group.

1. 8 Research (alternative) Hypothesis

1. There will be a statistically significant difference between the mean refractive errors in the dyslexic group and of the control group.
2. There will be a statistically significant relationship between the mean visual acuity of the dyslexic group and of the control group.
3. There will be a statistically significant difference between the mean of phoria of the dyslexic group and of the control group.
4. There will be a statistically significant difference between the strabismus mean angle of deviation of the dyslexic group and of the control group.
5. There will be a statistically significant difference between the mean accommodation functions of the dyslexic group and of the control group.
6. There will be a statistically significant difference between the mean fusional vergence amplitude and reserves of the dyslexic group and of the control group.

1.9 Scope of Study

1. This study is limited to the assessment of visual functions in dyslexic and normal readers. The visual functions investigated include: visual acuity, refractive error, ocular alignment, near point of convergence, accommodation functions and vergence reserves. The assessment of eye movement was not part of the study.
2. Screening for, and diagnosing dyslexia was not part of this study. The school psychologists' reports were relied on in selecting subjects who qualify to participate in this study. The information was obtained from the learners' school files.
3. The scope of vision parameters investigated is limited only to the prevalence and relationship between these variables in dyslexic and control groups as outlined in the hypothesis. Correlation analysis of different variables was not part of this study.

1.10 Assumptions

In this report, dyslexia is used synonymously with “developmental dyslexia”, “reading disability”, and "reading disorder” and will be used to describe children who find it extremely difficult to learn to read despite having normal intelligence, appropriate educational opportunities and absence of emotional disorders. Children so defined have reading age that is two or more years behind their chronological age[12].

1.11 Study Outline

This thesis is divided into six chapters. Chapter one indicates the rationale of the study, provides an overview of dyslexia, and details its purpose, objectives, significance and goals. Chapter Two (the literature review) gives a detailed review of literature in the area of dyslexia, learning disabilities and vision, with particular emphasis to vision variables as outlined in the hypothesis to be tested. This is followed by methodology in Chapter Three which details the research methodology in which a case-control study was done in two schools in Durban. The areas of vision variables evaluated include, visual acuity and refraction, binocular vision and ocular health evaluation. Chapter Four (Results) presents an analysis of the results obtained from the study. Chapter Five (Discussion) discusses the study findings and their meaning. Chapter Six presents conclusions from the study based on the study results, indicating the implications, applications and recommendations for future study and the study limitations.

1.12 An overview of dyslexia

Some children find it difficult to learn to read despite having normal intelligence, appropriate educational opportunities and absence of emotional disorders. Their reading age is two or more years behind their chronological age. Such children are referred to as being *dyslexics*. Where there is an associated deficit in intelligence, the condition may be described as generalized learning disability[12].

The term "dyslexia' is derived from the Greek words: 'dys' meaning hard or difficult and 'lexia' from the word 'lexicos' which means pertaining to words; so dyslexia means difficulty with words-either seen, heard, spoken or felt as in writing[13].

The World Federation of Neurologists[13] and the International Classification of Diseases-10[14] defined dyslexia as "a disorder manifested by difficulty in learning to read, despite conventional instruction, adequate intelligence and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently constitutional in origin".

Dyslexia is a complex disability which affects different aspects of reading. The acquisition of reading related skills are coordinated by visual, motor, cognitive and language areas of the brain. Consequently, dyslexia can result from deviation of normal anatomy and function of cognitive and language areas in the brain [15].

Dyslexia refers to a cluster of symptoms resulting in people having difficulties in specific language skills, particularly reading[15]. The mystery in dyslexia as a syndrome lies in the fact that dyslexics have "difficulty to learn to read despite having average or above average intelligence, adequate auditory and visual acuity, absence of frank brain damage, no primary emotional problems and have adequate educational instructions" [16].

Dyslexia is a developmental disorder that shows in different ways at different developmental stages. As documented by Krupska and Klein [13] dyslexia is a learning disability characterised by problems in expressive or receptive, oral or written language that manifest initially as difficulty in learning letters and letter sound association, which is followed by difficulty in learning letters and reading words accurately which consequently results in impaired reading rate and written expression skills (handwriting, spelling and compositional fluency). Some dyslexics find it difficult to express themselves clearly or to fully understand what others mean when they speak. The effects of dyslexia reach well beyond the classroom as it can affect the person's self-image. It makes them feel "dumb"[13, 17]. Dyslexia describes a different kind of mind, often gifted and productive, that learns differently. An unexpected gap exists between learning aptitude and achievement in school [18].

Many dyslexics are creative and have unusual talent in areas such as art, athletics, architecture, graphics, electronics, mechanics, drama, music, or engineering [18]. Some dyslexic learn best with a multi-sensory delivery of language content which employ all pathways of learning at the same time, seeing, hearing, touching, writing, and speaking[18]. It is primarily not a problem of defective vision, although underlying vision deficit has been known to exaggerate the dyslexics' reading problems [18].

According to Critchley[19], “the child, otherwise normal as regards to intellectual status and emotional stability, finds an isolated difficulty in mastering the significance which lies behind printed or written symbols, and of necessity finds it extremely hard to align the verbal components of speech (as emitted by the mouth and as received by the ear) with the empirical characters which are set out on paper in one form or another”. Dyslexics are unable to acquire written language skills through ordinary learning and teaching methods and often fail to progress in education[19].

A dyslexic individual displays a characteristic pattern of decoding (recognising) and encoding (spelling) difficulties with written words[20]. Interestingly, dyslexics may not have overt difficulties with spoken language, yet do have marked difficulties with written languages[21]. The difference between written and spoken language is that written language is seen while spoken language is heard. This fact may explain why vision has always been implicated on the topic of dyslexia [21].

Dyslexics experience difficulties with visual-verbal matching necessary to establish word recognition ability. Even when a clear, single visual image is present, the dyslexic may be unable to decode the printed word in some cases. This may be related to the fact that the difficulty that dyslexics have is at a much more fundamental stage in the reading process, so the role of vision function is quite different in dyslexia than in other types of reading difficulty[22] (which may be peripheral such as hyperopia leading to difficulty in reading). The two main situations in which the term dyslexia now commonly applies are; when the reader has difficulty decoding words (that is, single word identification) and the second is encoding words (spelling). The second type is a frequent presentation in optometric practice that is when the reader makes a significant number of letter reversals errors (example b-d), letter transposition in word when reading or writing (example sign for sing) or has left-right confusion [23].

1.13 The Reading Process

Language development entails four fundamental and interactive abilities: listening, speaking, reading, and writing while learning to read involves a complex system of skills relevant to visual (the appearance of a word), orthographic (visual word form), phonological, and semantic (meaning of word and phrases) processing and a variety of behaviors such as letter naming, letter perception, word recognition and comprehension, each of which uses a different part of the brain. Reading is an interpretation of graphic symbols[24-26].

For some children, the ability to break a word into its smaller parts, a task crucial in reading, is extremely difficult. Dyslexia is a localized problem, one involving the sounds, and not the meaning, of spoken language. Speaking is natural while reading is different; it must be learned. To be able to transform the printed letters on the page to words that have meaning, the letters must be connected to something that already has inherent meaning- the sounds of spoken language. In order to learn to read, children must learn how to link the printed letters on the page to the sounds of spoken language and understand that words are made up of sounds and that letters represent these sounds, or phonemes[24- 26]. In other words, learning to read requires that the child be able to break the word into the individual components of language represented by letters and to be able to tell the difference between the individual phonemes that make up a word. Learning to read requires that the central principle behind the alphabet is understood, that is, words are made of phonemes and, in print, phonemes are represented by letters. Phonemes are the shortest units of sound that can be uttered in a given language and that can be recognized as being distinct from other sounds in the language. For example, the word cat has three phonemes: ca, ah, and ta. Blended together, the sounds form the word 'cat'[24-26.] When one speaks, the sounds are blended ttogether and are said one: "cat" [24-26]. To learn to read, a child must learn that there are three separate sounds. This is difficult for children with dyslexia. The inability to break word into its parts is the main reason why children with dyslexia have trouble learning to read[24- 26].

Furthermore, dyslexic children find it difficult to bring the print to language (such as when asked to read what they just wrote). For example, a child can copy the letters "w-a-s" correctly, but when asked what was written, a child with dyslexia may reply "saw." The problem in this case may not be related to vision, but rather one of perceptual skills of what the child does with a word on a page. The brain mechanism of going from print to language is phonologically based [24-26].

Reading acquisition builds on the child's spoken language, which is already well developed before the start of formal schooling. Once a written word is decoded phonologically, its meaning will become accessible via the existing phonology-to-semantics link in the oral language system. Thus, the child's awareness of the phonological structure of sound of speech plays a major role in the development of reading ability [24-25].

1.14 Eye Movement in Reading

For a person to be able to read a letter or word, the eye has to first identify the written material. Normally the eyes scan across the line of words on the page, stopping to fixate at various points, then making short jumps from one position to the next (some saccade eye movements are involved). Typically, there are around five fixation pauses in a line. Sometimes the eye will regress and go back to a previously passed over word element. A reader views the text mainly with the 'controlling ' or 'reference' eye, whilst the other eye diverges and converges within fine elements[27]. A sophisticated mechanism[27] (a connection of the visual receptors of the retina with the visual nervous pathway to the brain) [28] ensures control of this drift and prevents diplopia from being consciously observed. These drifts and subsequent recovery can be clearly seen by a number of techniques including infrared observation of the eyes[27].

The minimum time a person can spend on fixation and move to the next is around 250 milliseconds[27]. For skilled readers, the average saccade length is 7-9 letter spaces and the duration of saccades is of the order of 25-50 milliseconds[29] while the average fixation pauses last between 200-250 milliseconds[27, 29]. Thus our eyes are still for some 90% of the time while reading, and are subject to large changes in acceleration and deceleration. Even a good reader will regress and go back 10 % to 20% of the time[27, 29].

The textual image seen by the eyes is imaged onto both maculae, and transmitted to both cerebral cortex, where it is first received in the primary visual cortex (Brodman's area 17) with some initial processing of colour and tone occur. Progressively higher levels of processing occur in adjacent areas 18 and 19 with the highest level of visual language processing taking place in the angular gyrus (area 39). The angular gyrus is central to reading since it is here that hearing, speech and vision meets, and the written word is perceived in its auditory form. The auditory form of the word is then processed for comprehension in Wernicke's area as if the word had been heard[25, 27].

1.15 Characteristic Signs/Symptoms of Children with Dyslexia

Dyslexia is heterogeneous in nature and there is no single pattern of difficulty that affects all people. Dyslexic children frequently show a combination of characteristics (Table 1.1).

Table 1.1 Characteristic Signs/Symptoms of Dyslexia[: 16, 30-31]

Reading: Vision

− Holds book too close
− Word reversals
− Skips complete words
− Re-reads lines
− Points to words
− Word substitution
− Sees double
− Poor comprehension in oral reading
− Might see text appearing to jump around on a page
− Unable to tell difference between letters that look similar in shape such as *o* and *e*
− Unable to tell difference between letters with similar shape but different orientation such as *b* and *p* and *q*
− Letters might look jumped up and out of order
− Letters of some words might appear backwards: e.g. *bird* looking like *drib*

Spelling

− Omission of beginning or ending letters
− Can spell better orally than written
− Letter reversals
− Wrong number of letters in words

Difficulty with Reading

− Difficulty learning to read
− Difficulty identifying or generating rhyming words, or counting syllables in words (Phonological awareness)
- Difficulty with manipulating sounds in words
− Difficulty distinguishing different sounds in words (Auditory discrimination)

Auditory/Verbal

− Faulty pronunciation
− Complains of ear problems
− Unnatural pitch of voice
− Difficulty acquiring vocabulary
− Difficulty following directions
− Confusion with *before/after, right/left*
− Difficulty with word retrieval
− Difficulty understanding concepts and relationships of words and sentences

1.16 Implications of Dyslexia for Learning

Dyslexia affects people in different ways, and depends on the severity of the condition as well as the effectiveness of instruction or remediation. The core difficulty is with word recognition and reading fluency, spelling and writing. Some dyslexics manage to learn early reading and spelling tasks, especially with excellent instruction, but later experience their most debilitating problems when more complex language skills are required, such as grammar, understanding textbook material, and writing essays. The dyslexic syndrome therefore affects reading and learning in the following ways[26,30,34]:

1.16.1 Reading and Comprehension

One major difficulty dyslexics have is the time it takes to read and understand a text. This makes reading an extremely difficult task and they may report that they get tired and may get headaches after reading for a short while[30]. There is also difficulty in assimilating what they have read even when they know the words. Multiple-choice questions are usually difficult for them as they find it difficult to recognise words out of context[26,30,34].

1.16.2 Handwriting

Dyslexics have problems with handwriting since for some, forming letters takes concentration that their ideas get lost and their written expression suffers[30].

1.16.3 Proof-reading

Dyslexics with visual processing difficulties usually have difficulty in identifying errors in their own writings. Reading difficulties make it uneasy for them to see their own errors in expression and sentence structure grammar[26, 30].

1.17 Prevalence of Dyslexia

Estimates of the prevalence of dyslexia in Caucasian populations vary from 5% to 20% in the general population[16]. Pavlidis [31] reported that about 1% to 3% of the total population of children suffers from dyslexia and that 20% to 30% of those cases classified as "general reading failures" are probably dyslexics. Evans[32] reported a prevalence of 4 - 5% in children and stated probably more boys than girls are dyslexic. Park[33] documented that up to 15% of the school-age population has some degree of dyslexia with a ratio of four boys to one girl. The large variability in the prevalence reported by different authorities may be attributed to the differences in the diagnostic criteria and the cut-off point applied to the psychometric tests[14]. Dyslexia is the most common and the most researched type of learning disability[34].

A literature search revealed one study in Egypt that reported the prevalence of specific reading difficulty in 2nd and 3rd grades in elementary school population to be 1% and the male to female ratio to be 2.7 to 1. The authors concluded that the prevalence was low compared to that reported in western countries and that the difference may be due to the way the Arab language is written and read [35].

Contrary to the above reports that males tend to be more dyslexic than females, Guerin, Griffin, Gottfried and Christenson [36] studied dyslexia subtypes and severity levels with respect to gender differences. The authors[36] concluded that

> when objective criteria such as the discrepancy between achievement (in reading and/or spelling) and intelligence or direct assessment of coding skills are used as criterion and non-referred or random samples are assessed, the ratio of males to females identified as dyslexics approaches 1:1. When identification depends on referrals from parents and /or teachers, more males than females may be detected because of the nature and intensity of boys' behavioural reactions to the disability.

According to Shaywitz and Shaywitz[34], good evidence based on sample surveys of randomly selected population of children now indicates that dyslexia affects boys and girls comparably.

1.18 Aetiology of dyslexia

The literature contains diverse theories (not less than four major theories) on the aetiology of dyslexia probably due to the complex nature of the subject but several authors[13-15, 26 37-42] have maintained that it is a neurological disorder with a genetic origin. Despite decades of multidisciplinary research; neuropsychology, brain anatomy and neuro-imaging [37-42], the specific causes of dyslexia are still unknown. The leading assumption, however is that dyslexia fundamentally stems from subtle disturbances in the brain and other possible explanations of the cause of dyslexia such as language processing difficulties are based on the neurological etiology.

The aetiological considerations in dyslexia are:

1.18.1 Neurological Factors

As documented by Habib [37] the concept of the neurological basis of dyslexia was first mentioned independently by a Scottish ophthalmologist Hinshelwood in 1895 and a British physician, Morgan in 1896. Both found similarities of certain symptoms of dyslexia in some children. Dyslexia was then described as “visual word blindness”. The earlier understandings for the neurological basis of dyslexia came from neuro-pathological studies of brains from dyslexic persons. According to Habib[37], it was first reported by the French neurologist, Dejerine, in 1891, that damage to the left inferior parieto-occipital region (in adults) resulted in variable degree of impairments in reading and writing, suggesting that the left angular gyrus may play a role in processing the “optic images of letter”. It was subsequently thought that impaired reading and writing in the young dyslexic patients could be due to abnormal development of the same parietal region which was damaged in adult alexic patients [37].

Another perspective [13, 37] is that the dense distributions of ectopias (the presence of neural elements in places where they are not supposed to be found) all over the cerebral cortex (particularly in the perisylvian language areas) resulted in alteration of brain organisation. One such alteration in dyslexia is the lack of asymmetry in a language-related cortical region called the *planum temporale*, (an auditory area that lies on the superior surface of the temporal lobe). In normal subjects, the platinum temporale is usually larger in the left hemisphere. However, the dyslexics showed symmetry of the planum temporale [13, 37]. Furthermore, these ectopias may reduce cortical connectivity as suggested by recent positron emission tomography and magnetic resonance imaging studies [37].

Another speculation was that the development of ectopias could be due to foetal hormonal (possibly testosterone) imbalances during late pregnancy, which could also account for the possible male predominance in dyslexia [15, 30, 37, 38].

The maturation lag, which is believed to be due to the slower development of the nerve fibres of the corpus collosum (bundle of cells connecting the left and right hemisphere of the brain), has also been theorized to be a cause of dyslexia. A delay in the growth of the fibres linking the two hemispheres would result in affected children being physiologically incapable of tasks which require hemispheric organisation. This leads to the inadequate development of the language functions [12, 37]. However, recent neuro-imaging studies [39-42] have shown that impaired reading of alphabetic scripts (such as in the English language) is associated with dysfunction of the left hemisphere posterior reading systems, primarily in the left temporo-parietal brain regions.

1.18.2 Genetic Factors

Genetic considerations in dyslexia are derived from the fact that dyslexia runs most often in families. However, it is speculated that different forms of dyslexia may occur within the same family which also may means that it seems likely that the inheritance is indirect [15, 31]. However, genetic markers have been identified in chromosome 18 [38] and chromosomes 6 and 15 [15]. In fact, chromosomes 2 (DYX3), 6 (DYX2) and 15 (DYX1) in dyslexics have been reported to be inherited in an autosomal dominant mode of transmission [15]. Furthermore, Ramus [43] stated that "genetically driven focal cortical abnormalities such as ectopias and microgyri, in specific areas of left perisylvian cortex involved in phonological representations and processing, are the primary cause of dyslexia which is consistent with anatomical studies of dyslexic brains showing loci of cortical abnormalities, functional brain imaging studies showing that the very same areas are involved in phonological processing and show abnormal activation in dyslexics…"

1.18.3 Peri-natal Factors

Peri-natal factors may manifest as problems during pregnancy or complications after delivery. More importantly, it can also happen that the mother's immune system reacts to the foetus and attacks it, as if it was an infection. It has also been theorized (based on partial evidence) that dyslexia may occur more often in families who suffered from various autoimmune diseases (such as rheumatoid arthritis, Graves' diseases, multiple sclerosis, systemic lupus, Sjogren's syndrome)[31,37].

1.18.4 Substance Use during Pregnancy

Drugs such as cocaine (especially in its smokable form known as crack) seem to affect the normal development of brain receptors of the foetus. It has been documented that mothers who abuse substance during pregnancy are prone to having smaller babies and such infants are predisposed to a variety of problems including learning disorders. Thirdly, alcohol use during pregnancy may influence the child's development and lead to problems with learning, attention, memory or problem-solving. There is also a risk of foetal alcohol syndrome (characterised by low birth weight, intellectual impairment, hyperactivity, and certain physical defects) [30].

1.18.5 Environmental Factors

Environmental factors are risk factors for the development of reading disabilities [44]. Reading disabilities which are due to environmental influences have been referred to as non-specific reading disabilities [20] or pseudo- dyslexia as the reading disorder is secondary to extraneous factors and genetic factors play an important role [45]. "Environment factors play a significant role in the level to which neurological impairments manifest themselves. Encouraging, nurturing, and stimulating surroundings can reduce the impact of risk factors on learning, performance and life skills" [44]. Environmental circumstances which may profoundly influence the dyslexic child include parental attitude, the role of multilingualism in the home, attention problems, the drawback of frequent changes of school, the personality of the teacher and the child's emotional reaction to his difficulties [15,20,30].

It seems that the influence of environmental factors may best be described as a potential risk factor than a causative factor in dyslexia as there are diverse views on the relationship between environmental influences and dyslexia. According to Grigerenko[46] socioeconomic level, educational opportunity and home literacy level are major environmental risks for the manifestations of developmental dyslexia … the "magnitude of the effects was not strong enough to view them as powerful causal factors".

1.18.6 Nutrition

Nutrition plays an important role in bridging the gap between genetic constitution and a child's potential for optimal development. Nutrition is a basic requirement for the maintenance of growth and overall development while malnutrition and under-nutrition are associated with disorders in the normal development of intelligence, perceptual maturation, and academic achievements [47]. Studies conducted by Grant, Howard, Davies and Chasty [48] showed that there is an association between dyslexia and low concentration of zinc. Zinc is necessary for normal brain development and function, and essential for neurotransmission[44].

1.19 Diagnosis of Dyslexia

The first stage in the diagnosis of dyslexia is with awareness by parents or educators that a problem in reading exists. The initial point of assessment starts with the medical practitioner (possibly a paediatrician) who conducts a complete medical examination and obtains a comprehensive health history. A correct diagnosis of dyslexia starts with a very well taken case history especially good awareness of the child's developmental history. This may give indications of any medical condition that may be contributing to reading difficulties. If indicated, the child may be referred for a neurological examination. If dyslexia is suspected, the physician may then refer the child for further evaluation and treatment by a specialist in psycho-educational assessments. In most cases, the diagnosis of dyslexia is usually performed by the psychologist. The Psychologists conduct psychometric assessments, which include assessment of intelligence quotient (IQ), various aspects of reading performance, spelling, mathematics, sequential memory and other aspects of cognitive and emotional development[49, 50]. The major purpose of the diagnostic process is to isolate the specific difficulties associated with dyslexia and to suggest appropriate educational intervention [49, 50].

There are three methods for diagnosing dyslexia:

1.19.1 Exclusionary Method.

In the exclusionary method, the diagnosis of dyslexia is made when all factors involved in a nonspecific reading disability (reading problems resulting from factors such as intellectual disability, dysfunction of hearing or vision, inadequate learning experience, socio-cultural deprivation, primary emotional problems, poor motivation) are excluded [20,51]. The problem with the exclusionary method of diagnosing dyslexia is that dyslexia cannot be diagnosed until after the child has been failing in school for almost two years. By this time, constant failure may have produced a negative attitude towards school and psychological problems [31]. It provides a very limited description of the features of the disorder. Dyslexia is often defined in terms of the discrepancy between reading achievement and chronological age, or grade level failing to consider the possible overlap between some of the intelligence quotient tests and reading tests [52]. According to Snowling [53], IQ is not strongly related to reading and so the use of IQ in defining dyslexia is inappropriate, stating that many children with low IQ can read perfectly well and that the discrepancy definition (based on the difference between reading achievement and chronological age) of dyslexia cannot be used to identify younger children who are too young to show a discrepancy.

1.19.2 Indirect Method

The second method of diagnosing dyslexia is the indirect approach. A diagnosis is sought by attempting to associate neurological soft signs such as finger "agnosia" with reading failure. The drawback with this method is that many dyslexics do not manifest neurological soft signs [20]. Another type of the indirect method involves the analysis of cognitive tests. An example is the Wechsler Intelligence Scale for Children (Revised) (WISC-R) WISC-R which compares "verbal" versus "performance" [20].

1.19.3 Direct Method.

The third method which seems most reliable is the direct method which involves the use of characteristic decoding and spelling patterns to determine the specific dyslexia. It has the additional advantage of addressing the fact that dyslexia is heterogeneous [20].

1.20 Functional Imaging Techniques used in the Diagnosis and Study of Dyslexia.

There are functional imaging techniques for diagnosing and studying brain activity in dyslexia. These techniques include positron emission tomography (PET), Magnetic resonance imaging (MRI) and computed tomography (CT). The two major techniques include:

1.20.1 Positron Emission Tomography (PET)

PET is a non-invasive imaging technique that uses radioactively labeled compounds to quantitatively measure metabolic, biochemical, and functional activity in living tissue. It assesses changes in the function, circulation, and metabolism of body organs [54, 55]. The PET is a sophisticated nuclear medicine technique that looks directly at cerebral (brain) blood flow and indirectly at brain activity (or metabolism). The most commonly used labels are flourophores, which emit light when stimulated with light of the appropriate wavelength, and radio nuclides, which emit gamma rays or beta particles when they decay[56]. The dose of radionuclide injected is minute and does not pose any significant hazard. Various isotopes are used depending upon the brain region and function studied[54].

Unlike MRI or CT imaging which primarily provide images of organ anatomy, PET measures chemical changes that occur before visible signs of disease are present on CT and MRI images [54]. While PET is most commonly used in the fields of neurology, oncology, and cardiology, applications in other fields are currently being studied [57].

1.20.2 Functional Magnetic Resonance Imaging (fMRI)

Functional magnetic resonance imaging (fMRI) is a noninvasive, usually painless procedure that uses a powerful magnetic field, radio waves and a computer to produce detailed pictures of organs, soft tissues, bone and virtually all other internal body structures. The images can then be examined on a computer monitor or printed. The fMRI does not use ionizing radiation[57, 58].

Functional magnetic resonance imaging (fMRI) is a relatively new procedure that uses MR imaging to provide a picture of the brain's active rather than its static structure. The fMRI machines measure the level of oxygen in the blood through a technique called blood level-dependent (BOLD) contrast. The two different states of hemoglobin-oxygen-rich oxyhemoglobin and oxygen-poor deoxyhemoglobin differ in their magnetic properties. The huge fMRI magnets are sensitive to changes in the concentration of deoxyhemoglobin. As neural activity increases, blood flow to the vasculature of the brain presumably increases, altering this concentration. The more active a brain area is the more blood flows to it. Thus, fMRI can provide a moment-by-moment movie of brain activity.

Studies using fMRI are beginning to shed light on dyslexia. Functional magnetic resonance imaging (fMRI) is similar to MRI as both procedures use a similar scanner. The difference is that the fMRI uses somewhat more sophisticated hardware and software that allow it to capture brain changes (mainly blood flow) as a person performs a specific cognitive task. The functional magnetic resonance imaging (fMRI) scanner measures where blood flows through the brain during certain tasks[26].

Earlier studies of dyslexia were based on histo-pathological studies. According to Habib[37], the fMRI has an added advantage that cortical anatomy of the dyslexic brain can be demonstrated thus answering the criticism addressed to results from pathological findings.

1.20 Classifications of Dyslexia

Dyslexia can be classified into two broad categories according to its presumed aetiology. The following methods of classification have been documented by Helveston[59].

1. Primary dyslexia (specific developmental dyslexia)
2. Secondary dyslexia.

1.21.1 Primary Dyslexia

This is considered to be caused by a specific central nervous system defect. This neural defect is thought to be located in the angular gyrus of the dominant hemisphere. It is often hereditary and may affect more boys than girls. In primary dyslexia, the decoding process involved in language system is affected and reading becomes extremely difficult for the child. However, intellectual tasks that do not involve reading text are unaffected [59].

1.21.2 Secondary Dyslexia

There are two types of secondary dyslexia[59], Endogenous and Exogenous.

a. **Endogenous Dyslexia**: this results from pathological changes in the central nervous system secondary to trauma or disease such as childhood meningitis, hydrocephalus with brain damage and porencephalus[59]. Other medical causes include prematurity, congenital hydrocephalus, encephalitis, traumatic brain injury and lead or methylmercury poisoning[50].

b. **Exogenous Dyslexia**: this results from intellectual deprivation usually limited to lack of adequate educational opportunity or motivation[59] or due to low intelligence, socio-cultural deprivation, primary emotional problems, sensory impairment (visual or auditory), poor motivation or attention problems[20]. Reading disability due to these mentioned factors have been referred to as non-specific reading disability[20].

1. 22 Sub-types of Dyslexia

When children first start to read they learn to recognise simple words by their shapes (sight analysis), building their sight vocabulary. This is followed by learning how to analyse complicated words by breaking them down into their sound components (phonetic analysis). The dynamics of the two processes (Sight-analysis and Phonetic analysis) are important in explaining how words are decoded based on the neurologic-behavioural model documented by Christenson *et al* [20] and Evans [21]. Dyslexia can be divided into the following subtypes: [20, 21]

1.22.1 Dysphonetic (auditory/phonetic)

The individual has a minimal dysfunction involving the Wernicke's area. Readers have an extremely difficult time developing phonic word analysis, or decoding skills. Their typical reading errors are wild guesses (‘like’ for ‘little’), errors picking words with similar shapes ('horse' for 'house'), and semantic substitutions ('home' for 'house'). Their typical spelling errors are phonetically inaccurate ('ref'for 'rough'). This type of reader persists in using whole-word approach and will guess at unfamiliar words rather than using their word analysis skills. While they do not often continue to reverse letters and words after the age of eight, they often make spelling reversals. (For example: 'interver' for 'inventor' and 'wirters' for 'writers'). Typically, they often look at the first and last letter and the length of the word and then guess ('monkey' for 'money' or 'stop' for 'step")[20, 21].

1.22.2 Dyseidetic (visual-spatial)

In dyseidetic type of dyslexia, dysfunction occurs in the angular gyrus. The individual have high ability in phonic word analysis. They often have a difficult time learning the letters of the alphabet. They usually have a very low sight vocabulary, poor visual memory, poor perceptual skills and letter and word reversals. ('dig' for 'big' or 'saw" for 'was'). Their reversals often last past the age of eight and include both reading and writing reversals. This type of child is often a very slow reader who often will try to sound out familiar as well as unfamiliar words. They spell the word as it sounds. By first identifying the learning style of these children probably during the case history, the optometrist may know the child's strengths and weaknesses. Vision therapy can then be designed to fit each child's needs. Enhancing the child’s visual, perceptual and eye tracking skills, plus having the schools teach these children according to their strengths, enable them to achieve their full potential in school [20, 21].

1.22. 3 Dysnemkinesia (motor)

Dysnemkinesia is a less serious form of dyslexia and it involves minimal dysfunction of the area of the motor cortex involved in letter formation. Dysnemkinesics can be distinguished by their frequent letter reversals such as d for b, as in "doy" for boy. Additional dyslexic types occur when combinations of the three basic types arise such as dysphoneidesia, dysnemkineidesia, dysnemkinphonsia and dysnemkinphoneidesia[20, 21].

1.22.4 Dysphonetic-Dyseidetic

Dysphonetic- dyseidetic reader has a weakness in both whole-word and phonic analysis. Their reading errors include wild guesses ("fish" for "father") and word reversals ("no" for "on"). Their spelling is usually phonetically inaccurate and often bizarre. ("rit" for "faster") [20,21].

1.23 Theories of Dyslexia

Assisted by the increasing body of knowledge obtained by neurophysiological and imaging studies[14,] several theories have been proposed with the aim of characterizing the fundamental processes underlying dyslexia[14]. These theories can be classified under four major frameworks: phonological, visual, cerebellar and auditory.

1.23.1 Phonological–Deficit Theory

According to the phonological theory, affected individuals have difficulties in perceiving and segmenting phenomes leading to difficulties in establishing a connection between phonemes and graphemes [14]. The brain recognizes language in a hierarchical order. The upper levels deal with semantics (the meaning of words), syntax (grammatical structure) and discourse (connected sentences). The lower levels of hierarchy deal with breaking sounds into separate small units called phonemes (sound units). Thus before words can be comprehended at higher levels in the hierarchy, it has to be broken down into phonologic constituents that the alphabetic characters represents[15, 26]. An adequate reading development stems from some considerable level of spoken language already acquired by a child in the early years of life. Consequently, failure to develop the association between letters (grapheme) and sound (phoneme) has been considered to be a major cause of reading and spelling impairment in most cases of developmental dyslexia[60-62].

Reading requires some skills of phonological processing to convert a written image into the sounds of spoken language[1]. According to the phonologic-deficit hypothesis, people with dyslexia have difficulty developing an awareness that words, both written and spoken, can be broken down into smaller units of sound and that; in fact, the letters constituting the printed word represent the sounds heard in the spoken word[2].

According to Habib[37], neuropsychological studies have provided considerable evidence indicating that the main mechanism leading to reading difficulties is phonological in nature and that it has been repeatedly demonstrated that the core deficit responsible for impaired learning to read is phonological in nature and has to do with oral language rather than visual perception. At the brain level, this cognitive deficit would arise from a congenital dysfunction of certain cortical areas involved in phonology and reading[60]. At the neurological level, it is usually assumed that the origin of the disorder is a congenital dysfunction of the left-hemisphere perisylvian brain areas underlying phonological representations, or connecting between phonological and orthographic representations[60].

Brain imaging studies in dyslexics in response to a phonological task indicate under-activation of posterior brain regions (Wernickes's area, angular gyrus, and striate cortex) and relative over-activation in anterior regions (inferior frontal gyrus). These brain activation patterns provide evidence of an imperfectly functioning brain system for segmenting words into their phonologic constituents[39, 42]. Since most dyslexics show deficits in phoneme processing, the phonological deficit is the most significant, consistent marker of dyslexia and remains the predominant theory [15,34,37,39] hence the focus on phonology in the majority of remedial programmes [63].

Based on the phonological deficit theory, the other symptoms of dyslexia are considered as simple co-morbid markers that do not have a causal relationship with reading disability[62]. However, proponents of the phonological theory typically contend that these disorders are not part of the core features of dyslexia[62]. A major setback with the phonological theory is that it does not account for symptoms such as impairment in visual perception and problems with motor coordination that are found in dyslexics [15] and does not account for symptoms of dyslexia that are unrelated to phonetic decoding difficulties such as problems with short term memory and visual processing issues[64].

The two basic processes involved in reading are decoding and comprehension. In dyslexia, a deficit at the level of the phonologic units impairs the ability to segment the written word into its underlying phonologic elements. Consequently, the reader experiences difficulty initially in decoding the word and then in identifying it. The phonologic deficit is independent of other non-phonologic abilities especially the higher-order cognitive and linguistic functions involved in comprehension, such as general intelligence and reasoning, vocabulary, and syntax, are generally intact. A deficit in phonologic analysis and an ironical intact higher-order cognitive ability offers an explanation for the paradox of otherwise intelligent people who experience great difficulty in reading [26].

According to the phonological model, a deficit in a lower-order linguistic (phonologic) function prevents access to higher-order processes and to the ability to draw meaning from text. The problem is that the person cannot use his or her higher- order linguistic skills to access the meaning until the printed word has first been decoded and identified. Suppose, for example, that a man knows the precise meaning of the spoken word "apparition"; however, until he can decode and identify the printed word on the page, he will not be able to use his knowledge of the meaning of the word and it will appear that he does not know the word's meaning [26].

1.23.2 Cerebellar Theory

The normal pattern of cerebellar asymmetry is anomalous in dyslexia [13]. The cerebellar deficit theory suggests that the automatisation of cognitive processes and motor control in the cerebellum are disturbed in individuals with dyslexia[14, 15, 62]. Evidence for this theory comes from poor dyslexic performance in coordination, balance and time estimation. The cerebellar theory is related to cerebral dominance (greater proficiency of each cerebral hemisphere in acquisition and performance of certain specific functions) and lateralization (one-sided location of brain function)[13].

Physiologically, the brain operates cross-laterally; thus the left part of the brain controls the right side of the body and vice versa. The human brain is normally asymmetrical due to the specialized functions in the left and right brain. However, the dyslexic brain appears to be more symmetrical than the normal brain. The consequence of this is that both sides of the brain may be competing to handle language and therefore less efficient in handling processing language. The left hemisphere is especially important for the production of language. The right hemisphere also has some language capabilities, but has no ability to analyse speech sound. Secondly, 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. Furthermore, the cerebellum plays a role in the automatization of tasks, such as driving, typing and reading. A weak capacity to automatize would affect, among other things, the learning of grapheme-phoneme correspondences [13-15, 62].

1.23.3 Visual Deficit Theory

For many years, a major view was that reading difficulties are caused by dysfunction in the magnocellular subsystem [65-67]. The visual theory does not exclude the phonological deficit but emphasizes a visual contribution to reading problems in some dyslexics. The biological basis of the proposed visual theory is derived from the division of the visual system into two sub-systems which carry information to the visual cortex: the transient and the sustained systems[62].

Anatomically, the magnocellular pathway receives input from both rods and cones across the retina, and extends from ganglion cells in the retina to the two ventral layers of the lateral geniculate nucleus (LGN). The large cell bodies in these two layers give the pathway its name. It projects via the visual cortex and the dorsal or “where” stream to the parietal cortex. The parvocellular (or sustained) system on the other receives input from cones and therefore mainly the central retina, and runs from retinal ganglion cells to the smaller cell bodies of the four dorsal layers of the LGN. It projects via the visual cortex and the ventral or “what” stream to the infero-temporal cortex, and mediates colour vision and detection of fine spatial details[61]. The magnocellular system is the first to respond to a stimulus and relies on further detail from the parvocellular system (Table 1.2).

Table 1.2 Features of the Magnocellular and Pavocellular Systems[21,68]

Magnocellular(transient) System	Pavocellular (sustained) System
Large cells	Small cells
Dim light	Bright light
High contrast sensitivity	Low contrast sensitivity
Low spatial frequency	High spatial frequency
Peripheral	Central
Right brain	Left brain
Midbrain	Cortical
Non-cognitive	Cognitive
Emotional	Logical
Hyperopia	Myopia
Gross depth perception	Stereopsis
Achromotopsia	Colour vision
Fast transmission	Low transmission
Sensitive to large stimuli	Sensitive to small stimuli

The transient system is vital to the timing of visual stimuli and plays an important part in detecting the movement of objects (motion perception) and ultimately their signals are used to control eye and limb movements made in relation to visual targets[15,21]. Impaired function of magnocellular pathway will lead to destabilization of binocular fixation, which results in visual confusion and letters then appear to move around.

Dyslexics' eyes are unsteady when they are attempting to view small letters; hence their vision is unstable, they tend to make visual reading errors[15]. There is a tendency to superimpose letters on top of each other, and mis-sequence letters in a word[16,21]. Evidence for magnocellular dysfunction comes from anatomical studies of dyslexic individuals showing abnormalities of the lateral geniculate nucleus[15,62], psychophysical and neuroimaging studies [62, 64] showing decreased sensitivities in the magnocellular range (low spatial frequencies and high temporal frequencies) in dyslexics.

A deficit in the magnocellular system slows down the visual processing system, resulting in an unstable binocular control, inaccurate judgements of visual direction, a tendency to superimpose letters and mis-sequence of letters in a word[16, 21]. Some studies[65-67] have shown evidence in support of the magnocellular deficit theory of dyslexia.

1.23.4 Auditory Processing Theory

The auditory processing theory specifies that the deficit lies in the perception of short sounds and fast transitions (called the "rapid" or "temporal" auditory processing deficit). Such a characterization of the auditory dysfunction is consistent with the magnocellular theory, since magnocellular cells are particularly sensitive to high temporal frequencies[60, 62].

Proponents of the auditory processing theory hypothesized that impaired perception of brief sounds and transitions would be particularly detrimental to speech perception, hence would undermine the development of the child's phonological representations. Contrary to this hypothesis, Rasmus[60] reported that recent studies have now adequately confirmed that there is no reliable relationship between performance on rapid auditory processing tasks and speech categorization and discrimination, neither is there a reliable relationship between any auditory measure (speech or non-speech) and more general measures of phonological skill or reading ability, even when assessed longitudinally. A possibility is that the most auditorily impaired dyslexics also have severely impaired phonology and reading, although the reverse is not necessarily true [60].

Despite the fact that evidence exist in support of the theories, and that some of the deficits found in affected individuals are correlated with reading and spelling, they may not be causally associated with dyslexia. However, results from genetic research may have the potential to help delineate which cognitive and neurophysiological processes are causally related[14].

1.24 Cultural Differences in Dyslexia

The recognition of dyslexia as a neuro-developmental abnormality has been influenced by the belief that it is not a specific diagnostic entity because it has variable and culture-specific manifestations [69-71]. Recent neuro-imaging studies[39-42] have demonstrated that impaired reading of alphabetic scripts is associated with dysfunction of left temporo-parietal brain regions. However, it has been reported by Siok *et al* in two separate studies[69, 70] that in contrast to the assumption that dyslexia in different languages has a universal biological origin their study using functional magnetic resonance imaging with reading-impaired Chinese children and associated controls, showed that functional disruption of the *left middle frontal gyrus* is associated with impaired reading of the Chinese language (a logographic rather than alphabetic writing system).

The neural connections involved in reading and reading disorders may vary in different languages because of differences in how a writing system links print to spoken language[69, 70]. In Chinese for example, graphic forms (characters) are mapped to syllables, which differ markedly from an alphabetic system (such as English) in which graphic units (letters) are mapped to phonemes. These differences can lead to differences in how reading is supported in the brain[69, 70]. Readers of Chinese show relatively more engagement of visuo-spatial areas and left middle frontal regions for verbal working memory, presumably for recognizing complex, square-shaped characters whose pronunciations must be memorized instead of being learned by using letter-to-sound conversion rules[69, 70].

In two separate studies Siok, Perfetti and Tan[69] and Siok, Zhen, Charles, Perfetti and Tan [70] studied language-related activation of cortical region of Chinese dyslexic school children using the functional magnetic resonance imaging and found a reduced activation in the same left middle frontal gyrus region in Chinese dyslexics. Chinese dyslexics, by contrast, did not show functional or structural differences from normal subjects in the more posterior brain systems that have been shown to be abnormal in alphabetic-language dyslexics[69-70]. The authors concluded that the results of the studies suggested that the structural and functional basis for dyslexia varies between alphabetic and non-alphabetic languages and that the findings provided an insight into the fundamental patho-physiology of dyslexia by suggesting that rather than having a universal origin, the biological abnormality of impaired reading is dependent on culture.

The study by Paulesu, Demonet, Fazio and McCrory[71] gave another perspective. Using the positron emission tomography to study brain activity of dyslexics from three countries (Italian, French and English), the authors found the same reduced activity in a region of the left hemisphere in dyslexics from all three countries, with the maximum peak in the middle temporal gyrus and additional peaks in the inferior and superior temporal gyri and middle occipital gyrus. Their study showed that there was a universal neuro-cognitive basis for dyslexia and that differences in reading performance among dyslexics of different countries are due to different orthographies. Languages with transparent or shallow orthography (such as Italian), the letters of the alphabet, alone or in combination are in most instances uniquely mapped to each of the speech sounds occurring in the language. Learning to read in such languages is easier than in languages with deep orthography (such as English and French), where the mapping between letters, speech sounds, and whole-word sounds is often highly ambiguous [71].

1.25 Treatment/Intervention

Individualized instruction of dyslexics emphasizing increased phonologic awareness can have a favorable long-term effect on academic achievement. Individualized instruction aimed at increasing phonologic awareness, decoding skills, sight word vocabulary, and reading comprehension are particularly helpful to school aged children experiencing difficulties with reading. Most importantly intervention (provided by expert teachers) should be initiated early[50]. Reading disabilities require lifelong assistance, and optimal management strategies differ depending on the patient's age and circumstances. In early childhood, the focus is on remediation of reading, often with an emphasis on increasing phonologic awareness. Other strategies include using audio books and modified homework assignments. For secondary and college students, intervention focuses on accommodations which include extra time for reading, tape recorders in the classroom, audio books, instruction in word processing and the use of a spell-checker (poor phonemic association also causes problems in spelling)[34,50].

1.26 Role of Optometry in the Multidisciplinary Management of Dyslexia.

The role of the optometrist in the multidisciplinary management of dyslexia starts with an attempt to identify characteristics which may indicate that the child may be dyslexic. A complete visual examination should be conducted. Any vision anomalies detected should be corrected and a prompt referral should be made to the appropriate specialist in the diagnosis of dyslexia and a follow up should be made by the optometrist.

A comprehensive visual evaluation should include:[1, 72]

1. Evaluation for a sensory problem or refractive anomaly.
2. Evaluation for binocular vision problems.
3. Evaluation for ocular pathology.
4. An evaluation of visual motor skills (required for drawing and handwriting), eye movement control skills and visual imagery skills.
5. Evaluation of visual information processing including visual spatial skills (right/left discrimination) visual analysis skills (matching and discrimination skills).

The role of the optometrist in the management of reading dysfunctions is to identify existing vision disorders which can be achieved by evaluating the following aspect of vision functions:

1.26.1 Case History

A detailed case history is paramount for children who present with reading dysfunction. A thorough investigation of the pre-natal, peri-natal, and post-natal risk factors is important to establish the possibility of major developmental delay. For example maternal history of alcoholism may indicate foetal alcohol syndrome. Prematurity (early birth date of less than 37 weeks or low birth weight of less than 2500g) is also a factor in later learning. A working knowledge that may not necessarily mean expertise in all related areas may be adequate for the optometrist[72].

1.26.2 Refractive and Binocular Functions

A thorough investigation and compensation for refractive and binocular vision functions should be undertaken[44,72].

1.26.3 Visual-Motor Skills

Visual–Motor integration is the ability to coordinate visual information-processing skills with motor skills[44]. It is a very vital skill in academic achievement[44,72]. Children suffering from visual-motor dysfunction have difficulty copying written work accurately and efficiently. Difficulty with copying can reduce the speed and accuracy of writing which subsequently affects learning[44,72]. The Beery Test for Visual-motor Integration is particularly useful for the primary care optometrist. It requires only a few minutes to administer, with an added advantage that the scoring guide provides many examples of the pass-fail criterion for each item tested[72].

1.26.4 Visual-Spatial Analysis

"The visual-spatial skills allow the child to make judgments about location of objects in visual space in reference to other objects and to the individuals own body. It develops from awareness within the individual's body of concepts such as left and right, up and down, and front and back**.** It is important for good motor coordination, balance, and directional senses" [72]. The Rosner's Visual Analysis Skills programme is useful for the assessment of both visual-motor skill and spatial analysis[72].

1.26.5 Short- Term Visual Memory (Visual-Motor recall)

The visual memory test assesses the ability to recognize and recall visually presented material [44,73]. The ability to copy written material accurately is more or less a matching process when the written materials are close (such as copying from workbook to paper). When the reading material is separated from the actual visual-motor task such as copying from chalkboard to paper, the process becomes more complex. An example of short-term visual memory skill assessment test is the Getman-Henderson-Marcus Test of Visual recall[72].

1.26.6 Auditory Analysis Skills

Screening for auditory-perceptual skill at the primary care level is essential as the ability to analyze spoken language into separate sounds and sound sequence is directly related to reading and spelling success. Examples of tests to measure auditory perceptual skills are the Test of

Auditory Analysis Skills (TAAS) (which is easy to administer and score) and a more complex one: Test for Auditory-Perceptual Skills[72].

1.27 Optometric Treatment Options

The optometric treatment options for the correction of vision defects include the following options:

1.27.1 Correction of Vision Defects

1. Compensation for refractive error.
2. Treatment of visual efficiency deficits with lenses, prisms and vision therapy.
3. Treament of vision information processing deficits with vision therapy commencing with visual spatial orientation, then visual analysis, and concluding with visual-motor integration.
4. Referral to another health care professional, educational system and or psychologist should be considered at any time if underlying physical or neurological problems, cognitive deficits or emotional disorders are suspected[1, 50, 72].

The expected outcome of an optometric intervention is an improvement in visual function with the reduction of vision anomalies associated with reading which makes educational intervention easy[1]. Solan[47] proposed that the role of optometrists should not end with correcting vision anomalies in dyslexic patients but that optometrists should participate in community services to assist with the developmental environment of those whose genetic make-up may predispose them to having reading difficulties.

1.27.2 The Use of Tinted Lenses and Coloured Overlays

The patients rely on professionals to attend to their vision care needs. Consequently, it is imperative that we practice at the highest level of professionalism and ensure that anything we prescribe for our patients are supported with credible research.

As reported by Evans[74, 75] Olive Meares in 1980 suggested that some children's perception of text and certain cases of reading difficulties were influenced by print characteristics which subsequently resulted in visual perceptual anomalies such as words blurring, doubling and jumping. Subsequently, Meares and Irlen proposed that "Scotopic sensitivity syndrome' or (Meares -Irlen syndrome) – a syndrome of visual symptoms and distortion can be alleviated with coloured filters. Meares and Irlen claimed that the coloured overlays improve reading ability and visual perception, increase sustained reading time and eliminate symptoms associated with reading, such as light sensitivity, eyestrain, headaches, blurring of print, loss of place, and watery eyes[75]. This type of symptoms is reported both by people who experience frequent severe headaches of the migraine type as well as some people with dyslexia[76].

Following this initiative, Irlen developed a proprietary system in countries like the United States of America, United Kingdom and Australia to detect and treat Meares-Irlen syndrome. Meares-Irlen syndrome is reported to be treated with coloured filters, either coloured sheets (overlays) placed on the page or colored lenses. Computer users may attain a similar effect by changing the colour of the screen background and /or text while people that consistently work under the same lighting conditions can benefit from the colour therapy by simply varying the colour of the illuminating light[75].

The earlier studies of Irlen was criticized for its lack of published double masked studies with a placebo control to support her claims that the colour that helped had to be specific for each person[76].

According to Lightstone[76], the Intuitive Colorimeter (developed by Professor Wilkins) of the Medical Research Council in the United Kingdom was the first to be used to conduct a masked trial. With this instrument, it was possible to determine the optimum colour for the spectacle lens without placing lenses in front of the eyes and could be done in a way that the subject is unaware of the exact colour they had selected. At the end of the study, it was felt that the use of colour was credible and was then included as part of a routine assessment of people with specific learning difficulties at the Institute of Optometry, London[76].

As described by Lightstone[76], the Intuitive colorimeter is basically a large box which the patient or subject looks into. The space that the subject looks at is entirely diffused by a coloured light and so creates the effect of wearing coloured lenses. There are no other colours in the field of view and so no reference colours are available to help the subject decide the exact hue (colour) of the light that they are viewing. This encourages rapid colour adaptation. The person operating the colorimeter changes all aspects of the colour that the subject is viewing and the hue, saturation (depth of colour) and the brightness of the colour can be varied independently of each other. Although the procedure is subjective, the technique shows whether there is a specific colour that gives relief from the symptoms. If the effect is placebo, the results tend to be variable and no specific colour can be selected as the optimum colour[75, 76].

An advantage of the Intuitive colorimeter is that because of colour adaptation, the person is unaware of the exact color of the light shining on the text[74]. However, a major demerit with double-masked trial was that the results were purely subjective and there were no objective measurement of any improvement with the colour [76].

1.28 Potential Mechanism for Benefit from Tinted Lenses

Some theories have been proposed to be the mechanism of benefit from tinted lenses. However, Evans [49] suggested that these hypotheses have not been able to account for the high degree of specificity of the required colour, which has been emphasized by Irlen and substantiated by double-masked, randomized placebo-controlled trials.

The theories are:

a. **Pattern Glare**: The basis of the theory on how pattern glare explains the benefits of tinted lenses is that certain cells within the visual cortex are hypersensitive and so causes discomfort while viewing patterns of repeating black and white lines on a page [75]. Since some of the neurons in the visual cortex are sensitive to specific colours, varying the colour of the illuminating light may change the pattern of excitation within the cortex. This could account for the benefit from specific coloured filters. From this, it has been hypothesized that by changing the colour of the input, the stimulus is transmitted to other cells that are not hypersensitive and so prevent the distortions and discomfort occurring [75,76].

b. **Syntonics**: Syntonics is a colour vision therapy system used by some optometrist for the treatment of several conditions including strabismus, amblyopia, and reading disorders.

The therapy involves subjects viewing a light source covered by a colored filter. The theory is that the colour influences the endocrine system through the inferior accessory optic tract. The colour seems to be chosen on the basis of a hypothetical connection between an alleged autonomic nervous system imbalance and the type of heterophoria. Treatment is said to result in improved visual fields[74,75].

c. **Placebo Effect**: The placebo effect is one of the possible mechanisms for the benefit from tinted lenses. People may believe that a treatment works simply because it is claimed to be effective[74].

Williams and Kitchner[77] conducted a literature review on the use of tinted lenses and colored overlays for the treatment of dyslexia and other related reading and learning disorders and concluded that:

1. there was evidence that the symptoms associated with Irlen syndrome are related to identifiable vision problems such as binocular and oculomotor problems and that condition returned to normal when treated with lenses, prisms or vision therapy. When patients exhibiting the Irlen syndrome were treated with vision therapy the symptoms were relieved and therefore did not demonstrate the need for colored lenses.
2 most investigators did not control for the presence of vision anomalies.
3. the results of prospective controlled research on the effectiveness of tinted lenses or colored overlays varied.
4. the results of testing used to determine the most appropriate color were not repeatable.
5. the effects of spectral filters and colored overlays were not solely a placebo. Colored overlays and tinted lenses are not cures for dyslexia but may be useful reading aids for some individuals with reading difficulty.
6. there was a lack of agreement about the best ways to evaluate patients for the presence of Irlen syndrome.

The American Optometric Association[78] issued a policy statement on the use of tinted lenses and colored overlays which states as follows:

1. Undetected vision problems may be a factor in individuals who exhibit the symptoms of the Irlen Syndrome. A comprehensive eye/vision examination with particular emphasis on accommodation, binocular vision and ocular motor function is recommended for all individuals experiencing reading or learning difficulties as well as those showing signs and symptoms of visual efficiency problems.
2. The American Optometric Association encourages further research to investigate the effect that specifically tinted lenses and colored overlays have on visual function related to reading performance.
3. Vision problems are a frequent factor in reading difficulties. Ignoring the role of vision or inadequately evaluating the vision of individuals with reading problems is a disservice which may prevent the person from receiving appropriate care.

In concluding, Lighthouse[76] advices that until more is known about prescribing specific colored lenses, optometrists should be certain to offer the patient the best advice. According to Wilkins [79] some 20% of unselected children in mainstream education (not simply those with reading difficulties) find colored overlays of benefit, and the benefit is pronounced in 5%. Wilkins[79] emphasized that “colored filters do not provide a treatment for dyslexia – they provide a means of avoiding the visual stress with which reading is sometimes associated”.

1.29 SUMMARY

Dyslexia is a neuro-developomental condition that impacts on a persons spelling, comprehension, writing and reading, and not only limits their academic career, but also impacts on all areas of life that require these skills. Its diagnosis, management and treatment require a multidisciplinary team, as it can present with many characteristics which requires careful classification. While it is not always possible to identify the cause, it is generally considered to be a neurological condition with a genetic origin. It affects up to one fifth of Caucasians, with limited studies being done on other ethnic groups, including Africans.

The aim of the study was therefore to investigate the prevalence of vision defects in an African

South African population of dyslexic schoolchildren, with an attempt to identify high risk visual conditions that may be prevalent. It was hypothesized that there was no relationship between vision defects and dyslexia.

The reading process requires learning to transform printed letters on a page to words that have meaning. Words are made up of phenomes which are represented by letters, and it is the inability to break words into parts that result in the manifestation of dyslexia. Its characteristics include letter reversal, faulty pronunciation, difficulty with word retrieval and learning to talk. As all visual stimuli is transmitted through the eye, there is an association between ocular conditions and problems associated with letter, words and reading, hence the involvement of optometrists. The primary role of optometry is to identify and compensate for visual defects that may constitute an impediment to reading. Evaluation by an optometrist is therefore important to assess and provide advice or devices where appropriate.

Initial identification usually takes place by teachers or parents, and may result in the child being sent to a school equipped to deal with learning disabilities. Psychologists diagnose dyslexia using some range of psychometric tests. The advent of imaging techniques such as positron emission tomography and functional magnetic resonance has aided research in dyslexia, as these techniques enable the study of dyslexic brain activity as a reading task is performed. The two broad categories of dyslexia, one being due to a genetic neurological defect, and the other being due to a secondary incident that impacts on the brain. There are a number of theories regarding the underlying causes, the only theory related (still controversial) to visual system being the visual processing theory.

Chapter One provided the study aims, objectives, hypotheses to be tested, background information on dyslexia and rationale for the study, while Chapter two will review the related literature on dyslexia and vision.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The relationship between vision and dyslexia has been a subject of controversy in optometric and ophthalmologic literature. A review of existing literature [1-32] on the area of vision and dyslexia reveals that the studies conducted to investigate visual functions in the dyslexic subjects do not establish a causal relationship between vision and dyslexia, but tend to establish associations between dyslexia and certain vision variables. The literature review also shows that there exists a dichotomy between the ophthalmologists and optometrists on the subject of dyslexia and vision. The difference in perspective can be seen from the style of report in studies conducted by optometrists [5,6,83-84,91,98,100-101] and by ophthalmologists [2-4, 85, 95, 99,102]. Optometrists maintain that although vision may not be considered as a cause of dyslexia, compensating for visual defects make reading easier for the dyslexic child. Ophthalmologists hold the contrary view that vision does not, in any way, contribute to dyslexia. Dyslexia has also been thought to be a language-based learning disability[80]. Consequently, from the speech-language pathologists' perspective, "a child with a speech deficit may also have an emotionally distorted perspective, and a child whose classroom behaviour is hard to control may also be unable to read". The role of the psychologists is to perform psychometric assessments of the dyslexic child[32]. The educator is primarily involved with special educational intervention for the dyslexic child.

Flax [22] proposed that the role of visual factors in dyslexia "depends on the definition of vision that is considered", meaning that if vision is narrowly defined as visual acuity or clarity of sight, it is unlikely that there would be any relationship between vision and dyslexia. If other peripheral visual functions such as fusion, convergence, refractive errors and accommodation are considered, there is likely to be a relationship but then questioned the possibility of vision being a causative factor. Flax[22] reiterated that the most important aspect of vision that is closely linked to dyslexia is when vision is defined to include perceptual and integrative aspects of vision. It was concluded that "vision difficulties are part of the dyslexic syndrome"[22].

From a similar perspective, Solan[81] suggested that vision anomalies are contributory and frequently hinder responses to educational intervention. He emphasized that in cases where vision anomalies are factors involved in the reading disability, the effort required to maintain clear, single binocular vision decreases the efficient organization of the visual cognitive response.

This review has been structured in a way that an overview of a study will be made when it is first cited. Subsequently, such studies will be cited only with references to the vision variable being reviewed. Only the studies that relate directly to the topic of the present research such as visual acuity, refractive errors, near point of convergence ocular alignments, accommodation functions and vergence reserves are reviewed.

It is also important to note that there are many variations in the results reported by different authors. In view of this, the findings are thus presented on an individual basis. Various studies have attempted to study the relationship between dyslexia and vision, and have examined the different aspects of vision suspected of affecting reading ability. However, the major drawbacks that plague the researches in the subject are: Firstly, intelligence quotient is a factor to consider when defining dyslexia. However, only a few studies[5,87-89] consulted have considered intelligent quotient in their subjects' selection.

Another area worth mentioning is the fact that some of the studies lacked control group, which made the reports difficult to assess and utilize. In addition, some researchers failed to classify some visual functions such as binocular coordination and refractive errors thereby making it difficult to evaluate the impact of a particular vision variable on reading ability. Furthermore, some studies failed to indicate the eye examination techniques used in their protocol which makes the replication of such studies difficult.Given the inherent limitations with studies conducted to investigate vision in dyslexic children, these studies are important in guiding the teacher and clinicians on the appropriate intervention for the child.

2.2 Visual Acuity

Vision plays an important role in the reading process, as the ability to see printed material is crucial in reading. Reading efficiency and speed starts to decrease when the print size is less than three times larger than an individual's visual acuity threshold. A marked bilateral reduction in visual acuity can definitely limit reading performance but it is unknown if deficient visual acuity characterizes students who have difficulty to read[82.]

Available studies[3-5,83,84] that have attempted to see how visual acuity affects reading performance are presented starting with the first three studies in this review that found a higher prevalence of reduced visual acuity among dyslexics compared to normal readers.

In 1994, Latvala, Korhoenen and Penttinen [3] assessed the ophthalmic status of fifty five (55) dyslexic and fifty (50) control subjects in an age, gender and social class matched study in Finland. The subjects' school grade and intelligence quotient were not indicated. Since intelligence quotient is a major factor in the definition of dyslexia, the lack of information on intelligence quotient may lead to the questioning as to if the population studied were truly dyslexics. The authors assessed visual acuity using the Snellen chart and found that for the control group, all subjects had visual acuity of 0.7 (6/9) while in the dyslexic group two children (3.6%) had bilateral visual acuity of less than or equal to 0.7.

A study to examine the 'ophthalmological' status of school children with dyslexia in Norway was conducted by Aasved [4] in 1987. Visual examinations were performed on two hundred and fifty nine dyslexic children. The number of the participants from the control group was not clearly stated. The investigation techniques used was also not detailed. As a result, it may be impossible for other researchers to replicate the study. However, Aasved [4] reported that the dyslexic population had a higher prevalence of reduced visual acuity than the normal readers did. It was concluded that although there was no causal relationship between eye characteristics and reading difficulties, eye abnormalities should be corrected when detected in dyslexic children.

Evans *et al* [5], in 1993 studied some sensory and refractive visual factors in 39 dyslexic and 43 control subjects aged between seven years six months and twelve years three months in the United Kingdom. Participants from both groups had intelligence quotient of above 85. The authors found that the dyslexic group had a significantly worse near and distance binocular visual acuity, the "inter-ocular difference was not statistically different in the two groups and the difference between the best monocular and the binocular visual acuity was not statistically different between the two groups at distance or near". They claimed that the “reduced visual acuity may not have been due to refractive defects″. Apart from refractive errors, a reduced visual acuity may arise from pathological conditions such as cataract and glaucoma.

The following two studies reported similar prevalence of visual acuity worse than 6/9. In 1980, Hoffman[83] investigated the incidence of vision difficulties in learning disabled children in the United States of America. Vision evaluations were performed on one hundred and seven children with learning problems who were referred to the clinic for vision care from educators and psychologists. The subjects’ mean age was eight years eight months. As a comparison (control) group, twenty five patients between the ages of five and fourteen were selected from the general optometry clinic. The prevalence of visual acuity poorer than 6/9 was reported to be 10.28% among the learning disabled subjects. The subjects from the control group were not appropriately selected, not representative enough and were not age-matched, although the issue of the comparison group being inappropriately selected was acknowledged by the author. Another limitation with the study was that no information was given on the eye examination procedures followed. This may be problematic as it makes comparison with other studies and replication of the study difficult.

Sherman[84] conducted a study to “relate vision disorders to learning disabilities” in the United States of America in 1973. Thirty-nine boys and eleven girls participated in the study. The children were diagnosed as having learning difficulties by the referring psychologists. Their ages ranged from six to thirteen years. The technique used to measure visual acuity was not indicated but it was reported that five children (10%) had visual acuity poorer than 6/9.

Other studies reported the prevalence of visual acuity to be similar between the control and reading disabled group and include the following studies: In 1985, Helveston, Weber and Miller[85] (from ophthalmology) studied visual functions and academic performance in first, second and third grade children in the United States of America. One thousand nine hundred and ten children participated in this study. The Snellen chart and the Jaegar print were used to assess distance and near visual acuity respectively. The authors reported that 94% of the children tested had normal visual acuity and that visual acuity was not related to academic performance in a positive way. Although the study may be credited with a large sample size, a possible limitation with the application of the findings of this study was that the pass/fail criteria were arbitrarily chosen by the examiners "on the basis of previous clinical experience" without references to other research studies. Secondly, the authors failed to present the results of the statistical analyses of the relationships between vision functions and reading.

Grisham and Simon[82] conducted a review of literature on refractive error and reading process and reported that there are abundant and reliable scientific evidence that shows a higher prevalence of vision defects among reading disabled children than among normal readers. It was emphasized that there are cases where prescription of glasses has improved academic performance. Their analysis revealed no statistically significant difference in distance visual acuity among normal and disabled readers but that near visual acuity may be an index which distinguishes some children who are having difficulty to read and those who do not.

It is important to note that since reading is a near point task, a deficient near visual acuity may be more contributory to poor reading than reduced distance acuity. Consequently, Grisham and Simons[82] stated that "deficient distance visual acuity would not be expected to affect the reading skills of children unless substantial reading instructions take place on the chalk board. It is possible that distance acuity is a factor in the early grades when reading is first introduced".

In 2007, Grisham, Powers and Riles[86] studied visual skills of 461 poor readers in California high schools. The participants mean age was 15.4 years and there was no control group in the study. Participants for the study had been identified by the schools as poor readers. The vision functions measured were: visual acuity, near point of convergence, "convergence and divergence and fusional ranges", accommodative amplitude and accommodative facility. No information was given on IQ but it was mentioned that the basis for referral of students for assessment was poor reading performance, which was determined by the school and defined as reading two grade levels or more below grade level. Visual acuity was assessed using the Snellen's chart at six meters. The authors reported that 56.8% of the participants had visual acuity of 6/6 in both eyes, 26.1% had visual acuity of 6/9 in each eye while 17.2% had visual acuity of worse than 6/9 in either eye.

Another comprehensive study conducted in 2007 was reported by Kapoula, Bucci and Jurion[87]. Convergence and divergence functions in 57 dyslexic and 46 non-dyslexic age-matched children were studied in French dyslexic children. The mean age of the dyslexic subjects was 11.3 years, the mean IQ was 105 and the mean reading age was 8.91. The mean age for the control group was 10.7 years. The IQ score of the control subjects was not indicated. The vision functions performed included: visual acuity, stereo acuity, and cover test, near point of convergence and "measurement of convergence fusional amplitude (divergent or convergent). Unfortunately, the authors did not detail the testing procedures for the vision functions investigated but reported the results of the study. It was reported that all children had normal visual acuity.

In 2008, Alvarez and Puell [88] studied accommodation functions in school children with reading difficulties in Madrid, Spain. Eighty seven poor readers (mean age 9.2 years) and 32 control (mean age not indicated) participated in the study, all in grades three through grade six. Relative accommodation, amplitude of accommodation, and accommodation facility was assessed.

The most current literature reviewed was reported by Bucci, Gignac and Kapoula [89] in 2008. The authors studied poor binocular coordination of saccades in dyslexic children in France. Of particular interest to the current review is the assessment of visual acuity and refraction (though was assessed under cycloplegia), heterophoria, near point of convergence and fusional vergence reserves. The study participants comprised of 18 dyslexic children (mean age 11.4 years and mean IQ was 105). The control group comprised aged-matched non-dyslexic children, mean age 11. 2 years. There were no details on the method of assessment of visual acuity and refraction but it was indicated that a cycloplegic refraction was conducted. However, the authors reported that all children had normal visual acuity but the results for refractive errors were not reported

In 1991, a study on stereopsis, accommodative and vergence facility was conducted by Buzzelli [6] in the United States of America. Thirteen normal readers of average age, thirteen years three months and thirteen dyslexics, average age of thirteen years four months participated in the study. Both groups were matched for gender, age and intelligence quotient. The study design was comprehensive. The Snellen chart was used to assess the visual acuity. Buzzelli[6] found that the dyslexics did not perform worse than the control subjects in visual acuity.

Ygge, Lennerstarnd, Axelsson and Rydberg[2] studied visual functions in a Swedish population of dyslexic and normally reading children in 1993. Eighty six 9-year- old children matched to controls with regard to age, gender, class in school and intelligence participated in the study. VA was assessed with “ordinary optotypes charts”. They reported that the subjects from the control group had a better visual acuity than the dyslexic group at both distance and near and that the results showed statistically significant differences (distance at $p = 0.03$) and (near at $p = 0.005$).

A comparative study of dyslexic and normal readers using orthoptic assessment procedures was conducted by Goulandris, McIntyre, Snowling, Bethel and Lee[90]. The study was conducted in 1998 in the United Kingdom and comprised 20 dyslexic and 20 chronological and reading age-matched control participants. A unique aspect of the study was that the distance VA was assessed using the Cambridge Crowding Cards. This test, according to the authors, was devised to evaluate letter recognition acuity in conditions of 'crowding' when other letters surround the target letter and that the test is designed to ensure that abnormalities of vision, which would not be revealed reliably using single targets were detected. The near acuity was assessed using the Snellen's chart. The use of different VA chart at distance and near may raise a concern of standardization. They reported that the prevalence of distance and near VA (using a 6/9 criteria) was similar between the groups.

In 1992, Evans, Drasdo and Richards[91] investigated optometric correlates of reading disability in 10 children aged between eight and fifteen years who were referred to the optometry clinic by the child psychologist. The authors reported only the statistical values: mean binocular distance visual acuity of + 0.91 and mean binocular near visual acuity of + 0.89.

2.3 Refractive Errors

In the study by Alvarez and Puell [88] no information was given on the protocol used to assess refractive error but the refractive error results were reported. For the poor readers, mean spherical equivalent refractive errors for the right and left eye were 0.20 ± 0.6 and 0.20 ± 0.6 respectively. Fifty-seven (65.5%) children were emmetropic. In the control group, mean spherical equivalent refractive errors for the right and left eye were - 0.20 ± 0.8 and - 0.14 ± 0.80 respectively. Twenty (64.5%) children were emmetropic. In contrast, Evans *et al* [91] reported the mean spherical equivalent refractive error (by retinoscopy) of + 0.77DS for the (right and left eye was similar).

2.3.1 Myopia

Myopia is characterized by a decrease in distance visual acuity. Myopia would usually not be expected to affect reading skills since students can make the necessary adjustments to their reading positions. However, from a clinical standpoint, unusually high myopia, myopic anisometropia and astigmatism could influence patients near performance and cause some discomfort to the child. There is no evidence in the literature that myopia is associated with poor reading. In the study by Alvarez and Puell[88], 5.7% of the children from the dyslexic group were myopic compared to 19.4% from the control group.

In 1987, Rosner and Rosner [93] conducted a retrospective comparison of visual characteristics of data for two hundred and sixty one children with learning difficulties in the United States of Ameria who had been identified by the schools as manifesting learning difficulties (LD). The control group consisted of four hundred and ninety six children without learning difficulties. The subjects from both groups were of age range between six and twelve years. The children had been examined at the University of Houston Optometry Clinic. The data collection techniques used was not given but it may be assumed to be routine optometric eye examination protocols because the study was conducted at the university optometry clinic. The prevalence of myopia (minus 0.50 dioptres) was reported to be 54% in the non-learning disabled patients while 19% of the learning disabled patients were myopic.

One limitation with this study however, was that all subjects were patients of an eye clinic where the two main reasons for referral are reduced visual acuity and school learning problems. Consequently, the prevalence of visual defects in subjects selected from such a clinical setting may have been higher than those from a non-clinical setting.

In a review study conducted by Grisham and Simon[82] the prevalence of myopia was lower in the reading disabled group than among the normal readers. Similarly, Grosvenor [94] analysed data from several studies and concluded that myopia is consistently associated with good reading performance. One limitation with this analysis however that is the conclusion drawn from the review was based only on studies that found positive relationships between vision anomalies and reading ability. Grosvenor [94], however, remarked that "many authors failed to find the relationship because they used ineffective methods".

One of the earliest studies on the subject of vision and reading difficulty was conducted by Eames [95] in 1948 in the United States of America. He studied refractive and binocular vision anomalies in one thousand (1000)"reading failures, one hundred and fifty (150) unselected children and five hundred ophthalmic patients". Comparing the poor readers and the unselected groups (control) he found the incidence of myopia to be same in both groups (4%). Myopia was defined as -1.00 diopter sphere. There was no statistical analysis in that study and the data collection techniques were vague although it was indicated that no cycloplegia was used. While the study may be criticized as not being current, it is the major and early study to give an insight into the subject of vision and reading disability.

Eames[95] and Shearer[96] reported a similar prevalence of myopia (4%): Shearer[96] investigated "eye findings in children with reading difficulties". Two hundred and twenty two children participated in the study. The subjects were screened using the Keystone telebinoculars. The prevalence of myopia defined as - 0.50 dioptres sphere was 4 %. He concluded that vision functions are not related to reading ability.

2.3.2 Hyperopia

Hyperopia is often associated with poor reading performance probably through the mechanism of deficient accommodation and poor motor fusion skills [82]. A child with a relatively high degree of farsightedness may not report blur vision at distance due to compensation for hyperopia through the accommodation mechanism, which also is used to create clear vision at near. This results in overuse of the accommodation system both optically and physiologically and a subsequent fatigue or spasm of the accommodation system [97].

One of the studies that classified refractive error in the literature was conducted by Rosner and Rosner[93]. They reported that hyperopia appeared to be more prevalent (54%) in learning disabled than in the non-learning disabled children with a prevalence of 16%.

In the study conducted by Alvarez and Puell[88], 28.7% of the dyslexic group was hyperopic compared to 16.1% from the control group. Grisham and Simon[82] in a literature analysis of refractive errors and reading process reported that the prevalence of hyperopia among poor readers is higher than among good readers and that the correction of hyperopia resulted in improved performance.

Grosvenor [94] reported that hyperopia is usually associated with poor reading. Similarly, in Eames' study[95], 43% of poor readers had hyperopia while for the control group only 12% were hyperopic. The author gave no information on statistical analysis. Shearer[96] reported the prevalence of hyperopia to be 16%.

2.3.3 Astigmatism

Clinically, uncorrected moderate to high astigmatism can cause discomfort and lead to poor reading performance at near distance. Relatively few studies have attempted to study the relationship between astigmatism and reading disability. The prevalence of astigmatism reported was higher in the dyslexic group compared to the control group in all the studies reviewed [3,93,95]. These studies include: the study by Latvala *et al* [3] who reported that 3.6% of the dyslexic subjects were astigmatic (of greater than -1.00 diopter cylinder) and none from the control group had astigmatism of that magnitude. Eames[95] reported the prevalence of hyperopic astigmatism of more than -1.00 diopter cylinder among the poor readers to be 6% and 4% in the unselected group while the prevalence of myopic astigmatism was the same (1%) in both groups. Rosner and Rosner [93] found a higher prevalence (30%) of astigmatism amongst the non-learning disabled subjects compared to the learning disabled group (27%). In Shearer's [,96] study of eye findings in children with reading difficulty, the total prevalence of astigmatism classified as myopic astigmatism (3%) and hyperopic astigmatism (3%) reported was 6%. There was no control group in this study. In the study by Alvarez and Puell [88] astigmatism was detected in seven (8%) and eight (9.2%) right and left eyes respectively while astigmatism was detected in five children (16.1%) from the control group. Ygge *et al* [2] reported that the prevalence of astigmatism was higher in the dyslexic group (28%, left eye 25 %) compared to the control groups (right eye 18.3% left eye 24.3%) although there was no statistically significant difference between the groups ($p=0.25$).

2.3.4 Amblyopia

Only two studies on the available literature consulted reported on the prevalence of amblyopia both indicating a higher prevalence amongst the dyslexic group compared to the control group.

In the study by Latvala *et al* [3] the prevalence of amblyopia in the dyslexic group was 3.6% and none in the control group had amblyopia. Although a detailed prevalence of refractive error was not presented in that study, it was reported that nearly all subjects had visual acuity of 0.7. In relating refractive error to amblyopia, the prevalence of astigmatism in the control group was 3.6% and none from the dyslexic group had astigmatism. Consequently, a low prevalence of amblyopia may be related to fairly good visual acuities in both groups. On the contrary, Rosner and Rosner [93] reported that 4% of the non-learning disabled patients had amblyopia compared to the 3% found in the learning disabled patients. Hyperopia is the refractive error that is more often associated with amblyopia. However, this study presented a higher prevalence of amblyopia (4%) but a lower prevalence of hyperopia (16%) in the non-learning disabled patients. However, a difference of only 1% is not high enough to account for the difference.

2.3.5 Anisometropia

Anisometropia has been thought to be associated with poor reading skills probably through the mechanism of poor sensory and motor fusion rather than reduced visual acuity. It degrades binocular coordination and consequently reduces visual comfort and efficiency if the binocular coordination is under stress [82].

Three studies[2,3,95] reported findings on anisometropia: Latvala *et al* [3] reported a higher prevalence of anisometropia (of greater than or equal to one diopter) of 6% for the control group than in the dyslexic group with 3.6%, Similarly, Ygge *et al* [2] found a higher prevalence of anisometropia in the control group (15.8%) than in the dyslexic group (9.4%). Eames [95] reported that 13% of poor readers were anisometropic, while 6% from the control group had anisometropia. According to Grisham and Simons [82] only few studies have considered anisometropia to affect reading performance. The authors concluded that there was insufficient number of studies to draw firm conclusions from their review.

Other studies[2,5,98] failed to classify refractive error according to the type. These include studies by Evans *et al* [5] who investigated some sensory and refractive factors in dyslexia. The distribution of refractive errors was found to be similar in both the dyslexic and control groups. The details of the participants profile was given earlier (section 2.1). The refractive errors were assessed by distance retinoscopy and subjective refraction. A cross cylinder was used to measure astigmatism. The spherical equivalent refraction was calculated by adding one-half of the cylindrical components to the spherical component. It was not indicated if refraction was performed under cycloplegia. Ygge *et al* [2] assessed refractive errors objectively using streak retinoscopy under cycloplegia. They reported that the distribution of refractive errors were similar between the dyslexic and control groups.

Sucher and Stewart [98] examined 136 fifth and sixth grade children comprising seventy two with learning disability and 64 from the mainstream school as the control group. The learning disabled children were selected from a classroom of children attending special supervision and instruction. Children from both groups were matched by grade level. No information on intelligence quotient was given. The testing protocol used to assess refractive error was not indicated. The authors reported a higher prevalence of refractive error in the dyslexic (20.8%) than in the control (9.4%) group. As indicated earlier, refractive errors were not classified according to the types in the three preceding studies [2,5,98].

Hoffman [83] reported the prevalence of refractive error to be 21.5%. There was no report on the control group and the techniques used to assess refractive errors were not indicated. In the study by Helveston *et al* [85] only 1% of the participants had refractive error when assessed objectively with the retinoscope without the use of cycloplegia. Refractive errors were not classified according to the types (myopia, hyperopia or astigmatism).

In 1991, Hall and Wick [99] conducted a study to investigate the relationship between ocular functions and reading achievement in the United States of America. One hundred and eleven children (in grades one through grade six) participated in the study. Eleven ocular functions were investigated including visual acuity, saccade eye movements, accommodation facility, amplitude of accommodation, accommodation posture, heterophoria, horizontal fixation disparity, vertical fixation disparity, near point of convergence, titmus and Randot stereopsis. Accommodation facility was measured using the flipper technique. The amplitude of accommodation was determined using the push up to blur technique. Heterophoria, fixation disparity and near point of convergence were also measured but the techniques used were not indicated. The age range of the subjects studied was not indicated. Using multivariate correlation they found no statistically significant relationship between the ocular functions and reading abilities as they noted that the acquisition of reading skills is given by many forces which include the use of remedial instructions and language skills, the role of peer pressure and innate intelligence.

2.4 Near Point of Convergence

Anomalies of convergence is one of the common problems encountered in the optometric practice especially in the pediatric population and the reports on near point of convergence has been presented comprehensively in the literatures reviewed.

Grisham *et al* [86] measured the near point of convergence by asking the student if the clown face target was seen as single when the examiner held it approximately 20 cm in front of the student's eyes. If so, then the student was requested to say when the object appeared to double as it moved closer to the face. The examiner placed one end of an accommodative rule on the student's forehead and judged where the two eyes diverged as the target moved toward the student's face. The measurement was repeated three times. The authors found that 84.6% of the students had near points at 8 cm or closer which they considered "normal", while 15.4% had near point of convergence of 9 cm or farther.

In the study by Kapoula *et al*[87] the NPC was determined by placing a small pen-light at 30/40cm in the mid plane in front of the subject and moving it slowly towards the eyes until one eye lost fixation. The authors reported that the NPC was significantly more remote (>10cm) in dyslexics than in non-dyslexics (36% versus 15%).

Bucci, Gignac and Kapoula [89] followed similar protocol as in the study by conducted Kapoula *et al* [87]. The near point of convergence was determined by placing a small pen-light at 30/40 cm in the mid plane in front of the subject and moving it slowly towards the eyes until one eye lost fixation. It was reported that the NPC was not statistically different between the two populations: the median value was 5 cm for both dyslexic and non-dyslexic children.

Latvala *et al*[3] failed to indicate the technique used in assessing the near point of convergence but simply noted that "convergence ability was measured" but reported that convergence near point greater than or equal to 8cm was found in 12.7% of the dyslexic subjects and 2% of the control group. The authors concluded that the near point of convergence was the only variable that showed a statistically significant difference between the groups. They concluded that ophthalmic factors should not be overlooked as a contributing factor to dyslexia as they may constitute part of the dyslexic syndrome and recommended that vision anomalies should be corrected whenever detected.

Shearer's [96] findings are similar to the results reported by Latvala *et al* [3]. He assessed the near point of convergence using the keystone telebinoculars and reported that 12% of the participants in his study had convergence problems.

In a relatively elaborate study, Evans, Drasdo and Richards[100] investigated accommodative and binocular functions in dyslexia. The subjects were 43 control and 39 dyslexics aged between seven years, six months and twelve years three months. An intelligence quotient range of over 85 for the dyslexics and over 90 for the control with the Wechsler Intelligence Scale for Children (Revised) (WISC-R) was recorded. They measured the near point of convergence using the royal air force (RAF) rule. It was concluded that all subjects were able to report a clear subjective break and recovery, and reported no statistically significant difference between the two groups in either the near point of convergence.

Hoffman[83] assessed convergence using keystone visual skills tests but grouped the results as binocular coordination which makes it difficult to analyze and compare while in the study by Helveston *et al* [85], 98% of the participants had normal near point of convergence.

In 2002, Keily, Crewther and Crewther [12] investigated the relationship between functional vision and learning to read in Australian school children. Two hundred and eighty-four children (mean age 9.9 ± 1.8 years) received a vision screening emphasizing binocular anomalies associated with discomfort at near (distance and near visual acuity, distance vision "challenged with binocular +1 D lenses", near heterophoria, near point of convergence, stereopsis and accommodative facility). Children were classified as normal readers (n = 195), children with dyslexia (n = 49) or learning disabled children (children who have learning difficulty with impaired intelligence quotient) (n = 40). It was reported that the near point of convergence were better in the dyslexic group compared to the normal and the learning disabled group but found no statistically significant difference between the groups. In constrast, Evans *et al* [91] assessed near point of convergence using the RAF rule and reported a highly statistically significant relationship between NPC and reading retardation ($p=0.019$).

2.5 Heterophoria

Heterophoria is a common binocular problem and in clinical practice, it is particularly important when analyzed in conjunction with fusional reserve as it gives an indication of the zone of comfortable binocular vision.

The distance phoria is a clinical measurement of the tendency of the two eyes to deviate from parallelism when viewing a target usually at six meters. When a closer viewing target is utilized (say at about the individuals reading distance), the resulting near phoria measures the degree to which the eyes over converges (esophoria) or underconverges (exophoria) to the plane of the target[97]. This latent deviation requires fusional vergence to maintain single binocular vision and at near they involve the accommodation system. Smooth functioning of these systems particularly at near is important for near tasks[92].

Several studies[3,12,85,87,89,95,96,98,100,101] have attempted to investigate the role of heterophorias on reading ability and all reported remarkably varying findings. The assessment of heterophoria was extensive in the study conducted by Latvala *et al* [3]. Heterophoria at distance was evaluated using the cover test and Maddox rod. The prism bars was used to quantify their findings. The Maddox wing was used to assess phoria at near. At near, they reported a higher prevalence of esophoria (6.1%) among the control than the dyslexic group (5.8%) a higher prevalence of exophoria (25%) among dyslexics than the control group (12.2%) and a higher prevalence of vertical phoria (6.1%) among the control than the dyslexic subjects (3.6%). At far distance, they found a higher incidence of esophoria (11.3%) among dyslexics than the control (8.2%) subjects, a higher prevalence of exophoria (2%) among the control group than among the dyslexics (1.9%) and vertical phoria to be more prevalent in the control (4.1%) than in the dyslexics (3.8%).

Keily *et al* [12] assessed heterophoria using the Prentice card and reported that there was a slight but insignificant tendency for the dyslexic subjects to be more exophoric than the normal and those with learning disability but found no statistically significant difference. The test distance was not indicated.

Evans *et al* [100], in a study of accommodative and binocular functions in 43 control and 39 dyslexics reported that all subjects examined were orthophoric at distance with cover test except for one dyslexic subject who demonstrated 10 prism diopters right esotropia and two diopters right hypertropia which changed to 15 prism diopters right esotropia with two prism dioptre right hypertropia at near. At near, horizontal phoria results were similar in both groups.

Evans, Efron and Hodge [101] studied the incidence of lateral phoria in 45 children with specific learning disability in the United States of America in 1977. The participants were selected from a psychologist's file. The control group comprised of 364 children in second, third and fifth grades attending regular school. It was not indicated why there was such a big difference in the number of participants from both groups. The test used in assessing phoria was the "Rocket card which was used in conjunction with red- green spectacles". They reported a prevalence rate of 11.35% in the control group, while 22.2% of the children from the specific learning difficulty group had heterophoria. There was no statistically significant difference between the groups. In concluding, it was recommended that phoria conditions may not cause reading or learning disability but that the presence of such conditions could contribute to visual perceptual and attention abnormalities.

A report by Sucher and Stewart[98] contained limited information as the authors did not detail whether a higher prevalence rate among control (10.5%) than dyslexic (8.6%) was for near or distance phoria. Similarly, Eames[95] failed to indicate the distance at which the measurement was made but reported that 33% of poor readers had exophoria and 22% of control were exophoric but did not indicate whether distance or near.

Helveston *et al* [85] used the Wottring amblyoscope to determine "objective and subjective angle of ocular alignment" and reported that 96% of the participants in their study were orthophoric [85]. The criteria used to classify ocular deviation were not indicated.

Another comprehensive report of heterophoria was documented by Shearer[96]. The subjects were screened using the Keystone telebinoculars and reported that 1% of the study participants had vertical phoria (>1 prism diopter), 2% had esophoria (> 4 prism diopter), 3% had exophoria (> 4 prism diopter), 26% had exophoria at near. It was concluded that vision functions are not related to reading ability. Hoffman [83] reported that ninety three (93) subjects (86.9%) had problems of binocular coordination but failed to indicate whether it was phoria or tropia.

Kapoula *et al* [87] evaluated ocular alignment using the cover test and reported that at far distance, the median value of phoria was zero for both non-dyslexic and dyslexic children ($p = 0.19$). At near, the median value of phoria was similar between the two groups (−2 prism diopters for non-dyslexics and −1.5 prism diopters for the dyslexics ($p = 0.19$).

Bucci *et al*[89] measured heterophoria at near and far using the cover-uncover test. As documented by the authors, exophoria was not statistically different between the two groups ($p = 0.2$); the median was “0” prism diopters for dyslexics and 2 prism diopters for non-dyslexics. No information was given on other aspects of heterophoria.

Simons and Grisham[92] conducted a literature analysis on binocular vision anomalies and reading emphasizing studies with positive and negative relationship between binocular vision and reading. The authors concluded that binocular conditions such as esophoria, exophoria, restricted ranges of fusion, foveal suppression, accommodative insufficiency, and oculo-motor disorders at reading range are more prevalent among poor readers than normal readers.

In another study, Ygge, Lennerstarnd, Rydberg, Wijecoon and Petterson[102] investigated oculomotor functions in a Swedish population of dyslexic and normally reading children in 1993. The study comprised 86 nine -year- old dyslexic children matched to control with regard to age, gender and intelligence. Heterophoria was measured using the cover test. They reported that for the dyslexic group “23 pupils exhibited a phoria (26.4%: 9 eso- and 14 exo-phoria)” whereas in the control group “20 pupils had a phoria (23.2% 6 eso- and 14 exo-phoria)” and that the difference was not statistically significant ($p = 0.34$). At near, the incidence of exophoria was 43.7% for the dyslexic group and 45.3% in the control group. There was no statistically significant difference ($p=0.55$).

2.6 Strabismus

Several authors[3,4, 83-85, 90, 93,102] included the measurement of strabismus in their studies, reporting remarkably varying findings. Helveston *et al* [85] assessed ocular alignment using the Wottring amblyoscope and reported that only between 2% - 4% of the students had phoria or tropia of more than four prism dioptres. Latvala *et al*[3] reported the prevalence of tropia at near for the dyslexic group to be 3.6% and 2% for the control group. Hoffman[83] assessed ocular alignment using the keystone visual skills test and reported that 13 subjects (9 exotropes and 4 esotropes) (12.14%) had strabismus. It is difficult to comment if this relatively high prevalence of strabismus is related to hyperopia as the refractive error prevalence of 21.5% was not categorized as to the type. In a study by Sherman[84], a total of four children (8%) were strabismic; classified as: three exotropia (alternating) and one esotropia (alternating). Rosner and Rosner[93] in their retrospective analysis reported that in the learning disabled group 51% had esotropia, 39% had exotropia while in the non- learning disabled group 8% were strabismic. It was not unexpected to find a higher prevalence of strabismus in this retrospective study. Aasved [4] found that the dyslexics had a higher prevalence of manifest and latent convergent strabismus than the control subjects**.**

Goulandris *et al*[90] assessed strabismus using the cover test and reported that there was no statistically significant difference between the two groups in the prevalence of strabismus.

Ygge *et al* [102] reported that at distance, manifest strabismus was more frequent among the dyslexic (8%) pupils than the controls (2.3%) but that the difference was not statistically significant. At near, the prevalence of manifest strabismus was 8% (all eso-) for the dyslexics and 3.5% (all eso-) in the control group.

2.7 Accommodation Functions

2.7.1 Amplitude of Accommodation

The accommodation mechanism is extremely important for learning. Children who suffer some anomalies of accommodation are more prone to fatigue quickly and become inattentive than those who have normal accommodation function. According to Flax [22], an "inefficient accommodation function is a significant contributor to lowered achievement in the upper grade".

The findings on various aspects of accommodation functions were diverse. Metsing and Ferreira [103] studied visual deficiencies in children from mainstream and learning disabled schools in Johannesburg, South Africa in 2008. One hundred and twelve (112) children from two learning disabled schools and eighty (80) children from a mainstream school in Johannesburg participated in the study. The vision functions examined were: visual acuity, refractive status, ocular health status, accommodative functions (Posture, facility and amplitude), binocularity (cover test, vergence facility, smooth vergences, NPC and ocular motilities (direct observation). However, according to the authors, only the results for accommodation accuracy, amplitude of accommodation, vergence facility and saccadic accuracy are reported since only these variables showed statistically significant relationship on the relationship between the (mainstream and learning disabled) groups. Metsing and Ferreira [103] reported that a high percentage (51.6% and 53.3%) of low amplitude of accommodation for the right and left eyes respectively was found in the mainstream group compared to the 29.1% and 28.8% in the learning disabled group. The relationships between the mainstream group and reduced amplitudes of accommodation of the right *(p=0.04*) and left eyes (*p=0.001*) were found to be statistically significant (p*<0.05*). The relationship between the mainstream group and reduced amplitude of accommodation of the left eyes (Cramer's *V = 0.316*) was found to be moderate and that between the mainstream group and the right eyes (Cramer's *V= 0.286*) to be low.

In the study by Grisham *et al*[86] accommodative amplitude was assessed using the accommodative rule. "The student held an occluder over the left eye. The examiner asked if the student could see the (20/30) target at the larger end of the Occlud-A Measure held at about 20 cm from the face. If yes, then the student was asked whether the target was in focus or "not blurry". If the student responded that the target was in focus, then the target was moved at approximately 2cm per second toward the student's face, and the student was asked to report when the target first became blurry". About 63.8% of the participants had amplitude of accommodation of 11D which the authors considered equivalent to the expected amplitude of accommodation for the age. About 24.7% had inadequate accommodation amplitude while 11.5% had "borderline" amplitude of accommodation.

In the study by Evans *et al* [100], the amplitude of accommodation was measured using the push up method. They reported that the amplitude of accommodation was significantly reduced in the dyslexic group and that the mean accommodation lag was calculated for each eye but found no statistically significant difference between the two groups.

Alvarez *et al* [88] assessed monocular accommodative amplitude using the minus lenses method. The subject viewed horizontal line of 20/30 letters at 33cm as the examiner introduced minus lenses in 0.25D increments until the target first becomes blurred. According to the authors, the working distance adjustment used was kept at 2.50 DS to compensate for minification. The authors reported that monocular accommodative amplitude was significantly lower ($p < 0.001$) in the group of poor readers (right eye 9.1 D ± 2.3, left eye 9.0 D ± 2.3) than in the control group (right eye 10.5 D ± 1.7, left eye 10.5 D ± 1.7).

Helveston *et al*[85] measured the amplitude of accommodation using the push up to blur technique and reported that "an ability to accommodate more than eleven dioptres was found in between 90% and 93% of the students". Ygge *et al* [102] assessed amplitude of accommodation using the RAF rule and reported that the two groups performed similarly. A similar technique was used by Goulandris *et al* [90] and a lack of statistically significant difference between the groups was reported.

2.7.2 Accommodation Facility

In the same study, Evans *et al* [100] reported that the dyslexic group appeared to be slower at a test of accommodative facility. The authors discredited the flipper technique as "... the unnatural act of altering accommodation without changing vergence. They further noted that the "flipper test… would still imperfectly reflect the normal visual environment owing to the absence of a stimulus to vergence and accommodation".

Grisham *et al*[86] measured accommodative facility using the ± 2.00D lenses flipper technique and the technique was performed as follows: The ± 2D lenses was flipped each time the student said the target was "clear". The target for this test was the 20/30 target used for accommodative amplitude. The left eye was occluded. The student was asked whether the target was clear when held at about 40 cm. If so, then the student was told that the test would be timed and that it should be reported whenever the target was "clear". The examiner then started a stopwatch and counted the number of times the lenses were flipped in 30 seconds. That number was taken to represent the cycles per minute (cpm) and therefore to represent the student's ability to change accommodation over time. Based on the criteria used in their study, the authors reported that 76% of the students had adequate monocular accommodative facility while 23.6% had "weak accommodative facility of 9 cpm or less and 8.1% had accommodative facility of as low as 1 or 0 cpm.

In the study conducted by Alvarez *et al* [88] accommodative facility testing was conducted using the following procedure: The subject, wearing his or her habitual correction, was seated and positioned so that the spectacle plane was 40cm from the Bernell Acuity Suppression Slide (VO/9). A ± 2.00 D accommodative demand was used with a 20/30 test target at 40cm. The patient was asked to view the reduced Snellen's letters 20/30 in line 5 and say "now" when the letters in that line appear clear and single, and to report letters missing from lines 4 and 6 during the binocular testing. They reported that the binocular accommodative facility values were significantly lower ($p < 0.05$) in the poor readers group (4.9 cpm ± 3.1) than the control group (6.3 cpm ± 2.9).

Sucher and Stewart [98] assessed binocular accommodative facility at 35 cm using ±1.50 diopter flippers lens for "one minute" and "used the University of California Berkeley clinic standard of 20 cycles/90s as a "criterion for success" found a higher prevalence of accommodative infacility in dyslexics (22.2%) than the control group (8.6%).

On the contrary, three authors[6, 12, 93] found the control subjects to have better accommodation facility than the dyslexic subjects. The studies are: Rosner and Rosner[93] found a higher prevalence of accommodative infacility among the control (10%) than the learning disabled group (9%). Similarly, Buzzelli[6] found that the dyslexic subjects showed better accommodation facility than the control group. To assess accommodation facility, "patients were asked to clear the number 9 on the Bernell Vectogramm Target at 40cm … alternately viewed the target through a + 2.00DS and a – 2.00 DS lens… for 20 cycles)". There was no statistically significant relationship between the two groups.

Keily *et al*[12] assessed accommodative facility using +2.00DS and – 2.00DS flippers lenses with an N6 fixation target for one minute at 30 cm, rather than 40 cm because according to the authors, the children were required to hold the reading material. They reported that accommodative facility was better in normal readers than either of the poor reading groups.

In another study, Evans and Drasdo[104] reviewed ophthalmic factors in dyslexia and commented that convergence insufficiency, accommodative dysfunctions and unstable eye movements are more common in dyslexic population than in normal readers.

Latvala[3] simply noted that some aspects of accommodation were difficult to measure and failed to give any details.

2.7.3 Relative Accommodation

Alvarez and Puell[88] measured relative accommodation using a phoropter. The subject viewed a horizontal line of 20/30 letters at 40cm with his/her best refractive correction. The examiner introduced minus or plus spherical lenses in 0.25 D steps binocularly until the patient reported first sustained blur. Negative and positive relative accommodation values were similar in both groups. This was the only study accessed that reported on relative accommodation.

2.7.4 Accommodation Posture

Evans *et al*[100] assessed accommodation lag using the monocular estimate method of retinosocpy and reported no statistically significant difference between the dyslexic and the control groups.

Metsing and Ferreira[103] measured the accuracy of the accommodative response (lag or lead) objectively using the MEM retinoscopy in normal room illumination and found that the subjects from the mainstream school demonstrated a high prevalence of lead of accommodation (40% and 40.5% for the right and left eyes respectively). However, in the learning disabled group, a high prevalence of lag of accommodation (9.8% and 11.9% for the right and left eyes respectively) was found. The relationships were found to be statistically significant ($p < 0.05$) between the mainstream and the learning disabled group, and the lead and lag of accommodation for the respective groups of the right and left eyes ($p = 0.00$).

Sherman[84] assessed accommodation amplitude and relative accommodation using minus lenses and accommodative facility using the flipper techniques. The lens powers for the plus and minus lenses used to assess accommodation functions were not indicated. His findings may be difficult to utilize due to the somewhat unique way of classifying the results as "mechanical problems".

Flax[22] suggested further investigations in the nature of accommodative function in reading disabled children, indicating that the use of the push-up method of assessing the amplitude of accommodation is unreliable due to its lack of sensitivity. Flax[22] reiterated that accommodation has a contribution in learning disabilities and that accommodative function inefficiencies tend to play an increasing role as the youngster moves through school and that "inefficient accommodation function is a significant contributor to lowered achievement in the upper grade.

2.8 Vergence Facility

Vergences are a clinical measure of an individual's ability to overcome the prismatically induced optical displacements of a target in space. Convergence relates to each eye fixating closer in space than the real physical location of the target while divergence is the measure of the eyes to fixate further in space while still maintaining single binocular vision[97].

Buzzelli [6] assessed vergence facility as follows: "patients were asked to align a vertical picture (box-X-O) slide made of anaglyph material for monocular presentation under binocular conditions. The target measured 21 mm in the vertical meridian and 10mm in the horizontal meridian. The subjects alternately viewed the target through 16 prism base out and 4 prism base in. The test was continued for 20 cycles". The author reported that the dyslexics completed the vergence eye movement task significantly slower (300 seconds) than the normal readers (240 seconds). A statistically significant relationship between the groups was reported ($p < 0.05$). It was recommended that the possible role of vergence in dyslexia should be investigated on a larger sample of dyslexic and control groups.

Metsing and Ferreira[103] assessed vergence facility test at near (40 cm) with the subjects presented with a vertical row of letters (6/9) using the 8 PD (BI) and 8 PD (BO) mounted in a flipper device. They reported that the prevalence of poor vergence facility (20.5%) was found to be higher in the mainstream group compared to the learning disabled group (18.3%). The relationship between the mainstream group and poor vergence facility ($p = 0.000$) was found to be statistically significant (*$p<0.05$*). A medium to strong relationship was found to exist between the mainstream group and poor vergence facility (Cramer's $V = 0.369$). It was concluded that children from mainstream schools are likely to present with poor vergence facility compared to children from schools of the learning disabled.

2. 9 Fusional Reserves

The compensatory effect of fusional vergence reserves on phoria is very important as difficulty with reading is likely to occur when there is uncompensated phoria in conjunction with reduced fusional vergence reserves [92].

A major study was reported by Evans *et al* [100], which found that negative and positive reserves were significantly reduced in the dyslexic group relative to the control. The "prism vergence amplitude calculated as the difference between base out and base in break and recovery points was relatively reduced in the dyslexic group". They remarked, however, that "several subjects were unable to appreciate a subjective blur point but the results for the break and recovery were complete".

In the study conducted by Latvala *et al* [3], the incidence of fusional amplitude greater than or equal to thirty two prism dioptre at near was higher in the dyslexic (7.5%) than in the control (6.1%) group. At distance, they found fusional amplitude greater than or equal to15 prism dioptre to be higher in the control (12.2%) than in the dyslexic (9.4%) group.

Disordered vergence control was studied by Stein, Riddell and Fowler [105] in the Uniteed Kingdom in 1988. The subjects were thirty nine dyslexic children aged eight to eleven years and a control group of twenty subjects of similar age group. The vergence control was measured using the Synoptophore. They reported that two thirds of the dyslexic group had abnormal vergence control. According to the authors, vergence eye movements never seem to have been investigated in detail during reading before and that the study was the first in which eye movement recording have been used to demonstrate differences between dyslexics and normal readers.

According to Grisham *et al*[86], "Convergence and divergence break and recovery" were measured at 40 cm with a horizontal prism bar. The student was first asked if the clown face target on the smaller end of a standard optometric measure (Occlud-A-Measure; Bernell, Mishawaka, Indiana) could be detected. If so, then the student was requested to say whether the target appeared single or double. Once single vision was obtained, the bar was moved relative to the student's eye until double images were reported. That point was considered "break". Then the motion of the bar was reversed until the student reported the image single, and this point was considered "recovery". This procedure was first performed for base in (BI) position of the bar over the left eye, and repeated with base out (BO) position over the right eye. The authors reported that a large number of students had poor convergence skills: 38% break at less than 18 PD, and 9.5% recover at 7 PD or less. These values were considered to be in the "weak" to "very weak" range and remarked that in contrast to convergence, 'modal" values for break (14 PD) and recovery (10 PD) were not in the "adequate" range but would be classified as "very weak" for break and "weak" for recovery. As a result, very high percentages of students had poor divergence skills: 82% break at less than 20 PD, and 60% recover at less than 11 PD.

Kapoula *et al* [87] measured vergence reserves using prism bars at far and near distance for both groups. They reported that the median value for positive fusional vergence was 16 prism diopters and 14 prism diopters for non-dyslexics and dyslexics, respectively, at far distance ($p = 0.12$) and 20 prism diopters for both non-dyslexics and dyslexics at near distance. For negative fusional vergence they reported that "divergence amplitude" was significantly different in the two groups for both distances ($p < 0.005$). At far, the median value was 6 prism diopters and 4prism diopters in non-dyslexics and dyslexics respectively, and 12 prism diopters and 10 prism diopters respectively at near.

Bucci *et al* [89] measured fusional reserves at far and near using prism bars (base in and base out). According to the authors, orthoptic evaluation of vergence fusion capability showed a significantly limited divergence capability for dyslexics compared to non-dyslexics; the median value was 10 prism diopters for dyslexics versus 17 prism diopters for non-dyslexics. In contrast, convergence amplitude was in the normal range for the two populations, while for dyslexics, the amplitude was significantly larger than for non-dyslexics, the median value was 30 prism diopters and 18 prism diopters for dyslexic and non-dyslexic children respectively.

Ygge *et al*[102] assessed vergence fusion using the prism bar. They reported that the fusion convergence and divergence capacities at distance and near were similar in the two groups. The mean fusional convergence capacities at distance were 16.80 prism diopters for both the control and the dyslexic group. At near, the corresponding figures were 26.40 prism diopters and 26.7 prism diopters respectively. The mean fusional divergence capacity at distance was 6.50 and 6.20 prism dopters in the dyslexic and control groups respectively, whereas at near the fusion divergence capacity was 10.5 and 10.2 prism diopters respectively. There was no statistically significant difference between the groups.

2.10 Ocular Pathology

Ocular pathologies do not seem to be prevalent in the dyslexic population and it was not reported on in the literature reviewed. However, according to Evans and Drasdo[100], the perspective to relate ocular pathology to dyslexia is in individuals who were normal readers but developed reading disability due to pathological conditions such as stroke or tumors affecting the right hemisphere. These conditions may be relevant to the considerations of establishing the relationship between ophthalmic problems and dyslexia[100].

Only one study[83] included this as part of the investigation. Hoffman[83] reported that one child (0.93%) of the population of learning disabled children examined had acute conjunctivitis.

A major study on dyslexic subjects (although outside the cope of the present study but worth citing) was conducted by Raju[11] in 1997. She studied oculomotor control in dyslexia and reported that sixty five percent of the normal readers exhibited normal oculomotor control as compared to the eleven percent of dyslexics and that fifty four percent of the dyslexic population exhibited deficiencies in both automaticity and oculomotor skills, whilst twelve percent of the control subjects displayed the same.

LITERATURE REVIEW TABLE pages 70-72

2.11 Summary

Research into visual aspects of dyslexia has been undertaken mainly by optometrists and ophthalmologists. The main area of controversy is that ophthalmologists tend to deny any relationship between vision and reading ability, while optometrists assert that identifying and correcting visual defects are an important part of managing dyslexia. The findings of studies that have investigated vision function in dyslexic population since the 1940s are inconclusive, and reflect the complexities associated with identifying the causes of dyslexic as well as its diagnosis, treatment and management.

A range of study designs were used and the inclusion of a control group for example, depended on the objective of the study. Some authors either compared the prevalence of vision defects in a population of reading disabled group to the prevalence of similar vision defects in a group of normal readers, or only presented the prevalence of a particular visual condition in a group of reading disabled children. All the studies used convenience sampling methods at schools, or by including learners who were referred to their private practices, the size being determined by the number of dyslexic students available. The main areas of vision functions studied were visual acuity, refraction, binocular vision and ocular pathology. The study findings were inconclusive and the only vision variables consistently report ed across the studies was the association of hyperopia with poor reading performance.

The differences in results reported by the authors may be due to the methodological problems such as differences in instrumentation and techniques, failure/cut-off criteria, method of data analysis, lack of comparison group and subjects' selection from clinical population. There was a noticeable absence of studies on African children; research has shown that African persons are less at risk of myopia and more at risk for open-angle glaucoma than Caucasians. There is therefore scope for continued research among African children to determine whether there is any relationship between dyslexia and vision.

Research on dyslexia and vision that requires an interdisciplinary approach may yield different results due to different approaches by different professionals. However, it is challenging to design a study that would control for all variables possibly influencing reading ability and vision function. Reading performance is an extremely complex task and its measurement can be influenced by many factors.

Having reviewed the relevant literature on dyslexia and vision, Chapter three will present the research design, the study population, sampling procedure, methods of data collection and analysis.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter will present the research design, the study population, sampling procedure, methods of data collection as well as method of data analysis.

3.2 Research Design

The study was designed to provide empirical information to enable a comparison of the visual characteristics of dyslexic children and normal readers. A matched paired case-control method was adopted. Data was collected from both the dyslexic and control groups and analysed.

3.2.1 Sampling Design

Participants for both samples were selected using the convenient sampling method (based on available subjects) and an optometric eye examination was conducted.

3.2.2 Study Population and Participants

The study population comprised children attending a school for children with learning difficulties from which the dyslexic children were selected to participate in the study, while the control group consisted of learners from a mainstream Durban school.

i. **Dyslexic Group:** Participants for the study from the dyslexic group consisted of 31 African dyslexic children (the experimental group) selected from Khulangolwazi Special School for children with learning difficulties in Clairwood, South of Durban. Psycho-educational evaluation/diagnosis of dyslexia was not part of this study and was not performed. The school principal allowed access to all learners' file from which the dyslexic learners where selected based on the school psychologist's diagnosis. Learners attending this special school were referred from mainsream schools around Durban. The final diagnosis as to the type of learning difficulties was done by the school psychologist. None of the children were on any medication.

The mean age for the dyslexic participants was 13 years and the learners were in grades four through grade seven, considering the fact that they were children that were reading two grades behind their chronological age. There were 15 boys and 16 girls. Due to limited number of learners who were classified as dyslexic, it was difficult to recruit the targeted number of one hundred participants for the study. The subjects from both groups were 'African' South Africans of African origin.

ii. **Control Group:** Participants for the control group consisted of 31 children from a mainstream school in Durban (Addington Primary School). The mean age of the children was 11 years and 9 months. A total of 15 boys and 16 girls were chosen ranging from grade four to grade seven.

3.2.3 Inclusion Criteria for the Dyslexic group

To be included in the study, the subjects had to meet the following criteria:

1. An average or above average intelligence quotient. For this study, an average was taken as between 95 and above as recorded on the learner's file by psychologist.
2. Be two grades or more below grade equivalent in a mainstream school.
3. The child has not been absent from school for more than 10% of the attendance days. The information on the learners' attendance was supplied by the school principal.

3.2.4 Exclusion Criteria for the Dyslexic group

The following criteria resulted in children being excluded from the study:

1. Presence of any emotional problems (information from the learners' file).
2. Presence of any systemic condition.

3. Use of any systemic medication.

The inclusion and exclusion criteria for the control group were similar to the experimental group except that the children did not have any reading problems and were attending a mainstream school.

3.3 Ethical Clearance

The study protocol was approved by the then University of Durban-Westville research ethics committee. A letter of request for access to the schools was sent to the Department of Education (Appendix B). Written informed consent (Appendix C) for access to the schools (for both groups) was obtained from the Department of Education. Written informed consents were also obtained from the principals of the schools (mainstream and special school) (Appendix D). Due to the difficulty in reaching the parents, the school principals consented on behalf of the parents for the learners to participate in the study. The participants were fully informed of the purpose of the study and accepted to co-operate with eye examination procedures.

3.4 Testing Protocol

The testing was done first with the dyslexic learners and then at the mainstream school.

3.5 Study Setting

The same testing arrangement was used for both groups. A testing room was set up in one of the offices provided by the school principal. The distance acuity chart was placed at a point six meters away from where the subjects sat and was used for the distance acuity chart and all distance testing. The examinations were done under room illumination except for some procedures such as retinoscopy that required dim illumination resulting in the room being dimmed.

All testing was conducted in the morning as it was anticipated that better responses could be obtained when the children were not tired. Each school principal provided an assistant, who helped with various activities such as controlling room illumination. The rationale and technique for every procedure was fully explained to each participant and a trial reading was taken to ensure that all instructions given were understood. During the tests, subjects were asked (from time to time) if they were tired. For any answer to the affirmative, the testing was discontinued and the child was allowed to have a break. As a routine, a break of 10 minutes throughout the duration of entire procedure was allowed.

The testing instruments were provided by the International Center for Eye Care Education (ICEE). As the instruments were also being used by other researchers they were unavailable on certain days resulting in some tests being postponed until a later date. The data collection took an average of two months per school. All data were collected by the examiner alone and each examination took an average of thirty minutes to complete.

3.6 Data Collection Techniques

All tests were conducted in free space. The data collection techniques used in the present study was similar to techniques used in other studies [93,100,106-140] based on pediatric populations (Table 3.1).

Table 3.1 Data Collection Tools and Measurement Outcome

Instrumentation/Technique	**Measurement Outcome**
Bailey –Lovie LogMAR Charts	Visual Acuity
Royal Air Force (RAF) Rule	NPC, Amp of Accommodation
Welch Allyn Streak Retinoscope	Objective Refraction
Trial Frame and Trial lenses.	Subjective Refraction
Cover Test - Occluder and Prism Bar	Ocular Alignment
Maddox Rod/pen torch/Prism bar	Heterophoria and Tropia
Maddox Wing	Near Phoria
Prism Bar	Heterophoria and Tropia

Pen torch , PD rule	Cornea reflex test-strabismus
Retinoscope and neutralizing lenses	Accommodation Posture
Jackson cross cylinder	Refine subjective findings
Trial Frame and neutralizing lenses	Relative accommodation
+/-2 flipper lenses	Accommodation Facility
Direct Ophthalmoscope (Welch Allyn)	Ocular Health
Prism Bars	Fusional Reserves

3.6.1 Visual Acuity

Visual acuity is a measure of the acuteness or clearness of vision. It assesses the ability of the visual system to resolve detail which is dependent on the sharpness of the retinal focus within the eye, the sensitivity of the nervous elements and the interpretative faculty of the brain [106]. Visual acuity was assessed using the Logrithm of Minimun Angle of Resolution (LogMar) chart, which means that the letters change in size from line to line in equal steps of the log of the minimum angle of resolution (MAR). Visual acuity was assessed monocularly and binocularly for both distance and near. The LogMar chart facilitates algebraic operations for statistical analysis and allows for precise quantitative assessment of visual acuity. It is recommended for use in research studies in which visual acuity is a dependent variable[106].

Each subject was comfortably seated and the test was conducted with the examiner sitting in front in such a way that the subject's view was not obstructed. For monocular visual acuity, the subject was instructed to cover one eye with their right palm and to read the letters on the chart. This procedure was repeated binocularly and the test was done under normal room illumination [106]. No subjects wore spectacles so visual acuity for aided vision was not indicated.

3.6.2 Refractive Error

Refractive error was assessed objectively using the Streak Retinoscope (Welch Allyn) with a +1.50D fogging lens (for an arm's length of approximately 67cm) with the subject fixating a 6/60 (to maintain fixation) optotype on the distance visual acuity chart. As the subject focused on the distance target on the chart, the retinoscope light was passed across the subjects eye (right hand used to scope right eye and left hand used to scope left eye). The motions observed were neutralized with the appropriate lenses, plus lenses for 'with' motion and minus lenses for 'against' motion. The subjective refraction was performed through monocular fogging, refined using the Jackson's cross cylinder followed by binocular balancing [106]. The retinoscopic results were used for analysis.

Although retinoscopy was performed without cycloplegia as in other studies [3,95,107,108.], cycloplegic refraction was not performed because the researcher (an optometrist) was not licensed to use therapeutic drugs when the data was collected. However, it has to be acknowledged that a non-cycloplegic examination among children has limitations among those with hyperopia as the full extent of the hyperopia may be masked.

3.6.3 Near Point of Convergence

The NPC was measured using the Royal Air force (RAF) rule. The subject was instructed as follows: "This test measures your ability to turn your eyes in towards your nose. Look directly at the dot on middle of the line. The image may appear to be blurring (not clear). That is okay. However, if the dot becomes two, say 'two'. I will then pull the target away. If the dot becomes one again, say 'one' ". The subject was asked to fixate on the dot on the middle of the line as the target was advanced towards him. The objective reading was taken at the point when one eye loses fixation while the subjective reading was noted when the subject reported the target to be double. At a point when the subject reported double, the target was moved back until a point when the target was reported to be single again; this was taken as the recovery point. The final break and recovery points recorded were the average of three tests measurements. The measurement was taken three times in order to detect fatigue which may indicate poor convergence [111-113]. The objective reading was taken for analysis.

3.6.4 Strabismus

Strabismus was assessed using the Hirschberg test. A penlight was held about 50cm from the child's face in the mid plane and they were encouraged to fixate the light with both eyes open.

The location of the corneal reflection on each cornea relative to the centre of the pupil was then noted. The displacement of the corneal reflection from the centre of the pupil (angle lambda) was estimated in millimeters. An ocular alignment was observed as a symmetric displacement of the reflexes [114,115]. The examiner proceeded with the Kappa Test which is a test of monocular fixation and is done while the child was monocularly viewing the examiner's penlight. The penlight was maintained at 50 cm distance from the face. The purpose of this test was to determine the visual axis of each eye. The examiner observed the location of the corneal reflexes relative to the center of the pupil in the right eye and then in the left eye. A nasal displacement is signified by a (+) sign and a temporal displacement is signified by a (-) sign, with the amount quantified in millimeters away from center. Again, a normal location will likely be either centered, or +0.5 mm nasally displaced [114,115.]

The interpretation of the magnitude and the type of deviation requires the data gathered from both the Hirschberg tests. The fixating eye is the eye in which the corneal reflex location is the same on the Hirschberg and Kappa tests. The strabismic eye is the eye in which there was a difference. The change in location from the Kappa tests as compared to the Hirschberg test equals the amount and type of deviation. Every 1.0 mm of corneal displacement, is approximately equivalent to 22 prism diopters. A nasal change in location on Hirschberg testing from the visual axis denoted by the Kappa test denotes an exotropia. A temporal change in location on Hirschberg testing from the visual axis denoted by the Kappa test denotes an esotropia [114].

3.6.5 Heterophoria

Ocular alignment was assessed using the cover test at six meters and 40cm for distance and near respectively. It is an objective technique and is very suitable for assessing ocular alignment in children.

For distance cover test, the test target was a letter from the line above the subject’s best visual acuity of the worst eye. The subject was advised that the muscle balance of their eyes was assessed and that he should look steadily at the fixation target (an isolated letter on the chart) at all times and ignore the occluder. The cover/uncover (unilateral) cover test was performed to determine the presence of phoria or tropia [106,114-115]. To perform the unilateral cover test, the occluder was placed in front of the right eye; held for approximately one to two seconds and the left eye was observed for any movement. If no tropia or phoria present, the left eye was covered and the right eye then observed. Any movement observed was neutralized using a loose prism bar in the corresponding base direction. Base-in prism for exo deviation and base-out for eso deviation.

The alternating cover test was performed to assess the direction and magnitude of phoria or tropia (it measures the total angle of deviation) [106,114-115]. The test conditions were the same as the unilateral cover test. The subject was comfortably seated and instructed to look at the fixation target at distance. The occluder was placed in front of the patient's right eye, held for 2-3 seconds and then quickly placed on the left eye. The test was repeated several times with the occluder held in front of each eye before quickly moving to the other eye, while observing the eye that was just uncovered. Any deviation was neutralized accordingly [115]. The Maddox Wing was also used to assess near phoria under normal room illumination. The technique was assessed with the subject wearing his full subjective correction [115]. The use of cover test for the assessment of ocular alignment at both distance and near may have allowed for continuity and standardization. However, the cover test and the Maddox wing were used by Evans *et al* [100] in the same study. The subject was directed to look through the horizontal slits to view the chart that comprised of a horizontal and vertical scale and a horizontal and vertical arrow. The construct of the Maddox wing is such that the right eye sees only the arrows while the left eye sees only the scale. It achieves dissociation by presenting independent objects to the patient. As the images are dissimilar, the incentive to fusion is abolished and the eyes adopt the fusion free position [115]. The arrows are positioned at zero on the scales but through dissociation, any phoria will be indicated by an apparent movement of the arrow along the scale.

To measure horizontal phoria, the subject was asked "which white number does the white arrow point to?" The number on the scale represents the magnitude of the deviation and the direction. To measure vertical phoria, the subject was asked to indicate which red number the red arrow points to [115].

3.6.6 Evaluation of Accommodation Functions

a. **Accommodation Posture**: The assessment of accommodation accuracy was performed at the subjects' habitual near distance using the monocular estimation method (MEM). The MEM technique uses a specially made target with pictures or words suitable to the child's reading level. The card was attached to the retinoscope. The procedure was performed over subject's distance prescription and at his normal reading distance with enough light to provide a comfortable reading vision. Retinoscopy was performed on axis (right eye before left eye) as the child reads the words or describes the picture on the card aloud. As the retinoscopic reflexes were observed, an estimate of the magnitude of the motion was made and trial lenses were then interposed briefly (approximately 0.5 seconds) to avoid changing the child's accommodation status until no motion was observed. The lens power at which the motion was neutralized was taken as the lag or lead of accommodation. It is a lag of accommodation when the reflex is neutralized with positive lenses while it is called lead of accommodation if neutralized with negative lenses [112,113,116,117].

b. **Accommodation Facility**: this assesses the rate at which accommodation can be stimulated and relaxed repeatedly during a specific time period. It relates to the individual's ability to shift focus quickly and efficiently for varying distance. The procedure was performed with the best subjective correction in place monocularly and binocularly but only the result for the binocular assessment was utilized for the data analysis. According to Wick and Hall [120], binocular accommodative facility testing may not be a true accommodative facility measure such as monocular facility but clinically, binocular testing may be more useful because it gives a "real life" assessment of accommodation and binocular interactions of accommodation and vergence.

The target used was letters on a 6/9 range on a near point card and at the subject's habitual reading distance. A lens flipper of ± 2 diopter lenses was used. Letters and pictures used were appropriate to the child's ability. The subject was informed that he would be shown two different lenses and that one pair causes the system to work while the other pair relaxes it and was instructed to look at the materials as the lenses were flipped. Each time the print become clear and single he was to immediately report "clear". The lenses were flipped and child should report "clear" when the material gets clear. To ensure that subject understood the instructions, trial readings were first taken. The number of cycles completed per minute was recorded. One cycle meaning clearing both the plus and minus lens sides. The test was done binocularly[112-113,118-120] At near with no suppression control.

c. **Amplitude of Accommodation**: The amplitude of accommodation was assessed by Donder's push – up method using a Royal Airforce (RAF) near point rule; a rod with a movable target and metrics as well as dioptric marking. This procedure was performed monocular and binocularly. The subject was seated comfortably and instructed to read a line of letters on the card that corresponded to a visual acuity of 6/9 and told to keep the letters clear. The target was slowly moved towards the child along the rule until the child reported first sustained blur at which point the dioptric result was read off the Royal air force rule. Three readings were performed and an average taken. This test was conducted monocularly for each eye and then binocularly.

As reported by Wick and Hall [120] the minimum amplitude of accommodation expected is based on the subject's age and can be estimated from the Hofsetter's formula:
Minimum =15 - 0.25 (age)
Expected =18.5 - 0.3 (age)
Maximum = 25 - 0.4 (age)
The amplitude of accommodation was generally considered clinically important only when it falls below the expected age minimum [120].

d. **Relative Accommodation (RA):** Relative accommodation tests are plus-to-blur (negative relative accommodation) (NRA) and the minus-to-blur (positive relative accommodation) (PRA). The relative accommodation tests assess patients' ability to increase and decrease accommodation under binocular conditions when the total convergence demand is constant [106]. It is also an indirect assessment of the vergence system since the vergence demand remains constant while accommodative demand varies [121,122].

Relative accommodation was measured using the plus and minus lenses binocularly at near with distance subjective results in place [122]. In this procedure, the child viewed a reading target size letter size or picture of 6/6 size at the reading distance with the best subjective correction in place. Plus or minus lense powers was added in 0.25 diopter steps in approximately 2 seconds interval[121] to assess negative and positive accommodation respectively. This test was performed binocularly and the reading was taken when the subject reported a sustained blur. The relative accommodation is difficult to assess with trial lenses[121]. The trial lenses were used to assess relative accommodation in the present study. The use of the phoropter was not possible considering the study setting.

3.6.7 Fusional Reserves

The term fusional reserve is used synonymously with vergence reserves and prism vergence, vergence amplitude [121,123] or fusional amplitudes [111]. Vergence ability is measured using prisms placed in front of each eye. The amount of prism is increased gradually to measure the amount of fusional reserve the individual has in reserve to compensate for a phoria[112, 124]. The amount of base out prism required to produce diplopia is called positive fusional reserves or positive fusional vergence while the amount of base in prism required to produce diplopia is called the negative fusional reserves or negative fusional vergence [115].

Positive fusional vergence (convergence) and negative fusional vergence (divergence) were assessed using a prism bar in steps without suppression control although it has been reported by Wesson *et al* [125] that when suppression is controlled, the average vergence values will be lower because the test is stopped when the suppression is detected that is, if suppression is not monitored, the break is not detected until the stimulus is outside the suppression zone and a higher vergence value may be obtained. However,
Scheiman *et al* [126] argued that the significance of such suppression in binocular individuals is unknown.

Assessing fusional reserves in children with loose prism bars may be a better technique because it offers the possibility of viewing the eye movement objectively. Secondly, it removes the restriction imposed by testing children behind the phoropter. Finally, the test itself nearly duplicates the movement of the eyes under normal conditions allowing convergence or divergence in discrete steps rather than as a smooth-pursuit type vergence movement [125].

The test was performed with the target at six meters (test target 6/9 letter line) and at 40 cm (N5 text). The prism was placed in front of the right eye first. Base-in was routinely assessed first, the rational for this sequence of testing being that the convergence response stimulated during the base-out (or convergence) measurements may produce vergence adaptation (a fusional after-effect) which may temporarily bias the subsequent base in values in the base-out direction [127]. Typically, there is no blur point for base -in vergence testing at distance. This is because at distance, accommodation is already at a minimum and cannot relax beyond this point [115].

Base out prisms were used to measure positive fusional vergence while base in prisms were used to measure negative vergence. The subject was seated comfortably and instructed as follows: "I am measuring the ability of your ayes to converge and diverge". Watch the row of letters. Tell me when they first get blurry, if they do. Also tell me when they first become two rows of letters and when they become one again″. The prism was introduced over the right eye. 'Double' was first demonstrated to the child by placing a 20 diopter prism over one eye. If blur was reported, the prism power was increased until a break was reported. The prism power was then reduced until the subject reported that the rows of letters were single.

The technique was then repeated for base out prism and then the test was repeated at near. The break and recovery points were determined subjectively from the child's report of blur, break and recovery and objectively by observing the subjects eye movements. The objective findings were used for analysis.

3.6.8 Ocular Health

The only test performed to evaluate ocular health was direct ophthalmoscopy.

3.6.9 Vergence Facility

It was impossible to perform the vergence facility testing as the children could not fuse the base in prisms. So, vergence facility data was not available for analysis. The recovery point of the base in reserves may provide useful information on the vergence facility. According to Bishop [111], “blur and break points tend to reflect the quantity of fusion, whereas the recovery point indicates the quality of fusion, that is, the ease of change of fusional demands (facility) and the ability to maintain fusion (stamina)".

3.7 Statistical Analysis

The data entry was done by a staff optometrist who is skilled in statistical analysis. The data analysis was undertaken by the International Center for Eye Care Education statistician. Data was analyzed using the Statistical Package for Social Sciences (SPSS). Means, standard deviation and ranges were calculated for descriptive and comparative purposes at 95% confidence interval. The level of significance considered to support a hypothesis was taken as $P < 0.05$. For comparison, all data from both groups was subjected to a two-sample *t*-test (2-tailed) (Table 3.2). Participants who did not meet the pass criteria for any of the test variables were referred to their optometrist for further evaluation.

Table 3.2 The Diagnostic Criteria for Each Test Variable.

Variable	**Diagnostic Criteria**
Visual Acuity [128-131]	6/9

Refractive Errors [128-131]	
Hyperopia	≥ +0.75
Myopia	≥ -0.50
Astigmatism	≥ -0.75
Anisometropia	≥ 0.75 between the two eyes
Emmetropia	< - 0.50DS, < +1.00DS, < -0.75DCyl
Near Point of Convergence [132-134]	≥ 10cm
Accuracy of Accommodation [116,117,119,120]	Lag: ≥ +0.75. Lead: any minus finding
Accommodative Infacility [118,119]	> 7cycles per minute in response to +2 /-2.00 flipper testing, binocularly at near
Amplitude of Accommodation [106,119,120]	Binocular accommodative amplitude ≥ 2D below the expected value for the patients' age for minimum amplitude (using Hofsetter's formula) (15-1/4age).
Positive Relative Accommodation [106,121,122,124].	> - 2.37DS.
Negative Relative Accommodation [106,121,122,124]	> + 2 DS
Phoria [106,128]	
Distance	> 6 prism diopters exophoria or 4 prism diopters esophoria
Near	> 6 prism diopters exophoria or 4 prism diopters esophoria
Strabismus [131,135]	Manifest or intermittent manifest deviation of > 2 prism dioptres [135] or asymmetry in Purkinje reflex or compensating fixation; a misalignment of ≥ 2.5 degrees [131].
Fusional Reserves Limits	
Distance [119]	Base in: Blur X, Break 6, Recovery 4. Base out: Blur 10, Break, 16 Recovery 10.
Near [106,121,126]	Base in: Blur 14 ± 4, Break12 ± 5, Recovery 7± 4. Base out: Blur 22 ± 8, Break 23 ± 8, Recovery 16 ± 6.

3.8 SUMMARY

The study consisted of two groups of 31 participants from two schools in Durban. The study group was children with learning difficulties from which the dyslexic children were selected, and the control group was selected from a mainstream school. The mean age for the dyslexic participants were 13 years while the mean age of the children from the control group was 11 years and 9 months. A convenience sampling method was adopted to select the study participants due to the limited number of subjects to select from.

The vision functions investigated may be divided into three broad areas of visual acuity and refraction, binocular vision and ocular pathology, which corresponds with areas of vision function investigated in the literature review. Standard optometric testing procedures were used to assess the vision variables.

Visual acuity was assessed using the LogMAR chart, at both distance and near. Refractive error was determined objectively using a streak retinoscope (without cycloplegia) while the child fixated a 6/60 optotype at 6 meters with a fogging lens to control accommodation.

The near point of convergence was measured using the Royal Air force rule (RAF). Ocular alignment was assessed using the cover test at six meters and 40cm for distance and near respectively. For distance cover test, the test target was a letter from the line above the subject's best visual acuity of the worse eye. The cover/uncover (unilateral) cover test was performed to determine the presence of a phoria or tropia. The alternating cover test was performed to assess the direction and magnitude of the phoria or tropia. The test conditions were the same as the unilateral cover test. The Maddox Wing was also used to assess near phoria under normal room illumination. Strabismus was assessed using the Hirschberg test with a penlight held about 50cm from the child's face in the mid plane and was encouraged to fixate the light with both eyes open. The location of the corneal reflection on each cornea relative to the centre of the pupil was then noted.

The different aspects of accommodation functions were also measured. The assessment of accommodation accuracy was performed at the subjects' habitual near distance using the monocular estimation method (MEM). The accommodation facility was assessed using a ± 2 diopter lens flipper with the best subjective correction in place. The target used was letters on a 6/9 range on a near point card and at the subject's habitual reading distance. The amplitude of accommodation was assessed by Donder's push – up method using a Royal Airforce (RAF) near point rule. This procedure was performed monocular and binocularly with a 6/9 visual acuity as the test target. The relative accommodation was measured using the plus and minus lenses. The test target is a reading letter target size or picture of 6/6 size at the reading distance with best the subjective correction in place. This test was performed binocularly and the reading was taken when the subject reported a sustained blur.

The fusional reserves were assessed using prism bars in steps without suppression control. The test was performed at 6 meters (test target 6/9 letter line) and at 40 cm (N5 text). Base out prisms were used to measure positive fusional vergence while base in prisms were used to measure negative vergence. Ocular health evaluation was assessed using the direct ophthalmoscope.

Data was analyzed using the Statistical Package for Social Sciences (SPSS). Means, standard deviation and ranges were calculated for descriptive and comparative purposes at 95% confidence interval. The level of significance considered to support a hypothesis was taken as $P < 0.05$. To compare the data from both groups, all data was subjected to a two sample t-test (2-tailed). The methods used in this study were the same as those used for similar tests in the international literature reviewed in Chapter Two and the sample size was larger than most of the studies presented.

Chapter Four will outline the study results with the comparative and descriptive statistical analysis.

CHAPTER FOUR: RESULTS

4.1 Introduction

This chapter presents the study findings and the analysis of results obtained. The data for the prevalence of visual acuity, refractive errors, near point of convergence, accommodation functions and heterophoria are presented in histogram while the descriptive statistics are presented in tables.

4.2 Prevalence of Vision Defects

The prevalence is an indication of the subjects that have either achieved or did not achieve the pass fail criteria and is not a normal distribution of a particular condition. The prevalence rate of the vision functions is expressed in percentages. The other data is expressed as mean (M) and standard deviation (SD) and calculated for descriptive purposes at 95% confidence interval (CI).

If an association between visual function and dyslexia exists, a higher prevalence of vision defects in dyslexic children than in the non-dyslexic participants would be expected.

4.2.1 Visual Acuity (VA)

i. **Dyslexic Group:** In total, 32% of subjects in the dyslexic group had visual acuity less than 6/9 while 68 % had visual acuity of 6/6 and 6/5. The distribution of those subjects with VA ≤ 6/9 is as follows: 6.5% (2 subjects) had V/As of 6/9. 6.5% (2 subjects) had V/A of 6/12, 6.5% (2 subjects) had V/A of 6/15, 3% (1 subject) had V/A of 6/30, 3% (1 subject) each had V/A of 6/38, 6/48, 6/60 respectively (Fig 4.1).

ii. Control Group: In total, 32% of subjects in the control group had visual acuity less than 6/9 while 68% had visual acuity of 6/6. The distribution is as follows: 3% (1 subject) each had V/A of 6/9, 6/12, 6/15, 6/24 while 6.5% (2 subjects) had V/A of 6/30, 6/38 and 6/48 respectively (Fig 4.1).

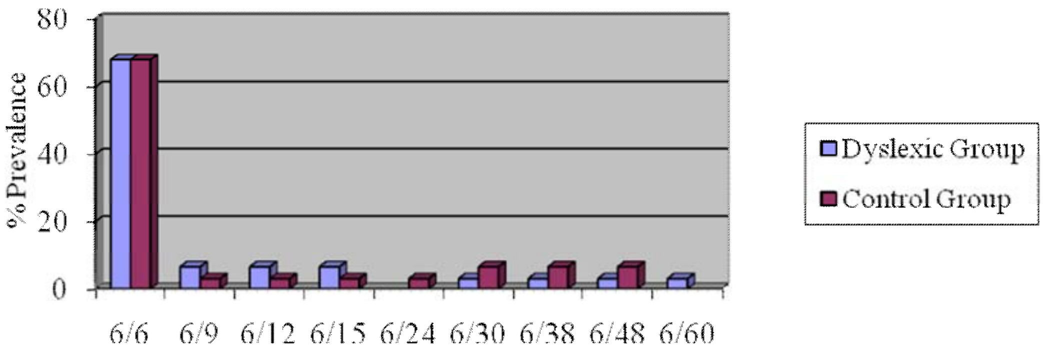

Fig 4.1 Prevalence of Visual Acuity

The mean visual acuity for the right eye for the dyslexic group was 0.17 ± 0.31 and 0.00 ± 0.24 for the right eye for the control group. There was no statistically significant difference between the two groups (*p = 0.29*). (Table 4.1) The mean visual acuity for the left eye for the dyslexic group was 0.20 ± 0.33 and 0.00 ± 0.24 for the control group. There was no statistically significant difference between the groups (*p = 0.23*) (Table 4.1). LogMAR acuity of 0.20 is equivalent to 6/9 in Snellen's notation (Appendix E. Visual acuity conversion table).

Table 4.1 Descriptive Statistics for Visual Acuity

Variable	**Group**	**N**	**(95% CI)**		**Minimum**	**Maximum**	***p***
			Mean (LogMAR)	**SD**			
V/Acuity							
RE	Dyslexic	31	0.17	0.31	0.00	0.10	0.29
	Control	31	0.00	0.24	0.00	0.90	
LE	Dyslexic	31	0.20	0.33	0.00	1.00	0.23
	Control	31	0.00	0.24	0.00	0.90	

4.2.2 Refractive Error.

i. **Dyslexic Group:** Twenty three percent (23%) of the dyslexic subjects had refractive errors while seventy seven percent (77%) were emmetropic (defined as retinosocpic findings of less than 0.5 myopia, less than +0.75 hyperopia or less than 0.75 astigmatism) (Fig 4.2). The distribution is as follows: 6.5% (2 subjects) had myopia, 6.5% (2 subjects) had hyperopia (both latent). As cycloplegia was not used in assessing refractive error, an estimate of the diagnosis of latent hyperopia was made based on a high difference between the retinoscopic findings and the subjective refraction results. In the event that the increased retinoscopic finding (that is, more plus) did not blur the subjects' vision, latent hyperopia was assumed. About 10% (3 subjects) had hyperopic astigmatism, 6.5% (2 subjects) had amblyopia (defined as visual acuity in either eye of 20/40 or a two-line difference in acuity between the two eyes with no improvement with pinhole) [141] and 6.5% (2 subjects) had anisometropia (defined as a difference of ≥ 0.75 in sphere or cylinder between the two eyes) (Fig 4.3).

ii. **Control Group:** Twenty two and a half percent (22.5%) of the participants from the control group had refractive errors classified as follows: 6.5% (2 subjects) had myopia, 3% (1 subject) had hyperopia, and 13% (4 subjects) had astigmatism and 6.5% (2 subjects) had anisometropia. No participant had amblyopia.

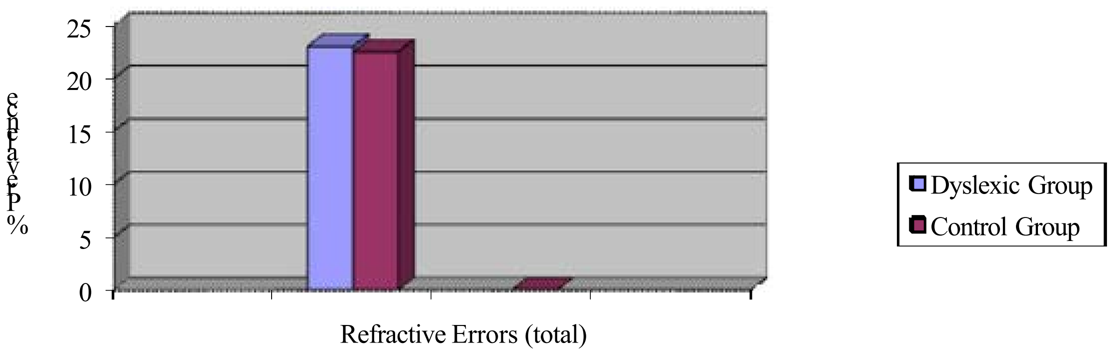

Fig 4.2 Prevalence of Refractive Errors (total

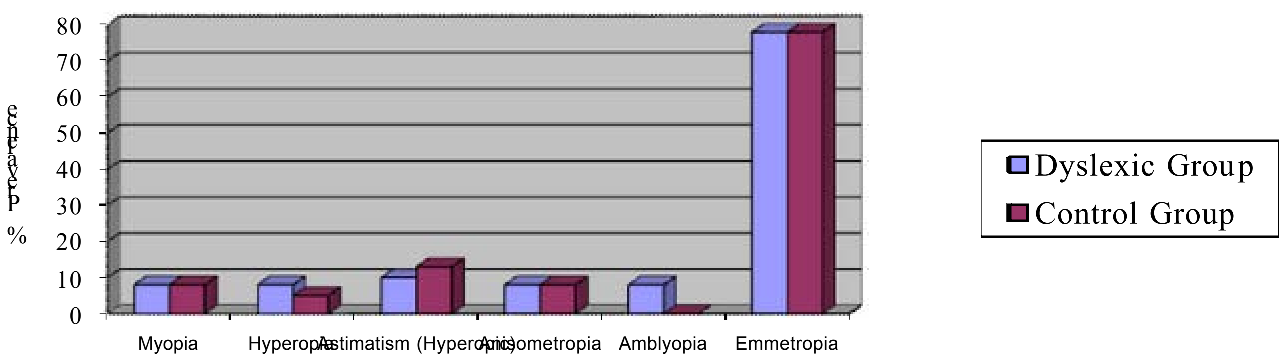

Fig 4.3 Prevalence of the Types of Refractive Errors

Refraction data for two children from the dyslexic group who had cataracts could not be obtained due to poor reflexes and were excluded from the analysis.

The mean spherical equivalent (SE) refraction for the right eye for the dyslexic group was 0.86 ± 0.98 and 0.70 ± 1.03 for the control group was. There was no statistically significant differences between the two groups (*p=0.66*). The mean spherical equivalent refraction of the left eye for the dyslexic group was 0.57 ± 1.01 and 0.49 ±1.09 for the control group. There was no statistically significant difference between the two groups (*p= 0.92)* (Table 4.2).

Table 4.2 Descriptive Statistics for Refractive Error

Variable	**Group**	**N**	**(95% CI)**		**Minimum**	**Maximum**	***p***
			Mean	**SD**			
RE (SE)	Dyslexic	29	0.86	0.98	-1.25	5.00	0.66
	Control	31	0.70	1.03	-3.50	3.50	
LE (SE)							
	Dyslexic	29	0.57	1.01	-1.50	4.00	0.92
	Control	31	0.49	1.09	-3.50	3.50	

4.2.3 Near Point of Convergence

i.. **Dyslexic Group:** Thirty three percent (33%, 10 subjects) had NPC break points (objective) of greater than or equal to 10cm while about sixty seven percent 67% (20 subjects) had NPCs of less than 10cm (Fig 4.4). One child complained of being tired and did not participate in this procedure, and was therefore excluded.

ii. **Control Group:** Forty eight percent (48%, 15 subjects) had NPC break point (objective) of greater than or equal to 10cm. Fifty two percent (16 subjects) had

NPC less than 10cm (Fig 4.4). Data on NPC for one child from the dyslexic group was lost.

The mean NPC break was 8.90 ± 5.03 for the dyslexic group and 12.60 ± 8.70 for the control. There was a statistically significant difference between the two groups (*p = 0.049*). The mean NPC recovery was 14.00 ± 5.88 for the dyslexics and 22.00 ± 8.20 for the control group. There was a statistically significant difference between the two groups (*p = 0.06*) (Table 4.3).

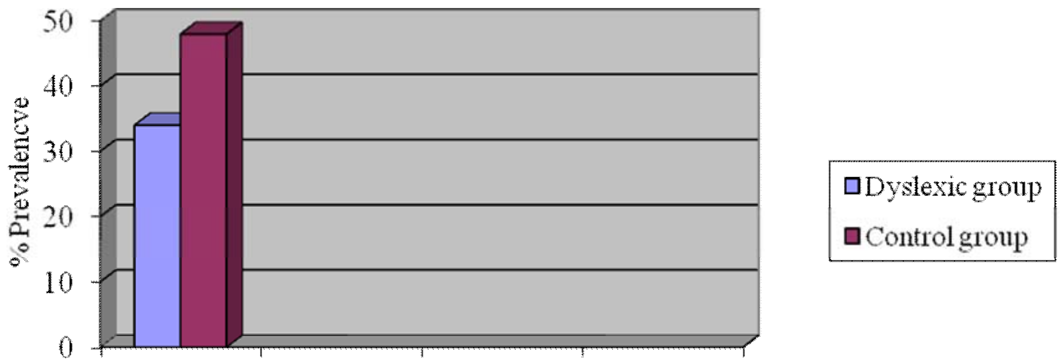

Fig 4.4 Prevalence of NPC breaks (>10cm)

Table 4.3 Descriptive Statistics for NPC Break and Recovery Points

Variable	Group	N	(95 % CI)		Minimum	Maximum	P
			Mean	SD			
NPC Break	Dyslexic	30	8.90	5.03	5.00	26.00	0.49
	Control	30	12.60	8.70	4.00	34.00	
NPC Recovery	Dyslexic	30	14.00	5.88	6.00	28.00	0.06
	Control	30	22.00	8.20	8.00	38.00	

4.2.4 Ocular Health

Six and a half percent (2 subjects) in the dyslexic group had cataracts (unclassified) on both eyes. No pathology was detected in the control group.

4.2.5 Heterophoria

i. **Dyslexic Group:** No subject in the dyslexic group manifested with a phoria at distance.

At near, 3% (1 subject) had an esophoria greater than or equal to 4 prism diopters, 3% (1 subject) had an esophoria of 3 prism diopters, 6.5% (2 subjects) had exophorias of greater than or equal to 4 prism diopters, 3% (1 subject) had an exophoria greater than or equal to 8 prism dioptres and 6.5% (2 subjects) had exophorias of 6 prism diopters. (Fig 4.5).

ii. **Control Group:** At both distance and near, no subject in the control group had phoria of greater than 2 prism diopters.

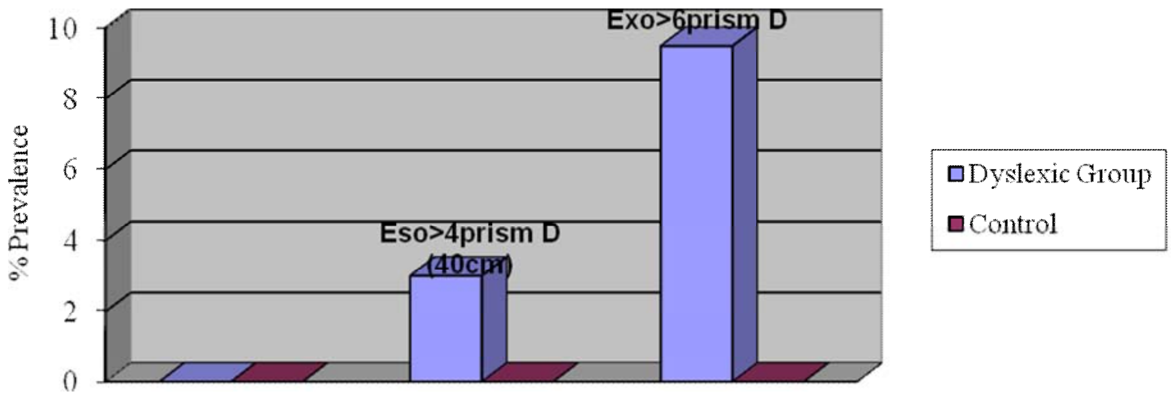

Fig 4.5 Prevalence of Phoria at Near (40cm) with Maddox Wing.

Four children from each group could not complete the test as they left to attend lessons. The mean exophoria for the dyslexic group was 1.63 ± 2.61 and 1.80 ± 0.42 for the control group. There was no statistically significant difference between the two groups (*p = 0.59)*. The mean esophoria for the dyslexic group was 3.50 ± 0.70 and 2 ± 0.00 for the control group. There was no statistically significant difference between the two groups (*p= 0.46)* (Table 4.4). No tropias were observed.

Table 4.4 Descriptive Statistics for Heterophoria

Variable	Group	N	(95% CI)	Min	Maxi	P

			Mean	SD			
At Near	Dyslexic	27	1.63	2.61	0.00	10.00	*0.59*
Exophoria	Control	27	1.80	0.42	1.00	2.00	
	Dyslexic	27	3.50	0.70	3.00	4.00	0.469
Esophoria	Control	27	2.00	0.00	2.00	2.00	

4.2.6 Accommodation Functions

a. **Accommodation Posture:** As shown in Figure 4.6, the distribution of accommodation lag is as follows:

i. **Dyslexic Group**

Thirty nine percent (11 subjects) had a lag of accommodation (defined as + 0.75 or greater), three and a half percent (1 subject) had lead of accommodation (defined as - 0.25 or greater) while fifty seven percent had normal accommodation posture.

ii. **Control Group**

Forty two percent (13 subjects) had lag of accommodation. About eleven percent (11%) (3 subjects) had lead of accommodation while about thirty nine percent had normal accommodation posture.

Three children from the dyslexic group could not continue with this test as they had to leave to attend class activities, while three children from the control group sought permission to be out of the testing room at that point. These children were excluded from the analysis for binocular accommodation lag.

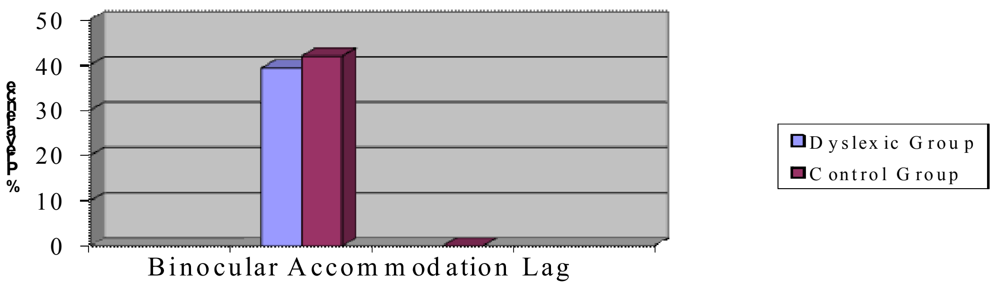

Fig 4.6. Prevalence of Accommodation Lag (≥+0.75)

The mean accommodation lag for the right eye was 0.91 ± 0.38 for the dyslexic group and 0.92 ± 0.57 for the right eye for the control group. There was no statistically significant differences between the two groups (*p =0.83)*. The mean for the left eye for the dyslexic group was 0.85 ± 0.36 and 0.91 ± 0.48 for the control group. There was no statistically significant difference between the two groups (*p = 0.61)* (Table 4.5).

Table 4.5 Descriptive Statistics for Accommodative Posture

Variable	Group	N	(95 % CI) Mean	SD	Minimum	Maximum	P
Accomm lag RE	Dyslexic	28	0.91	0.38	0.00	2.00	0.83
	Control	28	0.92	0.57	-0.50	2.00	
LE	Dyslexic	28	0.85	0.36	-0.50	1.25	0.61
	Control	28	0.91	0.48	-0.50	2.00	

b. **Accommodative Facility:** As shown in Figure 4.7 the distribution of accommodation facility was as follows:

i. <u>Dyslexic Group</u>

Forty six percent (46%, 13 subjects) had normal accommodative facility (defined as greater than 7cpm) binocularly at near while (54%) (15 subjects) had accommodation facility less than or equal to 7cpm (Fig 4.7).

ii. Control Group

Sixty seven percent (67%) (18 subjects) had normal accommodative facility (defined as greater than 7cpm) while thirty three percent (33%) (9 subjects) had accommodation facility less than 7cpm.

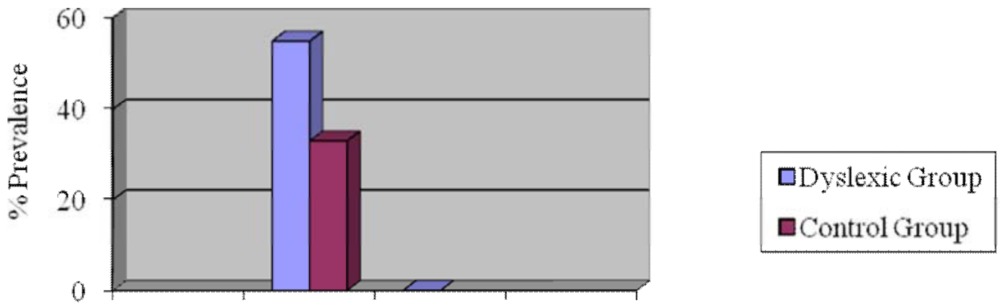

Fig 4.7 Prevalence of Reduced Binocular Accoommodation Facility at near(<7cpm)

Three children from the dyslexic group and four from the control did not complete the test as they indicated that they were tired. The mean binocular accommodation facility was 6.86 cpm ± 2.74 for the dyslexic group and 8.85 ± 3.69 for the control group. There was a statistically significant difference between the two groups (*p=0.027)* (Table 4.6).

Table 4.6 Descriptive Statistics for Binocular Accommodative Facility

Variable	Group	N	(95% CI)		Minimum	Maximum	*p*
			Mean	SD			
Accommodative Facility at near	Dyslexic BE	28	6.86	2.74	2	12	0.02
	Control BE	27	8.85	3.69	2	21	7

c. **Amplitude of Accommodation:** Monocular amplitude of accommodation in both eyes and for both groups did not differ significantly (not more than 0.50D) except for one subject who had a difference of 4 diopters between the two eyes. The amplitude of accommodation for two subjects who had latent hyperopia in the dyslexic group was relatively low (6.00DS and 8.00DS) as compared to age minimum amplitude of accommodation of 11.75DS. The amplitude of accommodation for two participants who had cataracts were excluded from the analysis.

Only the data for the monocular amplitude was analyzed. When accommodation amplitude is assessed monocularly, it measures the response for each eye individually and is particularly important to determine whether a patient has accommodative insufficiency [133]. The monocular amplitude of accommodation has been used to assess amplitude of accommodation function in several studies [86, 88,100,102-103]. The mean for the right eye for the dyslexic group was 11.98 ± 2.34 and 12.87 ± 1.08 for the control group. There was no statistically significant difference between the two groups (*p =0.07*) (Table 4.7). The mean for the left eye for the dyslexic group was 12.14 ± 2.14 and 12.87 ± 1.16 for the control group. There was no statistically significant difference between the two groups (*p =0.22)* (Table 4.7).

Table 4.7 Descriptive Statistics for Amplitude of Accommodation

Variable	Eye	Group	N	(95% CI)		Minimum	Maximum	*p*
				Mean	**SD**			
Amplit of Acomm	RE	Dyslexic	29	11.98	2.34	8	20	
		Control	31	12.87	1.08	10	15	0.07
	LE	Dyslexic	29	12.14	2.15	8	20	
		Control	31	12.87	1.16	10	15	0.22

d. **Relative Accommodation (NRA, PRA):** As shown in Fig 4.8 the results for the relative accommodation were as follows:

For the PRA, all subjects in both groups had PRAs of more than -2.00DS. For the negative relative accommodation (NRA), 89% of the dyslexic subjects had NRA greater than +2.00DS while 96% of subjects from the control group had NRA greater than +2.00DS.

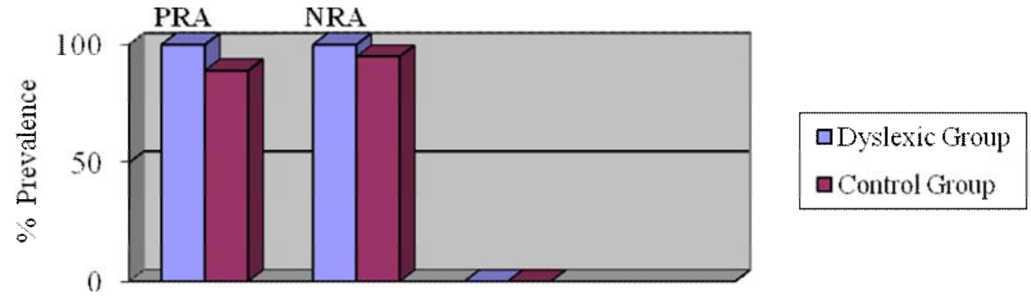

Fig 4.8. Prevalence of Relative Accommodation (NRA.+2,PRA,.-2.00)

Three children from the dyslexic group and five from the control group could not continue with the test for the assessment of relative accommodation as they had to attend important class activities.

The mean PRA for the dyslexic group was -6.23 ± 1.17 and -6.06 ± 0.63 for the control group. There was no statistically significant difference between the two groups (*p =0.51)*. The mean NRA for the dyslexic group was 3.22 ± 0.79 and 3.11 ± 0.47 for the control group. There was no statistically significant difference between the two groups *(p =0.68)*(Table 4.8). The findings for RA were higher than the published norm. This may be due to the process of addition of trial lenses.

Table 4.8 Descriptive Statistics for Relative Accommodation

Variable	**Group**	**N**	**(95% CI)**		**Minimum**	**Maximum**	***p***
			Mean	**SD**			
PRA	Dyslexic	28	-6,23	1.17	-9.00	-4.00	0.51
	Control	26	-6,06	0.63	-7.00	-5.00	
N RA	Dyslexic	28	3.22	0.79	2.00	6.00	0.68
	Control	26	3.11	0.47	2.00	4.5	

4.2.7 Fusional Reserves

The children in both groups either could not report or understand blur so the result for break and recovery was used in all analysis of vergence function.

a. **Base-in Vergence Reserves at Distance:** two children from the dyslexic group could not complete all aspects of the fusional reserves assessment because they were tired. These children were excluded in the analysis.

The mean base-in to break for the dyslexic group was 14.69 ± 6.83 and 16.00 ± 3.50 for the control group. There was no statistically significant difference between the two groups (*p =0.46)*. The mean base in to recovery for the dyslexics was 11.72 ± 6.20 and 12.80 ± 3.17 for the control group. There was no statistically significant difference between the two groups (*p =0.49)* (Table 4.9).

Table 4.9 Descriptive Statistics for Base-in Vergence Reserves at distance

Variable	**Group**	**N**	**(95% CI)**		**Minimum**	**Maximum**	**P**
			Mean	**SD**			
BI to Break (dist)	Dyslexic	29	14.69	6.83	4	40	0.46
	Control	31	16.00	3.50	10	22	
BI to Recovery (distance)	Dyslexics	29	11.72	6.20	2	35	0.49
	Control	31	12.80	3.17	8	20	

b. **Base-in Vergence Reserve at Near:** The mean base in to break at near was 11.85 ± 5.14 for the dyslexics and 12.83 ± 3.13 for the control group. There was no statistically significant difference between the two groups (*p=0.29)*. The mean base in to recovery was 8.72 ± 4.78 for the dyslexics and 10.32 ±3.35 for the control group. There were no statistically significant differences between the two groups (*p=0.17)* (Table 4.10).

Table 4.10 Descriptive Statistics for Base-in Vergence Reserves for Near.

Variable	**Group**	**N**	**(95% CI)**		**Minimum**	**Maximum**	***P***
			Mean	**SD**			
BI to Break (near)	Dyslexic	29	11.85	5.14	2	25	0.29
	Control	31	12.83	3.13	6	18	
BI to Recovery (near)	Dyslexic	29	8.72	4.78	1	20	0.17
	Control	31	10.32	3.35	4	15	

c. **Base-out (BO) Vergence Reserves at Distance:** Four children from the control group could not give a report on the recovery point. Two children from the dyslexic group could not complete the test. The mean base out to break at distance for the dyslexic group was 27.06 ± 9.25 and 24.16 ± 9.75 for the control group. There was no statistically significant difference between the two groups (*p=0.24)*. The mean BO to recovery for the dyslexic group was 18.76 ± 7.96 and 17 ± 6.93 for the control group. There was no statistically significant difference between the two groups (*p= 0.40)* (Table 4.11).

Table 4.11 Descriptive Statistics for Base-out Vergence Reserves at Distance.

Variable	**Group**	**N**	**(95% CI)**		**Minimum**	**Maximum**	**p**
			Mean	**SD**			
BO to Break (Distance)	Dyslexic	29	27.06	9.25	10.00	0.00	0.24
	Control	31	24.16	9.75	10.00	40.00	
BO to Recovery (dist)	Dyslexics	29	18.76	7.96	4.00	35.00	0.40
	Control	27	17.00	6.93	6.00	35.00	

d. **Base-out Vergence Reserves at Near:** The mean base-out to break at near was 21.60 ± 11.62 for the dyslexic group and 21.09 ± 8.42 for the control group. There was no statistically significant difference between the two groups (*p =0.84)*. The mean base-out to recovery at near for the dyslexic group was 13.35 ± 7.45 and 15.55 ± 6.25 for the control group. There was no statistically significant difference between the two groups (*p =0.16)* (Table 4.12). The comparative and descriptive statistsics for all variables is shown in Table 4.13

Table 4.12 Descriptive statistics for base-out vergences at near.

Variable	**Group**	**N**	**(95% CI)**		**Minimum**	**Maximum**	***P***
			Mean	**SD**			
BO to Break (near)	Dyslexic	29	21.60	11.62	8.00	40	0.84
	Control	31	21.09	8.42	10.00	40	
BO to Recovery (near)	Dyslexic	29	13.35	7.45	6.00	35	0.16
	Control	31	15.55	6.25	8.00	30	

Table 4.13 Comparative Descriptive Statistics for Dysleixc and Control groups.

Variable	Dyslexics (95% CI)			Control (95% CI)			
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	***P***
Visual Acuity							
RE	31	0.17	0.31	31	0.00	0.24	0.29
LE	31	0.20	0.33	31	0.00	0.24	0.23
Refractive Error							
RE	29	0.86	0.98	31	0.70	1.03	0.66
LE	29	0.57	1.01	31	0.49	1.09	0.09
NPC Break	30	8.90	5.03	31	12.60	8.70	0.49
NPC Recovery	30	14	5.88	31	22.00	8.20	0.06
Heterophoria (Near)							
Exo	27	1.63	2.61	27	1.80	0.42	0.59
Eso	27	3.50	0.70	27	2.00	0.00	0.46
PRA	28	-6.23	1.17	26	-6.06	0.63	0.51
NRA	28	3.22	0.79	26	3.11	0.47	0.68
Amp of Accommodation							
RE	29	11.98	2.34	31	12.87	1.08	0.07
LE	29	12.14	2.15	31	12.87	1.16	0.22
Accom Facility (bin)	28	6.86	2.74	27	8.85	3.69	0.03
Accomm Lag							
RE	28	0.91	0.38	31	0.92	0.57	0.83
LE	28	0.85	0.36	31	0.91	0.48	0.61
BI Break (Dist)	29	14.69	6.83	31	16.00	3.50	0.46
BI Recovery (Dist)	29	11.72	6.20	31	12.80	3.17	0.49
BI Break (Near)	29	11.85	5.14	31	12.83	3.13	0.29
BI Recovery (Near)	29	8.72	4.78	31	10.32	3.35	0.17
BO Break (Distance)	29	27.06	9.25	31	24.16	9.75	0.24
BO Recovery (Distance)	29	18.76	7.96	31	17.00	6.93	0.40
BO Break (Near)	29	21.60	11.62	31	21.09	8.42	0.84
BO Recovery (Near)	29	13.35	7. 45	31	15.55	6.25	0.16

Summary

Statistical tests were performed on the data to ensure scientific validity and were presented for comparative and descriptive purposes. The prevalence of visual acuity was similar between the dyslexic and control groups and there was no statistically significant difference between the two groups ($p = 0.29$ right eye, *0.23*, left eye).

The prevalence of total refractive errors was similar between the two groups and there was no statistically significant difference between the two groups. (p = 0.66 right eye and 0.92 left eye). Hyperopia was slightly more prevalent in the dyslexic group than in the control group. The prevalence of myopia was the same in both groups. Astigmatism was more prevalent in the control group than in the dyslexic group. The prevalence of anisometropia was the same in both groups. Amblyopia was more prevalent in the dyslexic group compared to the control group.

The control group had a higher near point of convergence break and recovery points than the dyslexic group. The NPC showed a statistically significant difference between the two groups, NPC break ($p = 0.049$) and NPC recovery ($p = 0.006$). The prevalence of exophoria at near was higher in the dyslexic than the control group. There was no statistically significant difference between the two groups ($p = 0.59$). The prevalence of esophoria in the dyslexic group was higher than that found in the control group but there was no statistically significant difference ($p = 0.46$).

The prevalence of relative accommodation was similar in both groups and there was no statistically significant difference between the groups. The dyslexic group had a reduced amplitude of accommodation compared to the control group and there was no statistically significant difference between the two groups ($p=0.07$ right eye and$p = 0.22$, left eye). The dyslexic subjects performed significantly worse than the control subjects in accommodative facility function and there was a significant difference between the two groups ($p = 0.027$). The dyslexic subjects had a lower accommodation lag than the subjects from the control group. There were no statistically significant differences between the two groups, right eye ($p = 0.83$) and left eye ($p = 0.60$).

At near, the negative fusional vergence (base in vergences)) was reduced in the dyslexics compared to the control group while the positive fusional vergence (base out vergences) was similar for both groups. There was no statistically significant difference between the groups.

($p = 0.21$ for BI break at near) and ($p = 0.84$ for BO break at near). Having analyzed the results, Chapter Five will discuss the findings in the context of the international studies reviewed in the literature.

CHAPTER FIVE: DISCUSSION

5.1 Introduction

A review of the literature reveals that studies, [2,3,5,6,87,89,90] conducted on dyslexic children have investigated the prevalence of vision defects in the dyslexic population and examined whether such vision anomalies are correlated with dyslexia by comparing vision characteristics in dyslexic subjects to normal readers.

The aim of this study was to determine the prevalence of vision defects in a South African population of the dyslexic school children and investigate the relationship between vision and dyslexia by comparing the vision characteristics of the dyslexic to the control group of learners from a mainstream school. The proposed null hypothesis was that there was no statistically significant difference between the means of the vision functions in the dyslexic population compared to the control group. A discussion of the results of this study is presented.

5.2 Prevalence of Vision Defects

5.2.1 Visual Acuity

The 32 % prevalence of visual acuity worse than 6/9 was the same for both groups. A reduced visual acuity could be due to ocular abnormality (such as cataract) or due to normal refractive error differences in the population. Visual acuity defects due to ocular diseases are usually not common in paediatric populations[142] but tend to be related to refractive error changes in the population[143]. This relates more in the present study as the prevalence of defects of visual acuity and the total refractive errors were similar. Consequently, in relating visual acuity to refractive errors, myopia, astigmatism and hyperopia may reduce distance or near visual acuity.

Visual acuity testing is widely performed in screening, refraction, and monitoring of disease progression. It is also used in both basic and clinical vision research as a way to characterize participants' visual resolving capacities[144]. Specific to the present study, visual acuity testing helps detect visual problems at the distances at which most school learning activities occur and gives useful preliminary information on how good or poor a child's vision is; reduced distance or near visual acuity gives an indication of poor vision that will necessitate further examination. However, in assessing how visual acuity relates to reading performance, it is important to note that visual acuity as measured with the traditional letter identification only assesses the ability to discern letters on the visual acuity charts and does not assess dynamic vision behaviour, binocular eye control or ocular stress and so may not necessarily mean normal vision. Furthermore, normal visual acuity may not necessarily mean normal vision since some people may have other vision defects such as color vision or reduced contrast or inability to track fast-moving objects and still have normal visual acuity. The reason visual acuity is very widely used is that it is a test that corresponds very well with the normal daily activities a person can handle, and evaluates their impairment to do them [145].

In relation to previous studies, the visual acuity findings in this study are similar to reports by Buzzelli [6], Goulandris *et al* [90] and Metsing and Ferreira [103]. On the contrary, Hoffman [83] found a lower prevalence (10.28%) of visual acuity worse than 6/9 in a group of learning disabled children. In contrast to the present study, however, the mean age of subjects in Hoffman's study was 8 years 6 months while the mean age in the present study was 13 for dyslexics and 11years 9 months for the control group. Grönlund *et al* [140] documented that age must be taken into consideration when describing and comparing VA in different populationsbecause VA develops from birth to adolescence. A lower prevalence (10%) of visual acuity worse than 6/9 was also reported by Sherman[84]. Latvala *et al* [3] reported a slightly worse distance acuity in the dyslexic group than in the control group but noted no statistically significant difference. Evans *et al* [5] found that dyslexic groups had a significantly worse visual acuity than the control group (Binocular distance VA, $p = 0.0164$ and binocular near VA, $p = 0.0018$). Similarly, Ygge *et al*[2] reported that the subjects from the control group had a better visual acuity than the dyslexic group at both distance and near and that the results showed statistically significant differences (distance at $p = 0.03$) (near at $p = 0.005$). Bucci *et al* [89] and Kapoula *et al* [87] reported the prevalence of visual acuity of all participants in their study to be normal. A study conducted by Grisham *et al* [86] lacked a control group but it was reported that 56.8% of the participants had 6/6 acuity in both eyes (compared to 68% in dyslexic group in the present study), 17.2% had 6/9 or worse (compared to a total of 31.5% who had visual acuity of 6/9 and worse in the present study). The mean age of the participants in the study by Grisham *et al* [86] was 15.4 years while the mean age of the participants in the dyslexic group in the present study was 13 years.

The factors which may affect the outcome of visual acuity measurements that may lead to variations in results reported by different authors include: size, position and distribution of retinal mosaics (retinal photoreceptors) [143], optical aberration, pupil size, clarity of the optical media, age, method and type of chart used, contrast, isolated or multiple letters, state of accommodation, illumination as well as the criteria used to define visual acuity[114, 140]. Psychological factors affecting visual acuity testing results include, blur interpretation, fatigue and malingering [143]. These factors may be difficult to control and could constitute confounding variables which may lead to variations in visual acuity results reported by different authors.

5.2.2 Refractive Error

The prevalence of uncorrected refractive error of 23% found in the dyslexic group was similar to the 22.5% found in the control group and there was no statistically significant difference between both groups ($p = 0.66$ right eye, $p = 0.92$ left eye). This finding may mean that the dyslexic subjects are not at more risk of a particular refractive anomaly compared to participants from the control group as the dyslelxic gourp has similar distribution of refractive errors.

Some studies [5,83,84,98,103,146] did not classify refractive error according to the types but presented the results for the total refractive error. On this basis, the prevalence of total refractive error (23% for dyslexic and 22.5% for the control group) in the present study is similar to reports by other studies: Hoffman[83] reported a 21.5% prevalence of refractive error in a study of the incidence of vision difficulties in learning disabled children. Although there was a marked difference in the sample size in both studies, the similarities in the findings may be because as with the present study, Hoffman's study was based on a population of learners in a special school referred for optometric care by educators, psychologists and reading specialists.

Similar to the present study, Evans *et al* [5] and Ygge *et al* [2] reported that the prevalence of refractive errors in the dyslexic and control groups was similar. Metsing and Ferreira[103] found no statistically significant difference between the learning disabled and the mainstream groups in their study. Contrasting findings were reported by Sucher and Stewart [98] who found the prevalence of refractive errors to be 9.4% for the control group although the 20.8% found in their dyslexic group is similar to the 23% found in the present study. Wesson [146] reported the prevalence of refractive error in children with reading dysfunction to be 38% while the prevalence of refractive errors was 16% in the study by Sherman [84]. In the study by Alvarez and Puell [88], the prevalence of refractive error was 42.4% in the dyslexic group while 41.5% of the control group had refractive error. When compared to the present study, the higher prevalence of refractive error in the dyslexic group can be accounted for by the relatively high prevalence of hyperopia (28.7%) and in the control group, the higher prevalence of refractive error can be accounted for by the high prevalence of myopia (19.4%). It is unclear why the prevalence of hyperopia was as high as no information was given on how refractive error was assessed.

Statistically, for the present study, the mean refractive errors for the dyslexic group were right eye: 0.86 ± 0.98, left eye: 0.57 ± 1.013 and: right eye; 0.70 ±1.03, left eye 0.49 ± 1.09 for the control group. There was no statistically significant difference (RE: $p = 0.66$, LE: $p = 0.92$). Evans *et al* [91] reported a mean spherical refractive error of 0.77DS (right and left eye similar). In the study by Alvarez and Puell [88], the refractive error results (descriptive statistics) reported were as follows: for the poor readers, mean spherical equivalent refractive errors for the right and left eye were 0.20 ± 0.6 and 0.20 ± 0.6 respectively. In the control group, mean spherical equivalent refractive errors for the right and left eye were - 0.20 ± 0.8 and - 0.14 ± 0.8 respectively. The descriptive statistics on refractive errors was not reported in the studies [3, 93] cited earlier which made it impossible to compare the statistical findings with the present study.

In the present study, about 68% of participants from both groups were emmetropic (defined as < -0.50DS, +1.00DS, and 0.75D cyl) while 65.5% of the dyslexic children and 64.5% of children from the control group were emmetropic in the study by Alvarez and Puell [88]. Only the study by

Alvarez and Puell [88] reported on emmetropia.

Refractive errors are among the leading causes of visual impairment worldwide and are responsible for high rates of visual impairment and blindness in certain areas. School children are considered a high risk group because uncorrected refractive errors can affect their learning abilities as well as their physical and mental development[147].

Several factors may lead to variations in results found in different studies. This include; the type of population studied (clinical or non-clinical), sampling method (convenience or cluster), classification criteria, examiner bias and more specifically, the use of cycloplegia in the assessment of refractive errors.

The following studies[2, 3, 88,95] categorized refractive errors as hyperopia, myopia, astigmatism, anisometropia or amblyopia.

a. **Hyperopia**: In the present study, hyperopia appeared slightly more prevalent (6.5%) among the dyslexic group than in the control group (3%). This result agrees with the report from other studies [93, 95] and Alvarez and Puell[88] who reported a much higher prevalence (28.7%) for the dyslexic group compared to 16.1% of the control group. Helveston[85] found no difference in the prevalence of hyperopia between the population of normal and poor readers.

   Hyperopia is the refractive error that is consistently reported [3,93,95,98] to be associated with reading difficulties so it was expected that one will find the higher prevalence of hyperopia in the present study.

   In the present study, two children had latent hyperopia (based on the assumption that increased plus did not blur the distance vision). The full magnitude of the hyperopic findings could not be estimated because cycloplegia was not used. Therefore, it is possible that the prevalence of hyperopia may have been under-estimated. Williams *et al* [148] studied the "prevalence and risk factors for common vision problems in children" and concluded that the 4.8% prevalence of hyperopia in their study was "an underestimate as data was collected without cycloplegia". Borghi and Rouse (cited by Scharre and Cree)[149] determined that on an average, 0.63D more plus was identified by cycloplegic refraction.

In relating hyperopia to reading difficulties, simple to moderate hyperopia may not cause constant blur at a distance or near point, but the extra accommodative effort produces asthenopic symptoms of intermittent blur, headache, fatigue and loss of concentration and inattention in some patients which may be mistaken for short attention span. Uncorrected hyperopia is associated with esophoria at near point which can stress the fusional vergence systems that hold the eyes in correct alignment. If the hyperopia and esophoria is excessive, an accommodative esotropia can result [81,150].. This may result in difficulty in reading.

b. **Myopia:** The 6.5% prevalence of myopia was the same in both groups. This result is similar to an equal prevalance of myopia reported by Eames [95] (4% in both groups). Alvarez and Puell [88] reported that 5.7% of dyslexics were myopic while 19.4% of the control group was myopic. The prevalence of myopia was higher in studies by Rosner and Rosner [93] (54% non- learning disabled and 19% learning disabled) and lower than the prevalence reported by Grisham and Simons[150]. In contrast to the present study, subjects from the study by Rosner and Rosner [93] were patients of an eye clinic where the two main reasons for referral were reduced visual acuity and school learning problems while subjects for the present study were referred to the special school mainly due to low academic performance which may not necessarily be vision- related. The subjects were chosen for the study irrespective of whether they complained of a visual impairment or not whereas in the study by Rosner and Rosner [93] study subjects had been identified as having a visual impairment. Therefore, the higher prevalence may have been from the selection protocol used by Rosner and Rosner [93] in their study.

The prevalence of myopia was not reported in several studies [3,5,6,84,98,146] referenced but was presented as "refractive errors" (was not classified as myopia, hyperopia or astigmatism). The onset and progression of myopia may be influenced by factors such as environment, nutrition, genetic predisposition, premature and low birth weight, the effect of close work, racial and cultural factors, differences in pupil size and illumination[143,151] Variations in the prevalence of myopia reported by different authors may be related to the variation in the above-mentioned factors.

c. **Astigmatism:**

The prevalence (13%) of astigmatism in the control group was higher than in the dyslexic group (10%) and there was no statistically significant difference between the two groups. Similarly, Alvarez and Puell [88] found a higher prevalence of astigmatism in the control group compared to the dyslexic group: astigmatism was detected in 16.1% from the control group compared to 8% and 9.2% right and left eyes respectively from the dyslexic group. In contrast, Latvala *et al* [3] reported that 3.6% in the dyslexic group had astigmatism and none from the control group had astigmatism. Ygge *et al* [2] reported that the prevalence of astigmatism was higher in the dyslexic group (28%, left eye 25 %) compared to the control groups (right eye 18.3% left eye 24.3%) although there was no statistically significant difference between the groups ($p=0.25$).

Rosner and Rosner[93] reported that 30% of non-learning disabled and 27% of learning disabled participants had astigmatism, which differed markedly from the findings in the present study despite the similarities in the study population. Eames[95] found an equal prevalence of astigmatism (7%) between the two groups studied.

Astigmatism affects vision in different ways. Clinically, astigmatism over 1.50 diopters can often cause severe eye strain and interfere with reading and even lesser degrees of astigmatism can be symptomatic in some patients [81].

Naidoo *et al* [157] studied refractive error and visual impairment in African school children in South Africa. Although the study was conducted specifically on mainstream school children, it relates to the present study as it provided useful information on the visual characteristics of school children in South Africa and forms a basis for comparison since all the studies reviewed in the present study were conducted on Caucasian population except for the study by Metsing and Ferreira [103] which did not provide much information on refractive errors in the their study of learning disabled children in Johannesburg, South Africa.

Naidoo *et al* [157] reported a prevalence of hyperopia of 1.8%, myopia of 2.9%, astigmatism of 6.7% and 6.8% right eye and left eye respectively. In comparison, the prevalence of refractive error for the control group in the present study was: hyperopia 3%, myopia, 6.5% and astigmatism 13%. The refractive error trend (astigmatism being higher in prevalence than myopia and hyperopia) was similar between the present study and the study by Naidoo *et al* [157] despite the difference in prevalence reported. Given that ethnic origins, culture, socio-economic class are comparable between both studies, the difference in prevalence, may (partly) have been due to different sampling methods (cluster versus convenience) and the use of cycloplegia in their study. The use of cycloplegia has been reported to yield spherical aberrations and unpredictable errors due to associated mydriasis [110].

It has also been documented [158] that the use of cycloplegia yields more positive retinoscopic findings, although this did not seem to apply in this comparison as the prevalence of hyperopia in the present study was higher than that reported by Naidoo *et al* [157]. A possible explanation for the difference in prevalence may be related to the different criteria used to define hyperopia. Bennet *et al* [159] stated that the degree of ametropia "… considered to be within normal limits in a particular study will drastically affect the prevalence". Similar opinion was noted by Gronlund *et al* [140] who stated that "the choice of definition will of course have a great impact on prevalence. In their study on Swedish children aged 4-15 years, Gronlund *et al* [140] defined astigmatism as ≥ 0.75 and stated that the prevalence of astigmatism would have been 21% (instead of 32%) had they defined astigmatism as ≥ 1.00. Furthermore, Grisham *et al* [86] in their "Study of poor readers in high school" noted that …"if one selected less stringent criteria, then the proportion of students with any given dysfunction would decrease". In the present study, the criteria used to classify hyperopia were ≥ +1.00D while Naidoo *et al* [157] used ≥ +2.00DS cut- off.

d. **Anisometropia:** Anisometropia may be defined as a difference of 0.75 (sphere or cyl) or more between the two eyes and this definition was the criteria used in this study [129]. Anisometropia, is of great clinical interest because of its intimate association with strabismus and amblyopia[141, 152].

The 6.5% prevalence of anisometropia was similar in both groups. This is comparable to results reported by Latvala *et al* [3] where the prevalence of anisometropia was 3.6% (2 subjects) for the dyslexic group and 6% (3 subjects) for the control group but contrasts with findings by Eames [95] who reported the prevalence of anisometropia to be 13% for poor readers and 6% for the control group while Ygge *et al* [2] found a higher prevalence of anisometropia in the control group (15.8%) than in the dyslexic group (9.4%).

In anisometropia, the difference in refraction as well as the refractive error causes the image to be out of focus on one retina, blunting the development of the visual pathway in the affected eye [141]. The fovea of an anisometropic eye receives images from the same visual object, however, the images from the more myopic or hyperopic eye are out of focus [153]. It appears that anisometropia is a major cause of amblyopia for at least one third of all amblyopias [131] and anisometropia is considered to be a causal factor in the pathogenesis of amblyopia and strabismus. It is also estimated that 6% to 38% of all cases of amblyopia are caused by anisometropia without strabismus, whereas in about 12% to 18% of the children with strabismus this is accompanied by anisometropia [154].

According to Grosvenor [114] uncorrected anisometropia, even of a moderate amount may induce eyestrain because it is impossible for the accommodation mechanism to maintain clear images on the retina at the same time. On the other hand, large amounts of anisometropia (2DS or more) may not cause symptoms as no effort is made to maintain single binocular vision [114].

Rutstein and Corliss[155] investigated the relationship between anisometropia, amblyopia and binocularity and concluded that higher degrees of anisometropia generally cause deeper amblyopia and poorer levels of binocularity for hyperopes but not for myopes and stated that "Although uncommon, small amounts of anisometropia can cause moderate amblyopia". However, the results of the present study failed to support this claims as none of the subjects had amblyopia resulting from anisometropia.

In anisometropia, the displacement or distortion of the image prevents the development of fine visual perception in the occipital cortex and puts the child at risk for developing amblyopia [141]. Anisometropia causes poor reading skills probably through the mechanism of poor sensory and motor fusion rather than reduced visual acuity. It degrades binocular coordination and consequently reduces visual comfort and efficiency if the binocular coordination is under stress [150].

e. **Amblyopia:** Two subjects (6.5%) in the dyslexic group had ambyopia due to cataracts and none from the control group had amblyopia. This result may be comparable to studies by Latvala *et al* [3] who reported 3.6% (2 subjects) for the dyslexic group and that of Rosner and Rosner [93] with a prevalence of 4% for the non-learning disabled group and 3% for the learning disabled group. Cataract is a major cause of amblyopia (deprivation ambyopia) by causing an impediment to the visual axis [141]. Other conditions that may lead to amblyopia include strabismus (which causes the images on the retinas to be dissimilar) and uncorrected refractive errors (especially as in anisometropia). Anisometropia is related to amblyopia. Amblyopia is a major public health problem. It is the most common cause of monocular vision loss in children and young adults. Early recognition and prompt referral are crucial, especially during infancy and childhood, to prevent permanent loss of vision [141].

5.2.3 Heterophoria

Heterophoria is the relative deviations of the visual axes when the eyes are dissociated [160]. Some degrees of heterophoria are considered normal for persons with normal binocular vision. Approximately 1-2 prism dioptres of esophoria or 1- 4 diopters of exophoria at distance should be considered to be within normal limits[161]. At near, 3-6 prism dioptres of exophoria is considered normal (physiological exophoria) [161]. A normal healthy eye is usually able to overcome these small deviations and so it is described as being compensated[161]. However, esophoria is much less compatible with comfortable vision than is exophoria. Any amount of esophoria in a patient with visually related symptoms may be problematic [162].

In the present study all subjects were orthophoric at distance. This report corroborates reports by other authors: Mathebula *et al* [163] studied heterophoria in a South African population of school children (mean age 10 ± 1.6 years) and reported that the mean distance horizontal heterophoria showed orthophoria. Similarly, Evans *et al* [100] reported that all subjects examined "were orthophoric at distance with cover test". According to Dowley[160] "the high prevalence of orthophoria is real" and that "the high prevalence of distance orthophoria… may be due to the coordinating influences of the same mechanisms that subserves prism adaptation". A similar view was expressed by Walline *et al* [164] who studied the "development of phoria in children" and stated that "nearly all of our subjects were orthophoric at distance".

The major findings in heterophoria was a 9.5% prevalence of exophoria at near which was more in the dyslexic subjects than in the control group with no exophoria. There was no statistically significant difference between the two groups ($p= 0.59$). At near, 3% (1 subject) of the dyslexic group had an esophoria greater than or equal to four prism diopters. An interpretation of the above finding is that the higher prevalance of heterophoria may mean that the dyslexic subjects may be more uncomfortable when doing near work than the nroaml readers. A possible explanation may be that according to von Noorden (cited by Kommerell *et a*l)[165] heterophoria typically causes asthenopia. Patients with asthenopic symptoms (feeling of heaviness, dryness and soreness of the eyes, pain in and around the eye, frontal and occipital headache and the eyes are easily fatigued) often have an aversion to reading and studying. Typically such complaints tend to be less severe or to disappear when patients do not use their eyes in close work[165]. It has been documented that decompensated heterphoria (heterophoria accompanied by symptoms) can be due to poor fusional reserves, problems with sensory fusion (such as in anisometropia) or may be due to an unusually large phoria which may be due to anatomical reasons or uncorrected hyperopia [161,166]. The presence of phoria could contribute to visual and attention abnormalities noted among children with reading difficulties, making near point visual activities more strenuous.

Nearpoint esophoria has been reported to be associated with childhood myopia progression [164,167]. In the present study, the only subject that had four prism diopters esophoria at near in the dyslexic group had +1.25 hyperopia while the subject that had 3 prism diopters esophoria had -1.50 DS myopia. However, due to the small sample size in the present study, it is difficult to draw any conclusion on the association between myopia and esophoria.

The findings on heterophoria as in other aspects of vision functions in the dyslexic populations reviewed are mixed. However, similar to the present study, Latvala *et al* [3] assessed near heterophoria using the Maddox Wing and reported a higher prevalence of near exophoria in the dyslexics than in the control group. Similarly, Kiely *et al* [12] documented that dyslexics tend to be more exophoric than normal readers. Evans *et al* [101] found a higher prevalence of lateral phoria in learning disabled subjects compared to normal readers. In contrast to the above findings, Sucher and Stewart [98] assessed phoria using the cover test (testing distance was not indicated in the results) but found a slightly higher prevalence of phoria in the control group than in the dyslexics. Evans *et al* [100] assessed near horizontal phoria using the Maddox Wing as in present study but found no difference in near horizontal phoria between the dyslexic and control groups. Bucci *et al* [89] reported that there was no difference in phoria results at both distance and near between the dyslexic and control groups. Metsing and Ferreira [103] found no statistically significant difference between the learning disabled and the mainstream groups on heterophoria.

The use of the cover tests for both distance and near to assess heterophoria may have allowed for standardization in technique but may not have implied that more valid results will be obtained. The cover test and the Maddox Wing have been used simultaneously to assess heterophoria in other studies[3, 100]. The possible sources of variations in results reported by different investigators include classification criteria and poor technique [168].

5.2.4 Near Point of Convergence

In the present study, the prevalence of a remote (greater than 10cm) near point of convergence was higher in the control group with 48%, than in the dyslexic group with a prevalence of 33%. There was a statistically significant difference in the near point of convergence break (*p=0.049*) and recovery *(p = 0.006*) between the two groups.

It may be that children who do not have reading difficulties tend to read more often than children who experience difficulty to read. This is because with increasing ability to read, there is likely to be more demand on accommodation and convergence resulting in near point stress as well as esophoria. The normal readers use and exercise the accommodation and convergence system more frequently. According to Owens and Wolf-Kelly [169], near work has long been considered a potential source of visual problems, stating that in their study, reading ordinary text at a near distance for about one hour induced significant changes in the resting postures of both accommodation and vergences. The authors indicated that "near work induces a recession of the near point of accommodation or vergences".

The near point of convergence break is associated with changes in inter-pupillary distance with age. As inter-pupillary distance widens with physical growth, the amount of convergence in prism diopters increases for a given distance from the subject [132]. Chen *et al* [170] studied near point of convergence in children aged 1-17 years and reported that an increasing incidence of remote near point of convergence with increasing age in their study might be due to the near work demands of primary school which might create a different level of near point stress than the near work conditions in pre- primary school years.

Similar to the findings in the present study, Evans *et al* [91] reported a statistically significant relationship between NPC and reading retardation (*p=0.019*). Contrasting findings were reported by other authors: Bedwell *et al* [171] studied visual and ocular anomalies in relation to reading difficulties and reported that 46.6% of the group of "good readers" had abnormal near point of convergence compared to 58% of "poor readers". Similarly, Bucci *et al* [89] and Kapoula *et al* [87] reported that the near point of convergence was significantly more remote in dyslexics than the control. In the study by Latvala *et al* [3], 12.75% of the dyslexic group and only 2% from the control group had a near point of convergence of worse than 8cm. A statistically significant difference between the two groups was reported (*p=0.0385*). Metsing and Ferreira [103] found no statistically significant difference between the learning disabled and the mainstream groups on the near point of convergence function. In a study that lacked control subjects, Grisham *et al* [86] reported a lower prevalence (15.4%) of NPC (9cm or further) in a group of high school poor readers. The authors measured NPC three times on each subject in other to detect fatigue but stated that "it should therefore be noted that fatigue may be a problem for poor readers; even if they are able to converge at 8 cm, if they tire easily, then the ability to sustain convergence during longer periods of reading may suffer".

In the present study, the measurement of the near point of convergence was repeated three times on each subject in order to detect visual fatigue that the children experience everyday. This approach was documented by other authors [86,87,89, 111-113,] Some authors[111-113] have recommended the measurement of the near point of convergence several times in order to detect fatigue which is often indicative of poor convergence fusion system which may affect distract a child from reading [172].

5.2.5 Accommodation Functions

a. **Accommodation Facility:** Accommodative facility assesses the rate at which accommodation can be stimulated and inhibited repeatedly during a specific time period. It relates to the individual's ability to shift focus quickly and efficiently for varying distances and is extensively used in the reading process [6].

Only the result for the binocular accommodative facility was recorded and was used for analysis in the present study. Siderov and Johnston [174] noted that monocular accommodation measurements provides a direct evaluation of the dynamics of accommodative response while binocular testing of accommodative facility provides similar information but also reflects the interactive nature of the relationship between accommodation and vergences.

For the dyslexic group, 54% (15 subjects) had inefficient accommodation facility while only 33%

(9 subjects) of the control group had inefficient accommodative facility. Statistically, the control group had a better accommodative facility (8.85cpm ± 3.69) than the dyslexics (6.86cpm ± 2.74) and there was a statistically significant difference between the two groups *(p =0.027)*. It has been documented [100] that an abnormal accommodative facility could imply difficulty in changing focus from far to near and subsequently lead to a lack of interest in learning. An efficient facility of accommodation is particularly important because a greater period in school involves changing focus between the chalkboard to near task such as writing at a desk. Low values of accommodative facility have been associated with symptoms related to near point asthenopia[134].

The result of the present study corresponds with findings by Evans *et al* [100] who reported that dyslexics appeared to be slower at a test of accommodative facility. Similar results were reported in other studies [12,88,,98] but contrasts with results reported by Buzzelli [6]. Buzzelli [6] assessed accommodation facility using a Bernell Vectogram that utilized a polarised target to control for suppression. Buzzelli[6] assessed accommodation facility as follows: "patients were asked to clear the number 9 on the Bernell Vectogram target at 40cm. They alternately viewed the target through a ± 2D lens. The test was continued for 20 cycles (a cycle being clearing the plus and minus lens, each presented once). The total time in seconds was recorded for the right eye, left eye, and both eyes. The polarized target controlled for suppression". The use of the vectogram to assess accommodation facility by Buzzelli[6] differs from the flipper technique that was used in the present study. Secondly, there was no control for suppression in the present study. The difference in results found between the two studies may be due to the lack of control for suppression in the pre sent study. Siderov and Johnston[174] stated that "clinical measurements of binocular accommodation facility could vary depending on whether or not suppression has been monitored...".
A total of 31.7% of the poor readers in the study by Grisham *et al* [86] had inadequate (9cm or less) accommodative facility.

Allison[173] suggested that there are different norms submitted by different authors for accommodative facility measurements and that apart from adhering strictly to recommended norms for accommodative facility testing, other factors to be considered when evaluating accommodative facility include the difficulty and speed of responses to the plus and minus lenses and whether the subjects fatigue easily [173]. Kedzia *et al* (cited in Zadnik)[175] documented that the factors that affect the testing of accommodative facility include; the size and position of the text being read, the complexity of the target, reaction time of the child to call out the symbol and the magnification or minification factors introduced by the lenses themselves. The above variables are factors to be considered in assessing the variations in the findings for accommodative facility reported in this study as compared to other studies.

b. **Amplitude of Accommodation**: Accommodation is the ability to adjust the focus of the eye by changing the shape of the crystalline lens to attain maximum sharpness of the retinal image of an object of regard. The absolute magnitude of the accommodative response is termed the accommodative amplitude [120].

Statistically, the dyslexic group had a slightly reduced monocular amplitude of accommodation (mean 12D) compared to the control group (12.87D) but there was no statistically significant difference between the two groups (*p=0.70*). The slight difference in the mean amplitude of accommodation between the two groups may have been due to the two subjects from the dyslexic group who had latent hyperopia.

Similar to the present study, Álvarez and Puell[88] reported that monocular accommodative amplitude was significantly lower in the group of poor readers. Evans *et a l*[91,100] *,* in two seperate studies [91,100] reported that amplitude of accommodation was reduced in the populations studied. Ygge *et al* [102] and Goulandris *et al* [90] found no statistically significant difference between the dyslexic and control groups. Grisham *et al* [86] found that 24.7% of the children had amplitude of accommodation which the authors classified as "weak" or "very weak" while 11.5% had accommodative amplitudes classified as "borderline". In the present study, the mean amplitude of accommodation for each group was within normal age norms according to the amplitude norms and Hofsteter's formula [106,161].

In the study by Metsing and Ferreira [103], a higher percentage of low amplitude of accommodation for the right and left eyes respectively (51.6% and 53.3%) was found in the mainstream group compared to 29.1% and 28.8% in the learning disabled group. The relationships between the mainstream group and reduced amplitudes of accommodation of the right *(p=0.04)* and left eyes (*p = 0.001*) were found to be statistically significant ($p<0.05$). Furthermore, the relationship between the mainstream group and reduced amplitude of accommodation of the left eyes (Cramer's V = 0.316) was found to be moderate and that between the mainstream group and the right eyes (Cramer's = 0.286) to be low.

When accommodation amplitude is assessed monocularly, it measures the response for each eye individually and the limiting factor is the magnitude of blur-driven accommodation. Monocular amplitude measures are particularly important to determine whether a patient has accommodative insufficiency [107]. The amplitude measured binocularly is usually greater than the monocularly measured amplitude due to the influence of both the blur-driven accommodative response and accommodative and vergence responses [120, 175]. Clinically, the amplitude of accommodation is considered important mainly when it falls below the expected age norm in which case the child may experience blur vision at near. Secondly, a difference of up to 2D between the two eyes may also be considered clinically significant [120].

An inefficient accommodation function may lead to difficulties in learning as the focusing system of the eyes play a major role in the learning process. Children who suffer some anomalies of accommodation are more prone to fatigue quickly and become inattentive than those who have norrmal accommodation function [87]. Symptoms of accommodation insufficiency are specifically related to near vision work [176].

Factors affecting the measurement of amplitude include: differences when measurements are taken monocularly as compared to when assessed binocularly, the angle of gaze, target size, age, refractive error, race and climate [175].

c. **Accommodation Posture:** During near vision the eyes are not usually precisely focussed on the object of regard, but the accommodation lags a small amount behind the target. If the accommodation lag is small, then the blur it causes is insignificant; if high then it can result in blurred print during reading [142].

About 39.28% (11 subjects) of dyslexic subjects had lag of accommodation compared to 41.93% (13 subjects) of the control group. The mean accommodation lag was similar in both groups: 0.92 for control and 0.88 for the dyslexic group. There were no statistically significant differences between the two groups, right eye ($p = 0.83$) and left eye ($p = 0.60$). Similarly, Evans *at al* [100] reported that the mean accommodation lag did not show any statistically significant difference between the dyslexic and control groups. On the contrary, Metsing and Ferreira [103] found a high prevalence of lead of accommodation for the mainstream group but a high prevalence of lag of accommodation in the learning disabled group. The relationships were found to be statistically significant ($p<0.05$) between the mainstream and the learning disabled group and the lead and lag of accommodation for the respective groups of the right and left eyes ($p =0.00$). In another study Evans *et al* [91] reported a mean accommodation lag of + 1.12DS.

An individual with a lag of accommodation habitually under accommodates and may lead to difficulty with reading. An accommodative response that manifests as an excessive lag of accommodation may indicate latent hyperopia, esophoria or may be associated with accommodative insufficiency or accommodative spasm, poor negative vergences or when patient is overminused [177]. The prevalence of high lag may be related to the prevalence of latent hyperopia and esophoria in the present study.

C. **Relative Accommodation (PRA, NRA):** The relative accommodation tests assess the patients' ability to increase and decrease accommodation under binocular conditions when the total convergence demand is constant[67]. It is also an indirect assessment of the vergence system since the vergence demand remains constant while accommodative demand varies [121]. The results for the relative accommodation for all subjects from both dyslexic and control groups were unexpectedly high. The norm for the mean NRA and PRA were given as approximately +2 or - 2 diopters from two reports consulted [119, 121] while the relative accommodation results in this study ranged between 3 and - 6 diopters. Similarly, a higher relative accommodative value was reported by Chen *et al*and Abidin[139] in a study of vergence problems in Malay school children. The only available study accessed that reported on relative accommodation was conducted by Álvarezand Puell [88] who reported that the negative and positive relative accommodation values were similar in both groups of children. Statistically, the results were: (NRA: Control group 1.9 ± 0.6 poor readers: 1.9 ± 0.6. PRA: Control group 2.3 ± 0.9. Poor readers 2.0 ± 1.3) compared to the findings from the present study: (NRA: Control group was 3.11 ± 0.47. NRA dyslexic group 3.22 ± 0.79) (PRA Control: – 6.06 ± 0.63; PRA dyslexic was -6.23 ± 1.17). The *p* values were not indicated.

The higher values found in the present study may be due to the process of addition of trial lenses specifically. The phoropter has been reported to be a better technique to assess relative accommodation [119].

Although the relative accommodation was not assessed by many authors, different opinions were expressed regarding the assessment of relative accommodation: Latvala *et al* [3] noted that positive and negative relative accommodation ranges are "difficult to take and unreliable". According to Morgan [178], the PRA and NRA results are often unusually high but recommended that such tests results can be used as a sort of indicative way and can only be interpreted loosely and suggested that the use should be restricted to special circumstances. Garcia and Fransisco [122] reported that high NRA can be associated with disorders such as accommodative insufficiency and convergence excess while high values of PRA are related to anomalies in which accommodative excess appears but concluded that PRA and NRA findings were used mainly as complementary diagnostics tests of some disorders in literatures consulted.

A high value of the negative relative accommodation could indicate that the children were exerting maximum accommodation effort. Because 2.50D of accommodation is exerted at the 40cm working distance, the maximum amount of accommodation that would be expected to relax accommodation at 40cm would be 2.50D. A value greater than 2.50D would mean that accommodation may not have been fully relaxed during the subjective refraction [114]. Generally, a high value of the NRA may also mean that the refraction may have been under corrected for hyperopia or over corrected for myopia [122]. Garciaand Francisco[122] reported the relationship between high NRA values and under corrected hyperopia to be due to the etiology of hyperopia.

According to Grosvenor [114,] the amplitude of accommodation is a limiting factor for the expected value of the PRA. For example, "If a patient has an amplitude of accommodation of only 1.50D, we would expect the minus-lens-to-blur test to be no greater than -1.50D…" A high value of the positive relative accommodation is related to convergence insufficiency [122]. Illumination and the range of fusional vergence also affect the relative accommodation. An excessive illumination will give an erroneously high finding due to the increased depth of focus [100].

Dysfunctions of accommodation can significantly interfere with the comfort, clarity, speed and accuracy of reading as the child develops reading skills [51]. Wick and Hall [120] suggested that the results for the tests of accommodation are more meaningful when analyzed together, as the results of individual accommodation function may not give a true reflection of the child's accommodation dysfunction.

5.2.6 Fusional Reserves

Fusional vergence amplitudes is a clinical measurement of a person`s fusional vergence ability. It reflects the ability of the oculomotor system to maintain sensory fusion in spite of varying vergence requirements [179]. The horizontal vergence reserves describe the amount by which the eyes can be converged or diverged whilst the subject maintains fusion [100,161.] It is a measure of how much fusional vergence is available in 'reserve' that can be used to overcome a phoria. The amount of base out prism required to produce diplopia is called positive fusional reserves (measures convergence) [100]. The measurements of convergence fusion are also referred to as the 'amplitude of fusional reserves [111]. Clinically, the fusional amplitude provides information about a patient's ability to maintain comfortable binocular vision [100,112].

The participants from both the dyslexic and control groups either could not report or understand blur so the result for break and recovery was used in all analysis of vergence function. Evans *et al* [100] reported similar observations. For the fusional reserves, only the findings for the near positive fusional vergence (convergence) are emphasized. The positive fusional reserves/vergence (measures convergence ability) may be more important in assessing reading dysfunction. More so, it has been suggested by other authors [112,121,180] that near measurements are more relevant in assessing vision functions in dyslexic children.

Based on Bishop's [111] recommended norm of between 30 and 40 prism diopters for positive fusional amplitude at near, the prevalence of abnormal positive fusional vergence at near was 83% for the control and 74% for the dyslexics. This appears unusually high. Walters [168] explained that a possible reason for an unexpected high base out finding is that exophoric conditions makes compensating for base out more difficult than base in testing. It is unclear if this is the case in the present study although the prevalence of exophoria at near in the present study was 9.5%. The compensation for a phoria is maintained by fusion reflex, so knowing the magnitude of the vergence amplitude that is needed to compensate a given phoria is very useful clinically[181].

For the present study, at near, the negative fusional vergence (base in vergences) was reduced in the dyslexics compared to the control group while the positive fusional vergence (base out vergences) was similar for both groups. Overall, there was no statistically significant difference between the groups, ($p = 0.21$ for BI break at near) and ($p = 0.84$ for BO break at near). Evans *et al* [100] reported that the dyslexics have reduced fusional reserves compared to the control group. Bucci *et al* [89] reported reduced divergence capabilities in dyslexics at near.

When assessing fusional reserves, the blur point is a function of the flexibility between vergence and accommodation. When little flexibility exists, the addition of even low prism causes a simultaneous accommodation shift with resultant blur. Lack of low blur findings may indicate an inadequate flexibility bond between accommodation and convergence. The break point is an indication of the quality of binocular function. Break values will be adequate when fusion ability is good while the recovery measure is a more subtle indicator of the quality of binocular function. Consequently, reduced blur, break, or recovery findings indicate the presence of near point stress

[182]. Some subjects from both groups had break values higher than 40 prism diopters for base in and base out reserves. Wesson et al [125] in their study reported a similar observation on objective testing of vergence ranges. Such high break findings may be because suppression was not controlled while assessing the fusional reserves in the present study. When suppression is controlled, the average vergence values will be lower because the test is stopped when the suppression is detected. If suppression is not monitored, the break is not detected until the stimulus is outside the suppression zone and a higher vergence value is obtained [125]. However, it is important to note that the significance of such suppression in binocular individuals is unknown [126]. Again, in special cases such as suppression, large abnormal findings (compared to normative ranges) may permit better functions in reading than a lower abnormal finding [183]. For example, an individual who totally suppresses the vision of one eye is less apt to have difficulty at reading than the individual who only partially suppresses the vision of one eye [183].

Ygge *et al*[102] assessed vergence fusion using the prism bar. They reported that the fusion convergence and divergence capacities at distance and near were similar in the two groups. The mean fusional convergence capacities at distance were 16.80 prism dopters for both the control and the dyslexic group. At near, the corresponding figures were 26.40 prism diopters and 26.70 prism diopters respectively. The mean fusional divergence capacity at distance was 6.50 prism diopeters and 6.20 prism diopters in the dyslexic and control groups respectively, whereas at near the fusion divergence capacity was 10.50 and 10.20 prism diopters respectively. There was no statistically significant difference between the groups.

Latvala *et al* [3] reported a prevalence of fusional amplitude greater than or equal to 32 prism diopters to be 6.1% for the control group and 7.5% for the dyslexic group, using referral criteria of 32 prism diopters at a distance of 33cm. At near, a testing distance of 40cm was used in this study. The difference in prevalence between the two studies might be from the different test distances used. Furthermore, as detailed by Rouse *et al* [158], large intra subject, intra-examiner and inter-examiner variations in the assessment of fusional reserves have been reported. Vergence amplitudes have been reported to vary with alertness, that is, whether the subject is tired or rested or under the influence of a toxic agent [184].

Bedwell *et al* [171] reported that neither convergence nor divergence, were significantly related to reading difficulty". Similarly, Metsing and Ferreira[103] found no statistically significant difference between fusional vergences amplitude (Base-out/ base-in) at near. No details were provided.

There are several limitations with the assessment of fusional reserves. Sheedy (cited by Rouse *et al*) [158] remarked that " the general opinion is that when fusional vergence tests are repeated on the same patient, the second value found may be quite different from the first... a difference of 10 PD from one fusional vergence amplitude measurement to another is not unusual unless rigorous controls ar a typical difference of 3- 4 prism diopters but can measure differences as large as 12 prism diopter on follow up visit and that inter-examiner variation can be as large as 10 to 16 prism diopters. The authors concluded that the positive fusional vergences difference could be due to children having difficulty understanding the instructions or expected endpoints, children being slower responders or may be poorer observers. The blur readings on the vergence reserves for both distance and near were excluded in the analysis as it was difficult to get the children to elicit a proper response. It is possible that the children did not understand the instruction or the concept of blur despite repeated explanations and trial readings. This variable is often difficult for young subjects to understand. Similar problems were encountered by Evans *et al* [100] who commented that "several subjects were unable to appreciate a blur". Scheiman *et al* [126] stated that "we were unable to consistently obtain a blur finding from our sample" and that ..." less than1/3 of the subjects were able to report a blur, we therefore, only recorded the break and recovery findings".

Wesson *et al*[125] emphasized that the "major limitations of any vergence measurement is"…necessity to obtain a subjective response to blur, break and recovery and that working with children whose responses are not reliable is difficult". It was suggested that a break and recovery point could be determined by observing the subjects' eye movements as prism power is increased. This technique was applied in this study. However, most children have difficulty maintaining fixation long enough to measure vergence ranges.

Vergence is influenced by several factors including awareness of the distance of the object (proximal vergence),cross-linking with the accommodative system (acommodative vergence) and the fine tuning of ocular alignment during the fusion of each monocular image into a single percept (fusional vergence) [161] and other factors such as test target and lighting conditions [125]. Generally, in the assessment of a patient's binocular status, the fusional reserves may be more useful when analyzed with the phoria measurements [115].

The vergence system is closely related to the accommodative system and symptoms may at times appear similar. The symptoms associated with deficiencies with the vergence system include: letters or words appear to float or move around, postural changes noted when working at a desk, difficulty aligning columns of numbers, intermittent diplopia at either distance or near [185.] Furthermore, "dysfunctional vergence could cause an excess of eye movements, especially of small saccades. The ability to continue the rapid decoding of the visual characters decreases as more stress is placed on the vergence mechanism of the dyslexic during reading which makes them tire more quickly than normal readers" [6].

A possible explanation for the relationship between vergence control and reading proposed by Riddel *et al* (cited by Morad *et al)* [186] is that children with poor vergence control had impaired accuracy of spatial localization that may impend their ability to accurately determine the position of letters within words.

5.2.7 Ocular Pathology

Two participants from the dyslexic group had cataracts. Only the study by Hoffamn [83] reported that one child had conjunctivitis.

5.4 Summary

The results of this study do not vary significantly from the international studies in spite of the differences in study designs, tools and sample sizes. Although studies have indicated differences in the prevalance of open angle glaucoma and myopia between Caucasian and African populations, this study does not indicate a specific difference in the prevalance of vision variables between Caucasian and African dyslexic school children. However, the lack of studies on African children makes it difficult to reach any conclusions regarding structural differences that may affect the presence of dyslexia. Comparing the findings of this study with those done internationally highlights the complexity of investigating the visual conditions that may be associated with dyslexia and the need for rigorous and consistent testing methods in order to be able to compare results.

Having completed a discussion of the study findings in Chapter Five, Chapter Six will present the study conclusion and indicate its limitation as well as recommendations for future studies.

CHAPTER SIX: CONCLUSION

6.1 Introduction

Being able to read and write is an essential part of being able to interact with the world. As vision plays a major role in reading and the learning process, a normally working visual system is essential for efficient reading.

With as many as 20% of Caucasian children being affected to a greater or lesser degree by dyslexia [16,31], there is a need to identify its cause and develop remedial actions to reduce its effects. As studies [4, 59] have shown that intellectual ability is not the cause of dyslexia, research to enable people to reach their full potential, in spite of their impaired reading ability, requires a multidisciplinary approach, of which optometrists are part.

This study aimed to determine the prevalence of vision conditions in a South African population of African dyslexic children, and to study the relationship between vision and dyslexia in an African setting. This was done by investigating visual acuity, refraction and binocular functions between two groups of 31 African school children, one group attending a school for children with learning difficulties, and the other a mainstream school. This enabled a study of possible vision defects in African dyslexic children as well as a comparison between the two groups.

The study targeted African school children, its objectives being to:

1. determine the distribution of visual acuity disorders among dyslexic children.
2. determine the distribution of refractive errors among dyslexic children.
3. determine the distribution of heterophorias among dyslexic children.
4. determine the distribution of strabismus among dyslexic children.
5. determine the distribution of accommodation disorders among dyslexic children.
6. determine the distribution of vergence disorders among dyslexic children.
7. determine the distribution of ocular pathology among dyslexic population.

8. compare these findings to a similar group of non-dyslexic children.

A review of the literature showed that most studies that investigated visual functions in dyslexic school children were conducted on Caucasian population and that the findings of these studies were inconclusive. The broad areas of vision investigated in the previous studies [2-6, 87-89] were: visual acuity and refraction, binocular vision and ocular pathology.

As studies conducted on the African population was lacking, this study examined visual acuity (using LogMar charts), refraction (static retinoscopy without cycloplegia), near point of convergence (RAF rule), [accommodation functions: ± 2 flipper lenses to assess accommodation facility, MEM retinoscopy for accommodation posture and push–up method to evaluate amplitude of accommodation] ocular alignment (cover test and Maddox Wing) and strabismus (Hirschberg test) and fusional reserves (using prism bars).

The study was conducted on a African population of 31 dyslexic school children selected from a school for children with learning difficulties and 31 control participants from a mainstream school in Durban. Their ages ranged between 10-15 years. The participants were selected using the convenient sampling method as there were only a few participants classified as being dyslexics. All data collection procedures were conducted at the respective schools.

The prevalence of vision conditions were presented in percentages (%). Data was analyzed using the Statistical Package for Social Sciences (SPSS) and was expressed as mean (M) and standard deviation (SD) and calculated for descriptive purposes at 95% confidence interval (CI). The level of significance considered to support a hypothesis was taken as $P < 0.05$. For comparison, all data from both groups was subjected to a two sample t test (2-tailed).

6.2 Summary of findings

If an association between visual function and dyslexia exists, a higher prevalence of vision defects in dyslexic children than in the non-dyslexic participants (control group) would be expected.

6.2.1 Visual Acuity

The prevalence of visual acuity worse than 6/9 (23% dyslexic and 22.5% control) is the same in both the dyslexic and the control group and there was no statistically significant difference (*p =0.29, 0.23*, right and left eye respectively. This is similar to the findings by Buzzelli [6] and Goulandris *et al* [90] which found no statistically significant difference between the two groups.

The null hypothesis was therefore accepted as there was no statistically significant difference between the dyslexia and the control group (*p=0.29* for the right eye and 0.23 for the left eye).

6.2.2 Refractive Errors

The prevalence of refractive errors was similar in both groups. There was no statistically significant difference between the two groups (*p=0.66* for the right eye and *0.92* for the left eye). This is similar to the findings by Evans *et al* [2] which found no statistically significant difference between the two groups (*p=0.58)*.

The null hypothesis was therefore accepted as there was no statistically significant difference between the dyslexic and the control groups (*p = 0.66* for the right eye *and 0.92* for the left eye).

a. **Hyperopia** : Hyperopia was more prevalent in the dyslexic group than in the control group. This is consistent with findings in other studies [88, 93, 95].

b. **Myopia:** The prevalence of myopia was the same in both groups. This is similar to the findings by Eames [95] which found no difference in the prevalence of myopia between the two groups.

c. **Astigmatism:** Astigmatism was more prevalent in the control group than in the dyslexic group. This is similar to the findings by Alvarez *et al* [88] which found a higher prevalence of astigmatism in the control group than in the dyslexic group.

d. **Anisometropia:** The prevalence of anisometropia was the same in both groups (2 subjects each). This is comparable to results reported by Latvala *et al* [3] where the prevalence of anisometropia was 3.6% (2 subjects) for the dyslexic group and 6% (3 subjects) for the control group.

e. **Amblyopia**: Amblyopia was more prevalent in the dyslexic group compared to the control group. This is similar to the findings by Latvala *et al* [3] and Rosner and Rosner [93] which found a higher prevalence of astigmatism in the dyslexic than in the control group.

6.2.3 Near Point of Convergence

The prevalence of remote NPC (≥10cm) was higher in the control group than in the dyslexic group and there was a statistically significant difference between the two groups ($p = 0.049$). This is similar to the findings by Kapoula *et al* [87], Latvala *et al* [3] and *Evans et al* [91] who found a statistically significant difference between the dyslexic and the control groups on the NPC functions.

The null hypothesis was rejected as there was a statistically significant difference between the dyslexic and control groups ($p = 0.049$).

6.2.4 Heterophoria

The prevalence of exophoria at near was higher in the dyslexic group (9.5%) than in the control group with no exophoria. There was no statistically significant difference between the two groups ($p = 0.59$). The prevalence of esophoria in the dyslexic group was higher than that found in the control group and there was no statistically significant difference (*p =0.46*). This is similar to findings in other studies [3], [12,101,163] which found no statistically significant difference between the two groups.

The null hypothesis was accepted as there was no statistically significant difference between the dyslexic and control groups (*p=0.59* for exophoria) and (*p=0.46* for esophoria).

6.2.5 Accommodation Functions

a. **Amplitude of Accommodation:** The dyslexic group had a reduced monocular amplitude of accommodation compared to the control group but there was no statistically significant difference between the two groups (right eye, *p = 0.07,* left eye *p=0.22*). This is similar to the findings reported in other studies [3, 87, 91,102] which found no statistically significant difference between the two groups.

   The null hypothesis was accepted as there was no statistically significant difference between the dyslexic and control groups in accommodation amplitude (right eye, *p=0.07,* left eye, *p=0.22*).

b. **Accommodation Facility:** The participants from the dyslexic group performed significantly worse than the control group in accommodative facility function and there was a significant difference between the two groups *(p=0.027)*. This result corroborates findings reported in other studies [12, 88, 98,100] which found a statistically significant difference between the two groups.

   The null hypothesis was rejected as there was a statistically significant difference between the dyslexic and control group in accommodation facility *(p=0.027)*.

c. **Accommodation Lag:** The prevalence of lag of accommodation was higher in the control group compared to the dyslexic group and there was no statistically significant difference. There were no statistically significant difference between the two groups (right eye, *p=0.83* and left eye, *p= 0.60*). This is similar to the findings by Evans *et al* [100] which found no statistically significant difference between the two groups. The mean accommodation lag in the present study were: 0.92D for control and 0.88D for the dyslexic which is comparable to reports by *Evans et al* [91] who reported a mean accommodation lag of + 1.12D .

The null hypothesis was accepted as there was no statistically significant difference between the dyslexic and control groups in accommodation posture.

d. **Relative Accommodation (PRA, NRA):** The mean values for the relative accommodation are similar in both groups and there was no statistically significant difference between the groups. *(p=0.68* for NRA and *p =0.51* for PRA). This is similar to the findings reported Alvarez and Puell [88] which found no statistically significant difference between the two groups in relative accommodation.

The null hypothesis was accepted as there was no statistically significant difference between the dyslexic and the control groups in relative accommodation.

6.2.6. Fusional Reserves

For the present study, at near, the negative fusional vergence (base-in vergences) was reduced in the dyslexics compared to the control group while the positive fusional vergence (base-out vergences) was similar for both groups. There was no statistically significant difference between the groups, *(p= 0.21* for BI break at near) and (*p = 0.84* for BO break at near). This is similar to the findings by Evans *et al*[100] which found no statistically significant difference between the two groups.

The null hypothesis was accepted as there was no statistically significant difference between the dyslexic and the control groups *(p = 0.21* for BI break at near) and (*p = 0.84* for BO break at near).

6.2.7 Ocular Pathology

Two participants from the dyslexic group had cataracts

6.3 Implications of the Study Findings

a. **Causal Relationship:** This study presented the prevalence of some vision defects in a South African African population of dyslexic school children as compared to a population of non-dyslexic children, and could not establish any causal relationship between vision and dyslexia. The vision parameters that showed that statistical significance may only be reflective of factors associated with dyslexia but in a non-causal way. This may mean that the prevalence of the particular visual variable is much higher in the dyslexic population than in the control group. Vision is essential for reading, but the vision anomalies that are found to be associated with dyslexia also occur in children who do not have reading difficulties. It is therefore possible that other complex vision functions may be more related to the etiology of dyslexia than peripheral visual factors such as NPC and accommodative facility which showed statistically significant differences in the present study.

b. **Risk Identification**: The findings of this study also suggest that dyslexic children are not at more risk for the identified vision condition compared to non-dyslexic children. However, even when vision defects may not be the cause of dyslexia, the presence of uncompensated vision defect in a dyslexic child may constitute difficulty while reading and should be compensated for. Improvement in vision will make reading easier for the dyslexic child.

6.4 The Study Strengths

The study methodology was based on reports found in other studies and consisted of the following:

a. **Classification:** The subjects selected for the dyslexic group represent a dyslexic population that was classified according to the criteria used in the study by Latvala *et al* [3] and Evans *et* *al* [100]. The study was undertaken at a school for learning disabled learners and all students were assessed and categorized as being dyslexic by the psychologists.

b. **Study Examiner**: Examination of the subjects was conducted by the same optometrist who had some experience in paediatric optometry. This minimised the possibility of bias and inter-examiner variability.

c. **Examination Techniques**: The examination techniques used in this study were the same as the techniques used in major referenced studies which were published in peer-reviewed journals.

d. **International Relevance:** It is the first study that has assessed broad vision functions in a dyslexic population in an African setting.

6. 5 Limitations of the Study

The factors which may limit the generalization of findings of the study are as follows:

a. **Inattentiveness:** This occurred in some children after numerous tests and the possibilities of their lack of understanding of certain instructions. However, this problem was minimized as trial readings were taken for some procedures and the participants were instructed accordingly. As stated in Section 3.4, testing was discontinued when the child was tired. This approach helped to minimize fatigue which could have negatively affected the results. In addition, objective techniques that required minimal responses from the participants were utilized in several procedures such as the cover test, retinoscopy and the monocular estimation method for evaluating accommodation posture.

b. **Convenience Sampling**: This method of sampling was used given the limited number of available subjects from the target population. The available studies [2,3,5,6,87-91,102,103] on the subject of dyslexia, learning disabilities and vision also used the convenience sampling method.

c. **Generalised Findings**: The generalization of the findings of this study is limited by the fact that the refraction data was collected without the use of cycloplegia. At the inception of the data collection, the diagnostic drug usage by optometrists was not approved in the scope of practice in South Africa.

d. **Sample Size**: The sample size was small as there was only one school for dyslexic African children in Durban at the time of this study. However, review of the literature also reveals that the sample sizes on studies conducted on dyslexia, learning disabilities and vision were typically small. The targeted sample size of one hundred for this study could not be met due to the limited number of subjects available. The average sample size of eight published studies [3,5,6, 87,90,100, 102] conducted on dyslexic children was 41.

e. **Suppression Control**: The assessment of binocular accommodation facility and the vergence reserves were performed without controlling for suppression.

f. **Assessment of Relative Accommodation**: the use of a Phoropter would have yielded a more conclusive result.

g. **Eye Movements:** these were not assessed.

Despite the acknowledged limitations inherent in this study, the study provides useful information and a research perspective on the prevalence of vision defects in a South African population of dyslexic children, which has not been conducted before.

6.6 Recommendations

The following recommendations are made based on the findings of this study;

6.6.1 Future Research

1. The same study with a similar protocol, larger sample size with randomized sampling.
2. Investigate the relative accommodation in in both groups using the phoropter.
3. Assess the binocular functions with suppression control.
4. Assess refractive error under cycloplgia.

6.6.2 General Recommendations

1. All dyslexic children should have their eyes examined routinely to rule out possibility of vision defects impacting on their reading performance.
2. The Department of Education be reminded that visual defects can impact negatively on the reading ability of learners, and that teachers need to be more aware of pupils who may present with signs of visual problems, such as holding book too close, or battling to see the chalk board.
3. The principals of the mainstream school should also be informed that vision defects were detected in the non-dyslexic children.

6.7 Conclusion

As a neurological condition, which manifests primarily as a language-based disorder with difficulty with words, dyslexia requires a multi-disciplinary approach to its management, with an eye examination being needed to eliminate any possible effects that ocular conditions may contribute to reading problems.

The study provided the prevalence of disorders of visual acuity and refractive errors, near point of convergence, accommodation dysfunction, heterophoria, strabismus and fusional reserves among African dyslexic children of age range 10-15 years. The only vision variable that was more prevalent and that is significantly associated with dyslexia was the binocular accommodation facility, while only the near point of convergence (break and recovery) was significantly more prevalent in the control than the dyslexic group. The existence of these statistically significant differences between the two groups may not imply clinical relevance due to the small sample size. The comparison of vision characteristics between the dyslexic and control group indicates that the dyslexic children are not more at risk of having these vision condition than the non-dyslexic children although sample size was small.

Further research on African children will add to the body of knowledge about this group with respect to the relationship between vision conditions and dyslexia, about which very little is known. Only a few studies have provided evidence of the extent of dyslexia among African children, yet even a small percentage could result in many millions of children being affected, given the population of Africa. While the problems that result from dyslexia are not life threatening, they do affect people's opportunities and quality of life.

Unfortunately, many African countries do not have the resources to provide specialized schools for children with learning disabilities, and every effort therefore needs to be made to correctly identify the problems and possible causes of dyslexia. In order for African countries to implement the strategies to meet their millennium development education goals of ensuring that, by 2015, all children will be able to complete a full course of primary schooling, they need to provide not only for children in mainstream schools. They need also to plan for children whose academic ability would be enhanced by the appropriate diagnosis of learning difficulties, the provision of a simple eye test and spectacles or corrective apparatus where appropriate.

Dyslexia is not a disease for which a cure can be found, rather, long-term sustainable interventions need to be put in place to ensure that the problems are identified, and appropriate remedial action is taken to minimize the impact it has on their life. While many African countries may not be able to afford schools for children with learning disabilities, greater awareness of the manifestation of the condition needs to be made to all teachers in an effort to provide these children with the possibility of staying in main stream schools for as long as possible where there are no alternatives. With this in mind, it is anticipated that this study will contribute to the body of knowledge on vision conditions of African dyslexic school children.

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APPENDIX A. Definitions of Terms [13, 14,145,187,188]

Words	Meaning
Agnosia	Is a loss of ability to recognize objects, persons, sounds, shapes, or smells while the specific sense is not defective nor is there any significant memory loss. It is usually associated with brain injury or neurological illness.
Alexia	Complete loss of reading ability, usually acquired and is due to neurological injury in the area of temporal, occipital and parietal lobe.
Aphasia	Is a loss of the ability to produce and/or comprehend language, due to injury to brain areas specialized for these functions, such as Broca's area, which governs language production, or Wernicke's area, which governs the interpretation of language. It is not a result of deficits in sensory, intellectual, or psychiatric functioning, or due to muscle weakness or a cognitive disorder.
Auditory Discrimination	Ability to detect differences in sounds; may be gross ability, such as detecting the differences between those noises made by a cat and dog, or fine ability, such as detecting the differences made by the sounds of letters " m" and "n."
Autosome	Any chromosome other than a sex chromosome. (not on the X or Y chromosome) . Humans have 22 pairs of autosomes.
Broca's Area	Whereas the comprehension of language is more specified to Wernicke's area, production of language is situated in Broca's area. Broca's area is located in the frontal lobe by the motor cortex. Another function of Broca's area is "memories of the sequences of muscular movements that are needed to articulate words", or more simply, motor memories. Broca's area controls the movements of the lips, tongue, jaw and vocal cords when we are producing speech. Broca's area translates thoughts into speech, and coordinates the muscles needed for speaking.
Autosomal Dominant	A gene on one of the autosomes that, if present, will almost always produce a specific trait or disease.
Cerebellum	A large structure located at the roof of the hindbrain that helps control the coordination of movement, posture and balance by making connections to the pons, medulla, spinal cord, and thalamus. It also may be involved in aspects of motor learning. The cerebellum is similar to the cerebrum in that it has two

	hemispheres and has a highly folded surface or cortex.
Cerebrum	Is the largest part of the human brain, associated with higher brain function such as thought and action.
Cerebral Cortex	Is the outermost layer of the cerebral hemispheres of the brain. It is largely responsible for all forms of conscious experience, including perception, emotion, thought, and planning. The cerebral cortex is divided into four sections, called "lobes": the frontal lobe, parietal lobe, occipital lobe, and temporal lobe. The folds of the cerebral cortex give the surface of the human brain its wrinkled appearance, its ridges and valleys. The ridges are called ***gyri and*** the valleys are called ***sulci or fissures.***
Cerebral Hemisphere	Cerebral hemisphere is the two specialized halves of the brain. For example, in right-handed people, the left hemisphere is specialized for speech, writing, language, and calculation; the right hemisphere is specialized for spatial abilities, visual face recognition, and some aspects of music perception and production.
Cognition	The act or process of knowing. The various thinking skills and processes are considered cognitive skills.
Cognitive Ability	Intellectual ability, thinking and reasoning skills.
Comprehension	Understanding the meaning of words and sentences.
Corpus Collosum	Bundle of cells connecting the left and right hemisphere the brain.
Decoding	To translate writing into speech. It is the process of getting meaning from written or spoken symbols.
Encoding	The process of expressing language (selecting words; formulating them into ideas; producing them through speaking or writing).
Expressive language	Communication through writing, speaking, and/or gestures.
Functional Imaging	Techniques for obtaining images that represent physiological and metabolic processes performed by the organs of the body.
Finger Agnosia	Inability to distinguish the fingers on the hand. It is present in lesions of the dominant parietal lobe.
Incidence	The number of *new* cases that come into being in a specified population during a specified period of time.
Orthography	The orthography of a language specifies the correct way of using a specific writing system to write the language. Orthography is often used colloquially as

	synonymous with spelling. Spelling is only a part of orthography.
Logography	Writing system based on semantics or objects.
Semantics	The study of the meaning of words and phrases.
Prevalence	The number of *existing* cases of a disease or health condition in a specific population at some designated time or during some designated time period.
Phonologic Awareness	The ability to translate individual letters and letter combinations into sounds.
Phonological Coding	The ability to put together the phonemes and then verbally express words which have never been previously read or heard
Receptive	Language that is spoken or written by others and received by the individual. The receptive language skills are listening and reading.
Remediation	Adjusting the regular teaching methods in order to achieve the teaching goals for children with learning difficulties.
Socio-Cultural	Combined social and cultural factors as they affect the development of a child in all areas of life.
Syntax	Grammar, sentence structure, and word order in oral or written language.
Wernicke's area	Wernicke's area is involved with speech comprehension and is located in the left hemisphere of the brain, in the temporal lobe by the primary auditory cortex. People who have damage to Wernicke's area may demonstrate Wernicke's aphasia, have no problems communicating, but do not realize that what they are saying does not make sense to anyone else. Such people often have problems converting their thoughts into words and recognizing spoken words.

Appendix B. Request for Consent from Department of Education

Appendix C. Letter of Consent from Department of Education

Appendix D. Letter of Consent from Addington Primary School

Appendix E. Visual Acuity Conversion Table

Table 2.1 Conclusions from Major Studies on Dyslexia and Vision.

Author (s)	Areas of Investigation	No of Subjects Studied	Conclusion and Comments
Grisham and Simon [82]	Review of studies relating refractive error and reading performance.		Abundant and reliable scientific evidence that shows a higher prevalence of vision defects among reading disabled children than among normal readers. The prevalence of hyperopia among poor readers is significantly greater than among achieving readers and reported that the correction of hyperopia resulted in improved performance. Binocular conditions such as esophoria, exophoria, restricted ranges of fusion, foveal suppression, accommodative insufficiency,and oculo-motor disorders at reading range are more prevalent among poor readers than normal readers.
Latvala *et al* [3]	Visual acuity, refraction, ocular motility, near point of convergence, accommodation functions and vergence reserves	55 dyslexics, 50 control. Age range was 12-13 years	The two groups did not differ significantly from each other in visual acuity, refraction, phorias and tropias, fusion, or accommodation. There was a statistically significant difference in two variables: visual acuity and NPC . Ophthalmic factors ought not to be overlooked as a contributing factor to dyslexia as that may constitute part of the dyslexic syndrome and should be corrected whenever detected.
Aasved [4]	Visual acuity, refraction, ocular motility, convergence and accommodation functions	259 dyslexic children, no control group.	There was no causal relationship between eye characteristics and reading difficulties but eye abnormalities should be corrected when detected in dyslexic children.
Evans, Drasdo and Richards [5]	Visual acuity, refraction, ophthalmoscopy, spatial contrast sensitivity tests and Psychometric tests.	39 dyslexics, 43 controls, age range between seven years six months and twelve years three months.	It seems unlikely that the low-level visual deficits in the dyslexic group were major causes of their poor reading performance.
Hoffman [83]	Cover test, vergences, near point of convergence.	107 Learning disabled (LD) children, mean age was eight years three months	Further studies should be conducted on truly representative group.
Sherman [84]	Visual acuity, refraction, ocular	50 LD children, age range from	Eye examination of learning disabled children must include

	motility, amplitude of accommodation.	6 to 13years.	mechanical and perceptual-motor tests.
Helveston *et al* [85]	Visual acuity, Refraction, near point of accommodation, near point of convergence, ocular motility and ophthalmoscopy. The study investigated relationship between visual function and academic performance.	1910 school children attending regular school.	Visual function and academic performance were not statistically related in positive way.
Grisham *et al* [86]	Visual skills of poor readers in high school.	461 poor readers	Large numbers of poor readers in high school may be at high risk for visual skills dysfunction.
Kapoula *et al* [87]	Vergences in French dyslexic children.	57 dyslexic, 46 non-dyslexics	Vergence deficits are prevalent in dyslexic population.
Álvarez *et al* [88]	Accommodative function in school children with reading difficulties.	87 poor readers and 32 control	Findings suggest a reduced monocular accommodative amplitude and binocular accommodative facility, and suggested that accommodation functions should be assessed by an optometrist in children whose reading level is below average.
Bucci *et al* [89]	Poor binocular coordination of saccades in dyslexic children.	18 dyslexic and 13 non–dyslexics.	Poor coordination of saccades and instability of vergence during fixation of the word could be involved in the origin of reading difficulties in dyslexics.
Buzzelli[6]	Stereopsis, accommodative and vergence facility.	13 dyslexics, mean age 13 years 4 months. 13 normal readers mean age 13 years 3 months.	The possible role of vergence function should be investigated on a larger sample of dyslexics and normal.
Ygge, *et al* [2]	Visual acuity and refraction,	86 dyslexics, mean age 9 years.	No severe eye anomalies were found in any of the investigated children.
Goulandris *et al* [90].	Visual acuity, refraction, amplitude of accommodation, phoria, vergence reserves.	20 dyslexic, 20 control	Orthoptic assessments are very useful in dyslexia.
Evans, Drasdo and Richards [91]	Visual acuity, refraction,	10 children with reading	Sample size limits the interpretations of these findings.

	accommodation functions, NPC, vergence reserves.	disabilities aged between 8 and 15 years	Several areas of optometric techniques for further investigation were identified.
Rosner and Rosner [93]	Analysis of case records, refractive cases, strabismic, accommodative facility.	Retrospective analysis of 750 case records. Learning disabled and non-learning disabled patients. Age range was six to twelve years.	The relative importance of hyperopia and visual perceptual skills dysfunction was highlighted.
Shearer [96]	Refraction, phoria, convergence and stereopsis.	220 children with reading difficulties.	Vision functions are not related to reading ability.
Hall and Wick [99]	Visual acuity, refraction, amplitude of accommodation, accommodation facility, heterophoria, fixation disparity, near point of convergence	110 children, grade one through grade 6.	No statistically significant relationship between the ocular functions and reading abilities. The acquisition of reading skills is given by many factors which include the use of remedial instructors and language skills, role of peer pressure and innate intelligence.
Evans, Drasdo and Richards [100]	Accommodative and binocular functions.	39 dyslexics, 43 control. Age range was between 7 years, 6 months and 12 years 3 months	Accommodative and binocular functions are non-casual correlates of dyslexia.
Evans *et al* [101]	Lateral phoria	45 Specific learning disabled (SLD) children, 364 controls.	There was a statistically significant difference between the groups ($p>0.02$). Phoria may not cause reading or learning disability but could contribute to visual perceptual and attentional abnormalities.
Ygge *et al* [102]	Oculomotor and accommodation functions and vergence reserves.	86 dyslexics, mean age 9 years.	Ophthalmologists must offer careful eye examinations and treat any ocular, orthoptic, or neuroophthalological problems that make reading difficult for the dyslexic child.
Metsing and Ferreira [103]	Accommodative functions, vergences facility and reserves.	112 children from mainstream school and 112 from learning disability school.	It is important for full and proper visual screenings to be conducted at schools, irrespective of whether the school is a mainstream or school for the learning disabled.