Visual dysfunction: a contributing factor in memory deficits, and therefore learning difficulties?

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Visual dysfunction:

a contributing factor in memory deficits,

and therefore Learning Difficulties?

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.
ABSTRACT

Visual dysfunction: a contributing factor in memory deficits, and therefore learning difficulties?

This thesis is based on Educational Therapy (ET) practice which has found eye muscle imbalance is a key factor to be addressed in management of learning difficulties (LD). This level of oculo-motor (o-m) function is a “hidden” handicap as individuals are unaware of the problem; it is not routinely tested; and is not generally included in learning difficulties research. O-m function is omitted in standard paediatric optometry tests, and in school vision screening. Eye exercises increase the range of binocular fields of vision by employing stereopsis glasses and red/green slides. Central vision loss was uncovered when students reported words, seen by only the right eye, “disappear” or “switch on and off”. When the left eye was covered, right eye vision returned but was lost again with binocular vision, even though larger shapes on the screen remained complete. In effect, global vision was unaffected while right eye central (foveal) vision was suppressed. This is considered significant because students attending ET have learning difficulties with phonemic memory, spelling and reading deficits, which are predominantly left hemisphere processes.

The aim of this three-part study, consisting of School Survey, ET Intervention study and Case studies, was to: a) determine whether o-m dysfunction was found in a girls’ school population and/or was associated with LD; b) set up an Intervention study to explore the effects of vision training on the outcomes of a subsequent week-long word-skills programme in the ET practice. Two case studies were also examined, that of matched senior school boys whose outcomes were significantly different; and c) examine more closely the common pattern of muscle imbalance in two case studies of current junior school students. This tested the therapy assumption that mal-adaptive sensory feedback was contributing to o-m dysfunction. This notion is based on the Luria (1973) Model of Levels of Neural Function which provides the framework for ET practice, and the Developmental Model of LD that has evolved, in application and explanation.

Part 1 School Survey. This exploratory, cross-sectional study included a randomised sample of 277 participants in a private girl’s school. A 7-10 minute screening was provided by five optometrists, with an expanded protocol including o-m function. Also assessed were academic standards of reading comprehension and spelling, reasoning, visual perception, phonological skills, auditory, visual and phonemic memory, and arm dominance. Results showed visual
dysfunction and mixed eye dominance in approximately equal numbers. Of the 47% girls with visual dysfunction, not all had literacy problems; however, LD students had corresponding degrees of o-m dysfunction, memory deficit and mixed hand/arm dominance.

Part 2  Intervention study. The Research Question for the Intervention Study was: Does the difference in learning standards depend on which eye is disadvantaged in the case of weak binocularity? This question was answered by determining the outcomes to literacy levels once normal binocular o-m function and stable eye dominance were established. Twenty-four students (6 to 18 years) had Behavioural Optometry assessment prior to commencing therapy and were found to have o-m dysfunction, undetected by previous standard optometry tests. Eye exercise results showed 62.5% of the group had changed from left to right eye dominance. The dominance criterion was set by this group, indicated by the right eye holding fixation through full range of fusional reserves (binocular overlap), together with superior eye-tracking speed >20% by the right, compared to the left, eye. Associated significant gains in literacy and phonemic memory were also achieved by the newly established ‘right-eyed’ group. In spite of undergoing identical treatment, the ‘left-eyed’ group retained limited foveal binocularity, and made less progress in literacy outcomes.

Part 3 Two current Case Studies. Present ET practice benefited from insights gained from the 36% ‘unsuccessful’ participants of the previous study. Better therapy outcomes are achieved from an integrative motor-sensory approach, supported by Podiatry and Cranial Osteopathy. This detailed study involved two junior school boys who exemplified a common pattern of physical anomalies. For example, RW (8-year old male) had ‘minimal brain damage’ and LD that co-occur with unstable feet and o-m control, postural muscle imbalance, poor balance, motor co-ordination and dyspraxia. After 18, two-hour therapy sessions over nine months, he is now reading well, his motor co-ordination, eye tracking and writing are within the ‘low normal range’, and he is interacting competently with his peers.

Learning difficulties can be conceptualised as a profile of immaturities. The results of this three-part study have shown that once the ‘hidden’ handicap of right eye suppression is overcome with balanced binocular fields of vision, learning difficulties are ameliorated. This is affirmed by the positive gains achieved by these students, not only in literacy skills, but also ‘outgrowing’ immaturity in motor-sensory-perceptual development.
DECLARATION

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Chapter 1
INTRODUCTION

Visual dysfunction as a contributing factor in Learning Difficulties (LD)

This thesis addresses visual dysfunction from the perspective of an educational/behavioural optometry point of view. This approach considers that motor, perceptual and cognitive deficiencies commonly seen in children and adults with LD may be due to developmental consequences of small visual anomalies.

Briefly, the therapeutic imperative arising from this thesis is that a distinction needs to be made between assessment of specialised visual requirements for learning and literacy, compared with that of vision for safety and simple activities of daily living. Researchers who find no link between visual function and LD may in fact be using measures inappropriate for children learning the 'visual symbols of language'. The assumption underlying this research is based on professional experience of a common profile of visual anomalies that co-occur with LD, in all students attending Educational Therapy and forms part of the data base of the study. It is assumed therefore that neural interference from these deficits may have contributed to disrupted early childhood development.

Given that neural development, of visual and associative pathways, is of prime importance for cognitive development of a child, the ultimate purpose of the thesis is to pose questions for further research regarding the need to broaden the scope of visual assessment to include o-m function of children in general, in particular, those students with LD (see Section 1.5, Definition of terms).

This developmental approach is contrary to the medical approach as expounded in the paediatrics and ophthalmology policy statement (1998), which states:

Learning disabilities are common conditions in pediatric patients. The etiology of these difficulties is multi-factorial, reflecting genetic influences and abnormalities of brain structure. Early recognition and referral to qualified educational professionals is critical for the best possible outcome. Visual problems are rarely responsible for LD. No scientific evidence exists for the efficacy of eye exercises (“vision therapy”) or the use of special tinted lenses in the remediation of these complex pediatric developmental and neurological conditions (American Academy of Pediatrics, 1998, p.1217).

While this strongly held opinion guides current practice, current paediatric vision tests, including those conducted in schools, are restricted to simple acuity screening (Anderson, 2005). There are three limitations of this medical model, namely:
1. Standard optometric tests and school vision screening fail to make allowances for the
dynamic conditions of eye movements.

2. Static conditions of standard acuity tests fail to account for effects of fatigue and eye
muscle weakness, or subtle imbalance or incoordination when the eyes are moving
when reading and writing.

3. It omits to consider the possible impact of poor eye teaming on growing children. That
of o-m dysfunction and imbalance between the eyes on the neurological development
of visual pathways and associated sensory modalities.

While there continues to be mixed results from research of this medical model, with
controversy between medical and developmental theoretical models in principle and practice,
then the visual function component of this complex problem will continue to be obscured and
neglected. Clarity of definition, about what might be contributing factors, as opposed to causal
factors, is important for effective intervention programmes and direction of effort. Therefore,
the co-occurrence of o-m dysfunction in relation to LD is an important research topic.

Bowen (2002 Sept) rebuts the Paediatric and Ophthalmology (AAP/AAO/AAPOS) position
papers of 1998, 1982 and 1971, which assert there is no relationship between LD, dyslexia and
vision. Bowen's review is drawn from 1,400 identified references from Medline and other
database sources in order to examine levels of evidence in support of the 1998 position paper.
Bowen concludes that:
AAP/AAO/AAPOS (1998) position paper should be retracted because of the errors, bias and
disinformation it presents ... as it misrepresents a great body of evidence from the literature
that supports a relationship between visual and perceptual problems, as they contribute to
classroom difficulties (Bowen 2002, p.553)

Sensory maturity
This thesis addresses an Intervention Study and Case Studies which specifically examine the
developmental importance of o-m function for children learning to read and write, to better
explain and treat LD from the perspective of primary care-givers, namely, parents, teachers,
therapists and also administrators. When starting school, each child needs a level of sensory
maturity for 'school-readiness', (as shown in Figure 1) to support the ontologically advanced
symbolic memory system on which literacy is based. A task analysis of reading and writing
shows students must be able to assimilate and integrate auditory and visual information, when
transposing their already acquired language into its symbolic form, as literacy. In spite of
bridging experiences being provided in primary grades, a proportion of otherwise 'normal'
students still lack adequate basic abilities required for literacy. Consequently they fall further
and further behind their peers and consequently qualify as having 'LD' (see Definitions of
terms 1.5).
Purpose of the research plan

The purpose of this thesis is a therapeutic one. In Part 1, a ten-day snapshot assessment of 277 girls in a private school was conducted. Their visual function, perception, memory and literacy skills were measured. This was followed in Part 2 of this thesis with an intervention study consisting of vision training, followed by a word skills programme, for a sample of 24 students who were attending Educational Therapy. The purpose of the intervention was to determine:

1. how much importance might be placed on the observation that o-m dysfunction co-occurs with LD
2. review the nature of the practice and treatment protocols in the light of these findings;
3. validate findings of Part 1.

The follow-up, Intervention Study investigated how reading and spelling might be affected once normal foveal binocularity and stable eye dominance had become established with eye exercises.

The notion that o-m (o-m) dysfunction might interrupt connections with other sensory modalities, with neurological consequences, is supported by Wiesel and Hubel (1965) who state "abnormalities in neural functioning by subtle alterations of the sensory input ...depends not only on the amount of incoming impulse activity, but also on a normal inter-relationship between activity in the different afferents" (Wiesel and Hubel 1965, cited in Bach-y-Rita 1972, p.51-2). In both these ways the quality of sensory input is "the stimulus to growth that determines the 'architecture' of neural connectivity" (Purves 1994, p. 45) and so, anomalies of a weaker eye may cause neural development to deviate from latent pathways, of the "ocular dominance columns ... as during the process of 'address selection' [pre-determined destination – author's addition] axons must correct their early 'mistakes' by removing inputs from the
'inappropriate' eye" (Shatz, 1992, p. 36-7), a maturation process that may be hampered by ongoing o-m dysfunction and anomalous sensory input, contributing towards perceptual maturity and disruption to selective attention (see Section 3.4.1a SIS memory).

Too often students with LD are found to have 'normal' 20/20 vision under static conditions of eye tests, so are assumed to have no visual problems. However o-m dysfunction in these individuals can cause uneven eye posture and unreliability of focus, eye tracking and teaming, with weakened binocularity (Howell, 1986 see Section 3.1.5). In spite of normal acuity, in working conditions that involve eye movements, o-m imbalance can prevent accurate aiming of the all-important central (foveal) vision which discerns fine detail like print. Palmer (1999) states in his review of vision science that the prime function of o-m function is "fixation to position target objects of interest on the fovea where visual acuity is highest; and tracking to keep fixated objects on the fovea despite movements of objects or observer’s eyes or head (Palmer 1999, p. 520). Monaghan and Shillcock (2005) propose a model of LD as “hemispheric desynchronisation associated with visual anomalies within the two foveal fields of vision”, with ultimate “disruption within the cognitive representations involved in reading” (p. 45).

In practice, visual anomalies appear to co-occur with poor eye-hand co-ordination, lack of attention to sequential detail, together with weak auditory-visual links shown as poor phonological development and phonemic memory. Thus, any visual anomaly that adversely affects clear vision for near-work to identify visual symbols and encode memory traces; or weakens binocularity for bi-hemispheric integration of visual information; or impedes the feedback needed for fast, accurate eye movements for reading and writing, all or any of which can be said to contribute to LD.

Motor-sensory-cognitive deficits within a multi-deficit hypothesis of LD is supported by Ho (2002) who reports multiple impairments in one or more domains of rapid naming, orthographic, visual, and phonological processing that appear to contribute significantly to reading and spelling failures in Chinese dyslexics (Ho, 2002, p. 549). Willows, Corcos and Kershner (1993) found “verbal and visual processing factors ...and memory were prominent factors accounting for differences in orthographic processing between disabled and normal readers” (p. 173). This is the position held by Prideaux, Marsh and Caplygin, (2004) in which they suggest current research “highlights the need to enhance auditory and visual; and visual to auditory processing” (p. 10).
The clinical assumption underlying these studies is that o·m dysfunction may manifest as part of the 'LD' profile by academically disadvantaged students. The co-occurrence of anomalies of visual function, reduced memory span, in particular phonemic memory, suggests treatment of o·m dysfunction might ameliorate apparently associated LD. This thesis explores this question, to ascertain the degree of relationship that might be found between visual function (i.e. acuity and o·m function), memory and literacy. There is a growing support for this developmental approach from number of researchers in the field (Bassou, Granic, Pugh, & Morucci, 1993; Coltheart, 1980; Cornelissen, Salmelin, Tarkiainen & Helenius, 1999; Howell & Peachey, 1990; Lovegrove & Garcia, 1990; Newman, 1985; Pammer & Cornelisson 1998, 1999; Rayner, 1978; Robinson 2004; Stanley, Howell & Marks, 1988; Wimmer, 1993; and Stein, Riddell & Fowler, 1986; Stein, Riddell, & Fowler, 1989; Stein & Fowler, 1993; Stein & Walsh, 1997; Stein & Talcott, 1999; Stein, Richardson & Fowler, 2000; Stein 2001, 2001b; Talcott & Witton, 2001a). This list includes practicing Behavioural Optometrists who are specialists in o·m function and vision training. However, there is agreement that as yet there is no consensus about causal factors of LD (Snowling, 2001; Stein 2001), consequently there is little support for the treatment of visual anomalies in the management of LD, from either medical or educational professions.

This thesis argues for a 'developmental model' of literacy based on the quality and bi-lateral balance of sensory input, primarily auditory and visual (see Sections 3.1.1 & 3.1.2). Stein (2001b) states that children teach themselves to speak but need to be taught how to read as it is harder. This is because “We speak in words and syllables, but write in phonemes” (p. 509), consequently auditory discrimination is needed to segment words into individual sound units to be linked with its visual letter equivalent, additionally with sequences of letters and spelling patterns (orthography) of word forms (Stein, 2001), through the associative sensory system. The reliability and integration of auditory and visual signals ultimately influences accuracy of perception and reliability of symbolic memory. This concept is supported by Luria (1973, p. 74), “A disturbance of lower zones of the corresponding types of cortex ...must lead inevitably to incomplete development of higher cortical zones”. It follows that memory can be considered as the medium through which language-based learning is integrated with the visual symbols of language, that ultimately determines the level of comprehension and expression of literacy.

The developmental working model on which this thesis is based argues that motor, perceptual and cognitive deficiencies commonly seen in children and adults with LD may be due to developmental consequences of small visual anomalies. In spite of being minor, intermittent aberrations can significantly disrupt latent dominance pathways, or interrupt connections with other sensory modalities. This model has continued to evolve, from the observed pattern of
visual-perceptual-memory deficits commonly found in individuals with LD. This view is further reinforced by Part 2 Intervention Study that shows positive gains in literacy and learning efficiency once visual problems are corrected, near vision is clear and eye movements are coherent, so that balanced binocularity and stable eye dominance are achieved.

It is not being suggested that o-m dysfunction is a direct or sole cause of LD, but rather is an important aspect of auditory-visual integration for phonics, as well as for the totality of sensory stimulation that 'informs' the brain and promotes neural development. It is on this basis that this thesis canvasses awareness of the limitations of current paediatric vision testing. Specifically to identify students who might benefit from assistance to improve visual function, thereby lessening their degree of learning difficulty and enable them to achieve parity with their peers.

1.1 Current Causal Theories of LD

A snap-shot view of current research

A review of the current literature indicates that the directions of contemporary research is an ongoing effort to identify at what point auditory and/or visual processing fails to support tasks inherent in literacy. This sensory integration requires a high level of motor-sensory-perceptual development to support cognitive skills and literacy which is considered to be a pinnacle of human evolution. Findings and theories expressed in these research findings, when taken as a whole, amount to a collective statement about different aspects of a continuum of LD, by leading researchers in the field.

A summary of papers, submitted to the Essex University Symposium "Sensory basis of reading and language disorders" (2001), focuses on the sub-groups of specific language disorders and dyslexia. Topics that are considered as contributing to deficits in literacy and language are ranked here in order of causal probability. Auditory processing deficits are claimed to be most common, including phonological deficits, together with auditory sensitivity and speed of auditory information processing. Other papers include support for a "dual pathway model" of auditory and visual deficits, including transient auditory and visual sensory systems of the magnocellular pathways; cerebral hemispheric anomalies; balance, co-ordination and nutrition in cerebellar abnormalities, and genetics were also included in this comprehensive collection of papers. The following review of abstracts provides a context in which visual phenomena investigated in this thesis can be located.
Auditory processing deficit theory as the causal factor in dyslexia

A review of the Essex symposium shows central-auditory information processing is generally considered to be the major factor in reading difficulties, based on the fact that dyslexics have in common insufficient access to phonemic structure and sequence of sounds to match with spelling. As Snowling (2001) observed, the relationship between dyslexia and other learning disorders is not fully understood, however, language based deficits are possibly the causal link "in the output rather than input systems" (Abstract). Reid Lyon (1995) overviewed 150 current research papers on dyslexia. He found agreement in a root cause as the result of an inability to distinguish and process the sounds that make up speech, "with reading disability most precisely measured at the single word level and causally associated with phonological deficits (p. 2). Fletcher and Siegel (1994 cited Shaywitz 2002, p.1) found phonological impairment represents the most reliable predictor variable.

Much of scientific literature finds specific problems of dyslexia are mainly associated with speed of auditory processing, phonological skills required to learn to read at the critical time, verbal memory and labelling, (Goswami, et al., 2001; Hartley & Moore, 2001; Snowling, 1987 p. 148; Tallal, et al., 1996; Talcott, Witton & Stein, 2001; Wright, Zecker & Bowen, 2001). Dissenting observations are made by Watson and Watson (2001) who assert "measures of auditory processing in primary school children are unrelated to general speech recognition skills, or any aspect of academic achievement" (Abstract). Nittouer (1996) could find "no evidence in favour of a temporal processing deficit (cited Gerrits 2001, Abstract).

In general, it would appear that dyslexia can be distinguished from other learning disorders by identifying the phonological deficit, inaccurate and laboured decoding for word recognition and oral reading of text, in particular unfamiliar words, so these individuals continue to remain slow readers and poor spellers. These problems can also be identified in a variety of students, with other diagnostic labels, attending the 'Educational Therapy' practice in this study.

The Literature Review is extended and continued in Chapters 3, 9 and 10, as further information was sought to support findings from the Intervention Study and the two junior boys case studies in Chapter 8. Specifically for contemporary research into the influence of instability of eye dominance and binocular fusion of foveal vision, related (another word?) to outcomes of the word-skills programme.
1.2 Significance of the Study

Uncertain origins of LD lead to uncertainty in treatment direction

An accurate understanding of contributing factors in LD allows for effective intervention. Varying types and degrees of help are available, but not necessarily to all who need it. In spite of considerable research into dyslexia (Coltheart, 1980; Cornelissen, 1992; Fletcher, 2002; Lovegrove, 1990, 2001; Reid Lyon, 1995; Robinson, 2002; Shaywitz et al., 2002; Snowling, 2001; Stein et al., 1986, 2001; Talcott, 2002), which is one sub-group of LD, there remains a universal problem in management because of a lack of definitive explanation that can be both descriptive and prescriptive.

Parents, teachers, and policy makers require early identification of problems, to find the most appropriate therapeutic and educational intervention. Research based simply on statistical incidence of LD, matched against current acuity tests, may not be sufficient to uncover existing links between learning and vision. This approach taken in the Educational Therapy study is reported in Part 2, Chapter 7 and 8 of this thesis. It is considered to be a more naturalistic, clinical approach which allows for correction of abnormal visual function prior to any other remediation. Causal factors deduced post hoc, from the evaluation of any changes in both visual function and learning skills have become guidance for further remedial management of this complex topic.

Labels which deliver pre-determined outcomes

In principle, educational therapy supports motor-sensory-cognitive development to provide assistance and therapeutic challenges to extend students. A thorough understanding of an individual's condition is needed to explore avenues of improvement within his/her capacity. Without this understanding many children needing help may be overlooked; or challenged beyond their capacity leading to discouragement, or even alienation; or conversely, over-protected in an attempt to 'shield' a labelled child. This may hinder his/her development, if the child has learned to be 'helpless' and avoid normal, challenging activities. In effect, labels can compound problems of an already disadvantaged child and become fact, as a self-fulfilling prophecy, unless carers have sufficient understanding to effectively facilitate development.

Discipline needs to be encouraged with extra time and training provided in order to develop basic learning skills of perception and memory. In the long term, it is only an individual's improved competence that leads to a healthy self-belief, rather than by protection or artificial self-esteem boosting. An integral part of developing confidence is adequate sensory input to support the individual in challenges implicit in personal development. Assumptions associated
with labels can contribute not only to limitations for the child, but also institutional limitations. Resources and effective provision of services are necessary to support people of any age or condition, including mental or correctional institutions, who are struggling with LD.

"Clear vision isn't much help if you can't see straight"
This statement sums up the sub-liminal situation experienced by students with o-m dysfunction, of which they have no subjective awareness, until they experience the nature of these difficulties under the controlled conditions of eye exercises. This involves a form of biofeedback, with verbal descriptions of what they should be seeing as guidance through the exercises. The intent of vision training is that it will eventually raise students' awareness, with evidence of the brain's plasticity, when they begin to perceive what was not apparent before.

In normal working conditions - as opposed to standard vision tests where head, eyes and target are stationary, o-m co-ordination of the two eyes is required for tracking, scanning and an integrated ratio of vergence-to-accommodation for changing focus, to enable foveal fixation and fusion of the two retinal images of print into one perceptual image (Emsley, 1977; Howell & Peachey, 1990; Shillcock et al., 2001a). It is being argued that a weaker eye leads to intermittent degradation of one visual pathway that may weaken binocularity and interrupt bihemispheric integration of visual information.

The term 'visual dysfunction' indicates anomalies resulting in integrative failure in aspects of vision, due to differences between the eyes in acuity, eye muscle balance or eye movements, leading to poor eye teaming. Effects of this o-m dysfunction may include weak binocularity, poor focus and convergence for near work, or inaccurate movements. Any of which can interfere with speed of visual processing, adequacy of visual perception and eye-hand coordination, as well as learning skills. The basis for this concern is that it is apparent, from working with these students, that quite small o-m deficits can have a deleterious effect on the overall visual function, disproportionate to the size of the visual problem. Clusters of minor, intermittent problems are likewise common with these students.

The relevance of these 'clinically insignificant' problems is that for students, their quality of attention, perception and analytical skills generally improves following successful vision training, resulting in greater ease of learning and reliability of memory. This suggests o-m dysfunction may have been disrupting their learning processes. This description fits part of the pattern of perceptual and LD manifested by academically disadvantaged students in this
practice, as also reported by researchers (Juttner & Rentschler, 1997; Monaghan & Shillcock, 2005) and within under-achievers in an elite group of exceptional children (Congdon, 1989). The importance of this Educational Therapy approach, in a topic of such developmental complexity, is that the exact nature of factors contributing of LD will remain obscure unless intervention programmes can incorporate vision therapy, and demonstrate results from best practice. It is out of this work that a functional definition might emerge, rather than relying on proof of direct causal factors in experimental studies.

1.3 Purpose of the Study
The aim of this thesis is threefold, namely to:
a) investigate aspects of o-m dysfunction which are prevalent in disadvantaged learners;
b) identify what areas of learning skills are most likely to be affected; and
c) show what the results might be when visual training is effective in establishing normal visual function and stable right eye dominance as a means of notionally addressing limitations of current paediatric vision testing.

1.4 Research Questions
Clarifying terms of reference in the research plan
In brief, this three-part study investigates anomalies of memory and literacy performance in relation to visual dysfunction. This refers to any acuity or o-m dysfunction that may compromise the ability to sustain binocular foveal vision in near work, or may be associated with immature basic abilities of perception and memory, that ultimately impacts on standards of reading and spelling. It is reasoned that an association between o-m dysfunction and learning may indicate under-achieving students, whatever their learning status.

This thesis seeks to answer two aspects of the general research question. Firstly, to establish whether or not the visual problems found in the students with LD are also common in the normal school population, particularly amongst successful students. Of particular interest is weak binocularity, accommodation and convergence inadequacy (see Definition of terms 1.5), to establish whether or not this type of o-m dysfunction is both common and without negative consequences for learning. In effect, the aim is to estimate the prevalence of o-m dysfunction in a school setting, to establish whether any of these anomalies are associated with memory deficit or difficulties with literacy, as is found in Educational Therapy practice. The second
aspect of the question is to investigate possible effects of o-m dysfunction on dominance and to evaluate differences in educational outcomes after eye exercises, between those students who achieve normal visual function and stable eye dominance, and those who do not.

RESEARCH QUESTION 1

"Is there an association between anomalies of visual function (including acuity and o-m function) and LD, specifically in terms of visual perception, memory, spelling, reading comprehension and reasoning skills? As this complex question encompasses many different aspects, analysis of the data will seek to answer the following sub-questions as a way of answering the main research question.

Sub-questions for School Survey addressed in Chapter 6:
1. What proportion of students have visual dysfunction and of what type?
2. Do students with normal versus visual dysfunction differ in reading ability?
3. Do students with normal versus visual dysfunction differ in spelling ability?
4. Do students with normal versus visual dysfunction differ in memory span?
5. Is there a link between reading comprehension, spelling, and memory deficit?
6. Do students with established right eye dominance versus mixed or left-eye dominance differ significantly in reading comprehension, spelling, and memory span.

RESEARCH QUESTION 2

"Does newly established right eye dominance influence an individual's literacy level and memory function following a word skills intervention programme"?

Specifically, this question asks if there is a difference in reading comprehension, spelling and memory span between those students whose eye exercises have resulted in normal visual function and established right eye dominance, compared with those students who have undertaken the same eye exercises and word skills programme, but still display mixed or unstable eye dominance.

Implications of positive outcomes of vision training on learning skills

Evidence of any significant differences in literacy results from the Intervention Study would firstly, validate inclusion of o-m tests into the assessment protocols for ‘at risk’ children. Secondly, if this were to become a normal part of paediatric optometry and school vision screening, it would serve to acknowledge that a different set of criteria may be needed between adults and children in visual tests. Given that neural development, of visual and associative pathways, is of prime importance for cognitive development of a child, the ultimate purpose of the thesis is to pose questions for further research regarding the need to broaden the scope of
visual assessment to include o-m function of children in general, in particular, those students with LD.

**RESEARCH QUESTION 3**

Where in the associative sensory network, of individuals with LD, are connections failing or mal-adaptive adjustments being made? This question relates to the presenting pattern of physiological anomalies which is common to students with LD being assessed for Educational Therapy. This pattern includes unstable arches, spinal muscle imbalance, neck tension and o-m dysfunction, which might impact on physical comfort, sensory integration, and learning skills.

### 1.5 Glossary of Terms - Descriptive, rather than Definitive

Simple, descriptive terms or ‘common names’ are employed in this thesis, to assist clarity in a complex topic, rather than using the more accurate, but complex technical definitions employed by optometrists. Terms are arranged in alphabetical order, under four categories, LD; Dominance; Visual Terminology; and Optometric terms and functions.

**Learning Difficulties:** In this thesis LD refers to limitations in visual perception, memory span, and literacy skills and bi-hemispheric processing, which are multi-faceted, developmental aspects of learning not easy to define. The term is used generically to describe problems experienced by otherwise intelligent individuals who have no neurological signs or social/educational disadvantage to explain slow and unreliable development of literacy and numeracy skills (Critchley, 1970, p. 11; International Dyslexia Society cited in Fletcher, 2002, p. 27). Identification criteria used in schools, is reading age deficits between one and two years below chronological age. LD as a descriptive term can be associated with any diagnosis or condition. A sub-group identified as Specific LD (SLD) or Developmental Dyslexia (DD), within a wider range of manifest LD, have been extensively researched and reported in this thesis.

**Symbols / grapho-phonemes:** letter symbols representing the smallest unit of individual sounds (phonemes) which when combined become recognisable words. Grapho-phonemes, of integrated letter/sounds, are stored in memory as one element having interchangeable visual and auditory components. They are conceptualised by the author as a two sided, dyadic percept of a mental product having the combining power of two elements, namely auditory and visual
signals through the angular gyrus in the associative network (Luria, 1973; Shaywitz, 1998; Prideaux, 2004).

Arm / hand dominance - A discrepancy between latent arm dominance and preferred writing hand is referred to as 'crossed' or 'not established' dominance. The 'crossed arm test' was used as an indicator of latent laterality (Luria-Nebraska Neuropsychological Battery, 1966), whereby the dominant hand is that which is uppermost when the arms are folded. If muscle tone of one eye is weaker in the latently dominant eye, then hand preference will generally follow this perceptually dominant eye, in eye-hand co-ordination when a child is first learning to eat with a spoon, possibly becoming left handed 'by default'. A 'preferred' eye in traditional tests of dominance may not necessarily be the neurologically dominant eye, with alternating dominance, or 'unstable' eye dominance as indicators of such an anomaly. Developmentally, a misdirection of laterality may occur early in childhood as “using one hand dominantly starts in the second year, when the first function of the corpus callosum can be found” (Chilton Pearce 1977, p. 142). Part 2 Intervention study addresses the vexed question of what constitutes true eye dominance.

Eye dominance
Eye/hand dominance is the preferred eye matched to the writing hand.
A standard motor test to establish the ‘preferred’ eye is used in a monocular manner aiming along a pointing finger, for distance viewing, or to look through a small hole, for near viewing. This is distinct from sensory or perceptual superiority or stamina under binocular conditions, as this can depend on the activity or test, or level of fatigue or health. Even under vision training conditions where every response is recorded, eye dominance is difficult to determine and can be considered as a ‘survival of the fittest’ computation made by the brain, depending on circumstances. Mixed or unstable dominance may be due to a latently dominant eye becoming recessive by default owing to effects of o-m dysfunction on the “weaker” eye (in terms of muscle tone or co-ordination). It is being argued that, only when normal visual function is established in both eyes, true genetically latent dominant eye becomes apparent. That is, in a balanced partnership between two functionally equal eyes, within an optimal range of overlepping fields of vision.

Muscle dominance -- posture of any part of the body is maintained by dynamic balance within opposing musculature, between flexors and extensors. Eye posture (phoria) is likewise a balance between abductors and adductors. In the case of muscle imbalance, one muscle may be 'weaker' due to low muscle tone, trauma or neurological causes. Often when supervising eye
exercises, it is apparent that one set of muscles is tense and the opposing one stretched and weaker, in effect a tighter muscle will become the determining factor in visual dysfunction. In accommodation, vergence and phoria the eyes may be ‘out of balance’ due to muscle weakness resulting in weak binocularity, eye teaming and bi-hemispheric integration.

Visual Function

Vision: involves “three agencies that are essential for vision, namely light, the visual mechanism of the nervous system and the mind” (Emsley 1977, p. 1).

Visual Function: is a generic term that refers to both acuity as well as the dynamic processes involved in eye muscle, o-m function that directs anatomical parts of the eye, in order to facilitate stimulus for vision. These include the lens and retina for acuity, and eye muscles that position the eyes, provide eye movements and focussing mechanisms, in order to achieve optimum clarity of vision in a changing, working environment.

Visual dysfunction indicates Visual risk: in this thesis these interchangeable terms refer broadly to the group of subjects with any anomaly adversely affecting vision. This might acuity, or eye muscle weakness or imbalance that adversely affects the ability to sustain binocular foveal vision in near work, eye-hand co-ordination, or postural balance. The strain involved in working to maintain functionality under these circumstances contributes to fatigue, stress, poor concentration and motivation, and possibly under-achievement at any level of learning status.

O-m dysfunction: refers to specific eye-muscle function, of focus, eye movement and co-ordination and the characteristics of the group of subjects with any anomalous eye muscle weakness adversely affecting binocularity or clarity of vision, not related to lens shape acuity. It includes either imbalance of eye posture; vergence insufficiency, in converging or diverging the eyes to match focus in near and distance vision; focus is termed accommodation in optometry; or pursuits, tracking or saccades, which separately or in combination may result in blurred vision or anomalous retinal images, not due to poor acuity. An individual may have perfect acuity in the test situation, but poor attention to detail and weak binocularity when working if the eyes are not oriented and responding correctly for foveal fixation to be sustained in the detail-sensitive area, with cones cells, in central vision. That is, if instead of the fovea, the outer macula or peripheral vision - which is supplied by rod cells and do not discriminate colour or fine detail - is aimed at the point of interest. If one eye is mal-aligned, the individual may not necessarily be conscious of the difference, so long as perceptual clarity is maintained.
'Weak' eye describes the eye with less muscle tone, slower reaction time or co-ordination, or the eye is 'recessive' and loses fixation first under vergence stress in the case of poor eye teaming. A 'lazy' eye is heterophoric (out of alignment) in posture, as in strabismus.

Optometric terms and functions (see Appendix A)

The notes in Appendix A provide a functional description of technical visual terms relevant to an analysis of how minor o-m dysfunction can disrupt neuro-sensory integration and affect information processing. In effect these notes are interpretations of clinical observations, with the specifics of vision sourced primarily from Emsley (1977). This is not a modern text but provides a breadth of interpretive comment that supports the level of this thesis, for both the author and readers lacking an optometric background.

1.6. Summary of Thesis Chapters

The thesis has been broken up into the following sections:

Chapter 2 addresses the background to the development model proposed in this thesis, which is based largely on the work of Luria (1977) who provided a theoretical framework for therapeutic principles.

Chapter 3 addresses a wide ranging literature review of the field. This is necessary as the problem is a multi-disciplinary topic which covers not only causal theories of LD, but also the memory system and perception, all of which are relevant to the findings of these studies.

Chapter 4 addresses the quantitative and qualitative methodology used in the research reported in this thesis. As previously explained, these studies were initiated as a clinical exploration consequently they do not follow a traditional research plan. Quantitative analysis of data is employed, with interpretation of results couched in a qualitative style suited to the therapeutic nature of the topic.

Chapter 5 addresses the analysis of the 10 day school survey. There are three aspects of the analysis - the statistics derived from archived data, the raw results and the therapeutic interpretation. The school survey showed a positive correlation between literacy and memory deficit, between memory and visual dysfunction and also arm dominance. A key variable was phonemic memory. An interesting result is that 47% of the school sample had visual dysfunction but only 30% of those had reading difficulties. This finding raised the question on
which the follow-up study was based, namely, in the case of weak binocularity, did academic standards rely on which eye was dominant?

Chapter 6 addresses the intervention study methodology with the aim of quantitatively measuring any improvement in o-m improvement, dominance and literacy gains, and whether there was an association between these three variables.

Chapter 7 addresses the results and interpretation of the findings of the intervention study. This chapter describes a series of eye exercises which assist in re-establishing the natural dynamics of the visual pathways to the language area of the brain. The results showed that once both eyes were equal in o-m function, students who achieved greater than 20 dioptres of binocular foveal overlap were likewise found to have a right eye scoring capacity greater than 20% more than the left eye on a computer based tracking exercise. Range of foveal binocularity and superior right eye tracking capability were used as 'dominance' criteria in dividing the sample into two groups for statistical analysis of results. Although on average, there were significant gains for all students on the Educational Therapy programme, there were significantly greater gains made by students who had changed naturally from left to right-eyed dominance.

Chapter 8 addresses the philosophy of the therapeutic approach. An undergirding assumption is that in order to correct higher order deficits, a clear, strong baseline of lower order mechanics is needed for optimal proprioceptive feedback and sensory network associations. The assessment, ongoing treatment and results of two current students, provide insights into present Educational Therapy practice. These results support the view that improved sensory integration and o-m function greatly enhance the children's rate of cognitive development and literacy.

Chapter 9 summarises and integrates the findings from earlier chapters. It provides a notional model of right eye 'drift' to explain the finding of right eye foveal visual suppression frequently observed during eye exercises, which it is argued contributes to left-hemisphere-neglect and LD. This chapter also addresses the adequacy of the Development Model to map theory to practise. Findings support the premise underpinning this thesis, namely that o-m dysfunction responds to remediation and can also ameliorate LD.
Chapter 2
CONCEPTUAL BACKGROUND

2.1 Theoretical Framework of Educational Therapy

The source of details on optics of vision is from Emsley (1977) who provides a functional perspective for the understanding and supervision eye exercises. Clinical observations are informed by Luria’s model of three levels of Mental Function (1973).

2.1.1 Luria’s model of neural function as a working model

Aleksandr Luria (died 1977) was one of the founders of neuro-psychology, who combined research into local brain lesions with analysis and interpretation of cognitive functions of learning and forgetting, perception and attention. His observational tests, including the folded arm test of latent dominance used in this study, (Luria-Nebraska Neuropsychological Battery, 1966) were the source of information about neural processing, before the age of brain imaging. Such as functional MRI (magnetic resonance imaging) whereby neural function is now mapped electronically as subjects perform tasks. Luria’s work has provided a theoretical framework out of which therapeutic principles have evolved into the developmental working model on which this thesis is based (see p. 18).

The Developmental Model that has been unfolding supports a view that quality of learning depends on the scope, speed and reliability of the memory system. The memory is in turn informed by and supports the developing perceptual processes. For example, stereopsis is dependent on the balance and integrity of the senses that inform the two visual cortices as an example of the perceptual gestalt of bi-hemispheric integration, as such, it can be regarded as a metaphor for cognitive function, including literacy. Reliability is the key, because it appears that learning deficits amount to ‘immaturity’, due to limited sensitivity and efficiency of information processing, as a result of deficits in sensory input.

2.1.2 Luria’s description of neural activity

The complexity of neural organisation was conceptualised by neurobiologist Luria (1973) as being divided into three distinct functional systems, located in specific areas of the brain. The primary functional system is related to the state of neural alertness, rising through a second functional system (with three zones of increasing complexity of sensory processing, perception and memory), and finally to the third system of intentioned, expressive cognitive function.
THREE LEVELS of MENTAL FUNCTION
(adapted from Luria 1973, Model of Neural Activity)

Primary: AROUSAL

1. Level of alertness
   - Unit for regulating:
     * Tone, waking * mental states

Secondary: SENSORY, PERCEPTION, MEMORY

2. SENSORY
   - Reception
   - Integration

   PERCEPTION
   - Auditory
   - Tactile
   - Visual
   - Motion
   - Acuity & binocularity
   - Oculo-motor
   - Eye Teaming

   * Colour
   * Form / edge (local)
   * Stereopsis
   * Depth of field (binocular)
   * Movement (global)

   Bi-hemispheric Integration
   - Left - detail specific, sequential processing
     * Language
     * Form (incl. word)
     * Praxis (actions)
   - Right environmental
     * contextual
     * visual-spatial, body schema

   Categories
   - episodic
   - semantic
   - symbolic

   Stages
   - SIS Sensory Information Store
   - STM Short term
   - LTM Long term
   - SAS Supervisory attention system

   Conscious
   - Unconscious

   Explicit - definitive facts
   Implicit - skills

3. CORTICAL
   - inhibitory
   - activating
   - modulating

COGNITIVE

Tertiary: CONSCIOUS ACTIVITY

- Awareness
  - Word meaning
  - Intention
  - Planning
  - Responses

- Analysis
  - Concepts
  - Physical

- Intentions
  - Programmes
    - language - literacy - creativity
  - Verification

Figure 2. Levels of mental function

Adapted by the author from Luria, 1973
NOTE:

Primary function: relates to levels of **AROUSAL**. These are non-specific neural networks which are continuous and work on the principle of gradual change, with no connection to: *reception, *processing of external information, or *goal-directed behaviour.

Secondary sensory level: **MEMORY TRACES** arising from sensory stimulation. This relates to reception and relay of discrete impulses which differ from the primary level as they operate on an "all-or-nothing" principle, matching impulses with associative networks and lateralization of pathways. These networks are sensitive to disruption from competing or masking stimuli. If there is too much discrepancy in shape or timing, then associative networks do not fire, viz. auditory / visual signals in phonics.

Tertiary cortical level. **CONSCIOUS ACTIVITY** assumes the character of a complex, self-regulating system which takes place through two-way, combined interactions between all three functional brain units, with wave-like connections throughout the brain. It has "diminishing modality specificity and increasing functional laterality" compared with the secondary level functions.

2.1.3 Luria's model of Functional Organisation and Mental Activity

Figure 1 is a diagrammatic interpretation by the author of the integration of associative and interactive networks, in three functional levels (Luria, 1973). In effect it provides a context within which to place the key factors being addressed in this thesis. In this way, the role that acuity and o-m dysfunction may play in LD, namely perception, memory, lateralisation and cognitive efficiency can be represented graphically to facilitate understanding of the organisation and mental activity of participants in the study.

Luria explained the different neural communication processes:

The first fundamental functional system...of a 'non-specific' nerve net...modifies the state of brain activity...[within] a principle of gradual changes...without having any direct relationship to [the second system of] reception and processing of external information, or to the [third system of] formation of complex goal-directed intentions, plans and programmes of behaviour" (p. 67). The chief distinguishing feature of regulation of human conscious activity is [closely allied - author's addition] with speech" (p. 93) ...These systems [can not]...carry out...activity independently...[but] through combined working of all three brain units, each making its own contribution...in a self-regulating system (Luria, 1973, p. 99).

Luria described his model as a 'bottom-up' hierarchical system with all aspects of the visual modality needed to support and be supported by, effective associative functions. He portrayed the perceptual system as being a dynamic, searching aspect of consciousness. That is, abstracting the elements of interest from the visual, auditory, tactile and proprioceptive senses, in order for the mind and memory to make sense of what are essentially chemical, electrical impulses, as reflections of the outside world.

Luria stated that the secondary sensory, perceptual input into the memory:
Sensation and perception are regarded as active processes incorporating both afferent and efferent components as well as motor components. Visual perception is always based on active, searching movement of the eyes, picking out essential clues. Perception takes place through combined action of all three functional systems of the brain; the first provides the necessary cortical tone, the second system carries out analysis and synthesis of incoming information and the third provides for the necessary controlled searching movements, which give perceptual activity its active character (Luria 1973, p. 100).

Luria described the developmental principle as:

The relationships between...cortical zones [of the second functional system]...change through the course of ontogenetic development...[and depend on - author’s addition]...the integrity of zones which constitute their basis...A disturbance of lower zones of the corresponding types of cortex in infancy must therefore lead inevitably to incomplete development of higher cortical zones (Luria 1973, p. 74).

2.2 The Case for Adoption of Luria’s 1973 Model

2.2.1 Therapeutic application of Luria’s Model

Luria’s model supports a view that maturity of the memory system and learning ability in literacy is a reflection of the adequacy of sensory input, including visual function. Sensory stimulation is not only the source of information to the brain, but also acts as a stimulus to neural growth and connections. Consequently the quantity, quality and reliability of the sensory source influences the level of developmental ‘maturity’ the individual achieves at higher levels of cortical processing.

Sensory integrity, including o-m function, can be considered as determining reliability of signals for bi-hemispheric integration into higher levels of processing. A difference in relative maturity and efficiency of these sensory – perceptual– memory interactions may help explain the differences in reading and spelling performance in students who are otherwise matched in intelligence. This argument is pursued in the three studies of this thesis, namely that seemingly small anomalies of o-m function, in critical areas like foveal fusion, can have far-reaching developmental consequences.

2.2.2 A professional perspective as a ‘Developmental Working Model’

The conceptual basis of this thesis is a developmental working model which is effectively educational practice based on occupational therapy principles. This work was primarily with brain-damaged adults and then later with Cerebral Palsied (CP) children whose poor perceptual skills appeared related to clearly discernable o-m dysfunction, as part of their generalised lack of motor co-ordination. Poor acuity and o-m dysfunction are common in cerebral palsy, but it
does not automatically follow that the brain damage affecting vision must in itself account for all loss of learning potential. This is shown in CP children who have normal language skills, reflecting normal intrinsic intelligence. It can be reasoned that poor perception and slow rate of learning might be due to visual immaturity, with an associated difficulty in learning visual tasks as a secondary affect, but amenable to vision therapy. For these children, implementation of vision training might be adopted in the same spirit as physiotherapy is employed for physical disability. The distinction between what can be considered as being 'brain-damage', 'immaturity' and 'normal' becomes uncertain, when it is apparent that 'ordinary' school children can have similar, but not necessarily such severe difficulties, when attempting the same visual perception and memory tests as were employed with Cerebral Palsied children.

2.2.3 The form of therapeutic logic

It is not being claimed that the assumptions on which this therapeutic working model is based are necessarily accurate, or tested and accepted principles, but they do represent part of the process that has led to the results being reported in this study. In effect, the working model is what a therapist assumes is happening when an individual is learning to read and write. What is being considered are the inner workings of a youngster who is laying down the motor-sensory-memory pathways needed to acquire skills on which to build literacy. These notions incorporate causal assumptions and treatment options which are provisional until tested.

An analogy of this therapeutic logic is the Helmholtz constructivist theory about unconscious inferences within the processes of vision and perception (Helmholtz 1867, cited in Palmer 2002). The following quote serves a double purpose as it expresses the modern information processing view, which is fundamental to learning theory. It can also be taken as an analogy to describe therapeutic logical processes.

The visual system transcends the available optical information by implicitly making a number of highly plausible assumptions about the nature of the environment and the conditions under which it is viewed. When these assumptions are coupled with sensory data in the incoming image, they result in a process in which the visual system makes inferences about the most likely environmental condition that could have produced the image” (Helmholtz 1867 cited in Palmer 2002, p. 58).

Therapeutic logic can be likened to the Helmholtz theory of vision, because it uses ‘fuzzy logic’ (Palmer, 2002 p. 83) in that it is “not direct or verifiable because many links are hypothetical and judgement is a process of uncertain probabilistic inferences in which many different pieces of evidence can be integrated into a conceptual framework, as a heuristic interpretation process”. Palmer (2002) describes these heuristic processes as being “probabilistic inferences that make use of ‘rules of thumb’, usually based on additional hidden assumptions that are usually, but not always, valid” (p. 713), but which according to Palmer “is a procedure that
more often than not provides the correct solution” (p. 83). In therapy, this heuristic approach would likewise be considered as valid if it leads to successful outcomes, as according to Fletcher (2002) successful intervention practices are a solid base from which to work backwards towards a causal theory (Fletcher et al., 2002, p. 64).

2.2.4 Sensory influences on visual function, perception and memory

The concept that visual dysfunction may be a source of poor perception and immature memory span, has been the source and focus of subsequent work with normal children with LD in this Educational Therapy practice. In effect, helping otherwise normal children develop the basic abilities of motor-sensory-perceptual-memory skills needed for schooling. Vision training is now an integral part of this programme once students have been assessed for acuity and o-m function by a Behavioural Optometrist.

As noted in the Introduction, this thesis argues that many individuals develop what appears to be a ‘dominant’ eye, by default, owing to lack of balanced binocularity, due to one weak eye. It follows that eye exercises are designed to develop binocularity in both aspects, of both global and foveal vision, to allow the visual system to establish a stable, neurologically dominant (usually right) eye. A ‘bridging’ word-skills programme, to improve literacy levels to match class requirements, then becomes part of the Educational Therapy programme that continues to evolve.

Visual exercises to establish eye dominance

The notion that subtle and intermittent o-m dysfunction may have a negative impact on a child’s brain when functional pathways are developing (Luria, 1973, p. 74; Purves, 1994, p. 45) is supported by positive therapeutic outcomes. Once o-m dysfunction is corrected and stable eye dominance established, then results of literacy post-tests indicate students have largely ‘outgrown’ their LD in phonics, visualisation and memory, leaving only the ‘catch-up’ learning needed to gain class parity. Part 2 of the thesis provides a description of vision training and reports results of post-tests, indicating the ease of learning and literacy gains, once normal visual pathways are established.

Implications of intermittent sensory input

The concern is that standard optometric assessment overlooks subtle visual deficits which may constitute sensory and perceptual ‘neglect’ of the associative networks, in the reception and relay of discrete sensory impulses to the memory system. Mismatched sensory input may interfere with integration of vision and vestibular responses needed for proprioceptive senses,
in balance and motor-planning, as well as the feed-back for eye-hand co-ordination. Likewise, intermittent visual and/or auditory sensory input may confuse the establishment of an associative sensory system as required in the early stages of learning to read and write. Reliable signals, in form, sound and timing, enable transformation of spoken language into visual symbols of print, as phonics bonded as one dyadic unit. In other words, not only physical co-ordination but also memory and the higher order cognitive functions may be compromised by o-m dysfunction, at critical stages of development.

**Primary, secondary and tertiary effects of o-m dysfunction**

The over-whelming clinical conclusion is that regardless of definition or diagnosis, o-m dysfunction may be overlooked as a primary source of perceptual and memory deficit which has a secondary affect on higher levels of cognitive processing including literacy (Gerhardt 2004; Luria, 1973; Palmer 2000). All of which have a manifestly negative impact on emotional development and behaviour as a tertiary effect compounding LD. A tardy achievement of developmental mile-stones can be regarded as an early indicator of LD.

### 2.3 Matching Educational Therapy to Students’ Specific Needs

Educational therapy can be regarded as a clinical practice as it addresses the deficits contributing to the students’ pattern of LD. Some of the elements of the programme are educational in nature, but are presented in such as way as to develop motor-sensory integration, visual perception, phonological awareness and memory skills. However, in this paper the term ‘therapy’ is used instead of ‘clinical’ to discriminate between this and medical practice.

#### 2.3.1 Multi-disciplinary Educational Therapy

This Educational Therapy practice is, of necessity, located between the fields of occupational therapy, education, psychology and optometry. Experience shows these students’ needs can be lost in a hiatus between these disciplines, when areas of expertise or communication do not overlap. As students with LD present with a range of problems, all need to be addressed on the principle that strength is limited by the weakest link, so too with therapy. It is apparent that good results can not be expected until students have developed essential skills traditionally delivered from each one of these professions. The advantage of an Educational Therapy practice is that, with parents’ input and co-operation, full responsibility can be taken for incorporating all necessary elements seamlessly into each student’s programme. In this way, skills become naturally integrated, and monitored to ensure adequate implementation. The source of Educational Therapy activities is the author’s professional background as an
occupational therapist. In order to extend her understanding of language and memory she completed a degree in Psychology and Education with teacher training, followed by a Graduate Diploma in Art Education to research visual perception. Vision training exercises have evolved in co-operation with Behavioural Optometrists.

2.3.2 Inter-disciplinary therapy approach
The degree of separation between the professions presents parents, who are seeking assistance for their child's I.D, with some major problems. Causes of confusion can relate to differences of opinion about diagnosis, what are considered significant factors and appropriate management. The separation of professions into finite areas, with reports the main method of communication, provides too little opportunity for exchange of views, response to feedback, or approach to therapy as a whole, rather than lineal progression. No one person has responsibility for implementing, monitoring and adapting treatment, so this is often left to parents. Parents for their part have to deal with sensitive issues of how available an expert might be, or how much involvement to expect from each individual, or the degree of communication between professions. Often parents do not have sufficient knowledge of specialised areas, or confidence to ask the right questions to find the best solutions. Frequently there are behavioural problems and family dynamics to be sorted out before appropriate training procedures can be implemented.

The manner in which this Educational Therapy practice functions is with the support of a Behavioural Optometrist, Osteopath and Podiatrist to correct any compromising physiological anomalies, before commencing the programme. The therapist can address remaining areas of deficit, taking responsibility for integrating treatment from her expanded educational and occupational therapy base. A parent accompanies the child and is being informally trained in supervision, management and coaching strategies. Consequently the student is receiving ongoing support and home practice “a little bit, often” to optimise learning. The degree of challenge for the student can be finely tuned and modified as skills and attitudes improve. This organisation makes it possible for the therapist to monitor and direct ongoing process, from initial assessment, to planning and responsibility for outcomes of treatment (see Chapter 8 for case studies).

2.3.3 Therapeutic framework of ‘connectivity’
The Educational Therapy goal is to promote efficient connections between the associative networks. This is achieved by stimulating both right and left auditory and visual pathways to
enable simultaneous, integrated bi-modal (auditory / visual) signals for bi-hemispheric processing. Therapeutically it is a question of connectivity, so Occupational Therapy principles involve task analysis in which ‘loose threads’ of weaker skills are identified and supported with activities designed to connect motor-sensory pathways, which are interactively woven into a functional fabric of performance. In this way, an expanding and overlapping spiral of ‘synaptic circuits’ develops skills with increasingly integrated responses to educational challenges. That is, as part of a natural maturational process, developing competence in motor, perceptual, analytical, memory and literacy skills, with generative learning arising from optimal bi-hemispheric function.

Educational Therapy Framework within Luria’s Model (1973)

The therapeutic principles, outlined here, have evolved from earlier experience in the rehabilitation of adults and children with brain damage. The ongoing Educational Therapy programme has evolved over the last thirty five years, based largely on the conceptual framework provided by Luria's work in functional neuroanatomy. As the purpose of therapy is to help individuals with LD to realise their potential within the therapeutic terms of reference, with the involvement of their parents, any limitations to this developmental model is the therapist’s ability to be aware and understand problems as they emerge, her creative capacity to generate ‘bridging’ activities and the student’s capacity to respond. The effectiveness of this working model is being evaluated through increasingly refined research questions.

2.3.4 Assumptions from Professional Experience
Factors having a likelihood of contributing to poor visual processing:
 a) Any visual problem that interferes with eye teaming and binocularity
 b) Weak foveal fusion that adversely affects fine visual detail, affecting phonics.
Variables most likely to identify under-achieving students:

a) Unusually large discrepancy between spelling and reading levels
b) Limited auditory, and/or visual, and/or phonemic memory span
c) Visual perception immaturity, particularly depth of field perception
d) Difference between leading eye, preferred hand and latent (arm) dominance.

The review of concepts and paradigms emerging from current research supports the wide-ranging choice of assessment procedures used in this survey. These procedures were chosen as being criterion-referenced to skills demanded of all students, each day, as part of their schooling. The assumption underlying this study is that a certain profile of visual anomalies may interfere with memory span and so compromise learning skills in early childhood development. The methodology and methods adopted are discussed in the next chapter to address the key research questions.

2.4 Research Questions

Research Question 1: School Survey

Is there an association between anomalies of visual function (including acuity and o-m function) and LD, specifically in terms of visual perception, memory, spelling, reading comprehension and reasoning skills?

Research Question 2: Intervention Study

Does newly established right eye dominance influence an individual’s literacy level and memory function following a word skills intervention programme?

Research Question 3: Two Case Studies

Where in the associative sensory network, of individuals with LD, are connections failing or mal-adaptive adjustments being made?

2.4.1 Limitations and advantages of the study

The main limitation is that causal factors can not be determined within this empirical study however, the advantage is that the range and depth of findings provide some predictive assumptions, as a source of questions for further research.
2.5 Rationale of the study

2.5.1 Importance of the Study

Education can be expressed as a developmental process in the direction of interactive volition and co-ordination, with the child increasingly independent and able to interact with the world physically, socially and educationally. By school age, children need a baseline of basic abilities including motor skills, eye-hand co-ordination, visual and auditory perception, language, and memory skills.

2.5.2 Language converted into symbols of print

Converting spoken language into print can be considered as being the most highly developed ability on the evolutionary scale, with the use of symbols requiring a new order of learning. That is symbolic memory, a system more advanced than experiential memory, in that it can integrate auditory elements of spoken language into the visual equivalent as print symbols. This dyadic, phonemic memory is based in phonological awareness of individual sounds in words and can be considered as the foundation of literacy. In this thesis, it is being argued that likewise, a refined visual input with reliable pathways is an equal, integrated partner to phonological awareness in the development of an automatic, dyadic phonemic memory system.

2.5.3 Specialised requirements for paediatric visual assessment

Visual acuity, as well as o-m function, are both necessary to provide "controlled searching movements which give perceptual activity its active character" (Luria 1973 p. 100). It is important to emphasize the specialised nature of Behavioural Optometric assessment. This hour-long assessment includes not only acuity problems that can be corrected with prescription lenses, but differs from standard eye tests, as o-m balance and eye teaming for binocularity is evaluated, as well as adequacy of eye movements and the effects of fatigue. Treatment principles also differ, with therapeutic lenses to shift the visual system [rather than] compensating lenses that embed the difficulties" (Palassis, 2004, private communication). Inherent in this conceptual framework is the clinical observation that students with LD require more time and effort than other students, to build the symbolic memory needed for effective literacy. Consequently they can fall behind in class and become discouraged if they are not supported by extra time and input with intervention programmes. Unidentified, low-grade depression or stress may further confound students' efforts to achieve 'success' (Mandler, 1975, cited in Travers p. 673).

In this study, standardised tests and functional assessments of the 'basic abilities' are the same as those used in the Educational Therapy practice. Criterion-referenced activities represent what is expected of students in class, namely factors of visual function, hand and eye
dominance, visual perception, phonological awareness and memory span. Normative tests of academic skills of spelling, reading comprehension and reasoning skills are also included. Results of these tests will provide both an overview of the incidence of anomalies and a 'proficiency profile' of each individual student's strengths and weaknesses. Part of this study is a school vision screening protocol. This will serve to indicate numbers of pupils who need further assessment, with possible vision training and remedial resources, as well as identifying individuals who may be 'under-achieving', regardless of their academic success level. Under-achievement is difficult to determine, consequently the approach taken in the follow-up Intervention Programme is to treat any visual dysfunction with visual training, followed by a word-skills programme, to determine if improved visual function is reflected in literacy post-tests.

2.5.4 Implications beyond Schooling
Positive answers to the research questions validating assertions underlying this study would raise serious concerns regarding present management practices. Contrary to the prevailing medical view, commonly occurring o-m dysfunction is found to disrupt learning processes. Further research would be needed to test the reliability of this 'developmental' approach. Recognition of these subtle and currently over-looked visual anomalies would open up positive and far-reaching implications and provide a new avenue for minimization of LD. This therapy might then become more widely available, to include those physically and educationally handicapped individuals for whom career options have been restricted, due to o-m dysfunction and LD. Any impetus for change however, must come from increased recognition of the o-m aspects of the problem, supported by results of intervention studies that provide consensus regarding beneficial therapies.

2.5.5 Three areas of support for a developmental model of LD
The literature review in Chapter 3 looks critically at theoretical models on which the research priorities of this thesis are based, namely a therapeutic framework integrated with Luria's model of levels of sensory-perceptual-cognitive function. Contemporary research and theories are reviewed as to the nature of basic abilities of perception and memory, spelling and reading to provide an understanding of how an association may exist between visual function and literacy skills. Three strands of information are integrated. Namely Luria's model of levels neural function; current theories and research into essential preconditions of learning; and therapeutic experience from Educational Therapy outcomes, that provide an integrated, developmental model of LD. The question of how well the Developmental Model has worked is addressed in Chapter 8 with two current case studies, and in Chapter 9, which outlines evidence to support the Developmental Model of LD.
Chapter 3
LITERATURE REVIEW

3.1 Processes of Learning

Given the broad nature of this study and the clinical experience from which it emanates, the following review outlines insights provided from research literature. It includes processes involved in learning that are relevant to understanding LD followed by a review of current research. It is of necessity wide-ranging, in order to support the range of aspects of the problem from a clinical perspective. It also covers a number of decades, as much of the research done between 30’s and 80’s is relevant to the functional level at which therapies operate, forming the basis of assumptions upon which therapists work. The 1990’s - 2006 introduced technology providing greater depth of investigation of neuro-scientific research, which tends to support the earlier findings.

A therapist works to support students over areas of ‘non-connectivity’, which demands mindfulness of the holistic nature of learning, in order to identify particular aspects of a student’s information processing that is currently being neglected. From this integrative perspective it is necessary to recognise each area of research as a specialist area in its own right, but none-the-less represents part of a functional whole. Auditory processing is an essential aspect of literacy for phonological processing and in its association with visual input for phonemic memory.

This thesis focuses on the basic learning abilities, that of perception and memory skills and the visual factors that contribute to the development and proficiency of each individual’s information processing. The quality of sensory input determines perception and the developing structures of ‘learning’ processes according to Piaget’s theory of assimilation and accommodation (Piaget 1963, p. 34); visual dominance (Hubel & Weisel 1979, pp. 130 – 140); and the stimulation of dendrite growth and formation of neural pathways (Aoki & Siekevitz 1988, p. 58). Gerhardt (2004) states we are born with the same brain features. It is the sensory exposure and experience in early life that stimulates the brain’s neural connections, consequently greater and more varied the stimulation provides more connections to be made. Conversely, in the absence of activity, neurons atrophy (p.43). In accordance with Gerhardt’s observation, mismatched sensory signals in the sensory associative areas might likewise be misdirected and disturb the normal development of latent pathways.
From a number of theoretical perspectives, the chapter progresses towards a case for the adoption of Luria's model of levels of mental function (1973) as a working framework to address key factors drawn out from the review of the literature (Section 3.6). The chapter culminates in a rationale of the study, with its recurrent theme of therapy that facilitates connectivity as the dynamic that can ultimately overcome LD.

3.2 Visual Factors and Learning

In order to determine what factors contribute to clarity of vision, a distinction needs to be made between 'visual acuity' (generally termed 'vision') and 'o-m function'. The latter term relates to the strength, balance and co-ordination of the eye muscles which influence the ability to focus clearly on near work, as well as how well the eyes work together. Poor eye teaming can adversely affect visual perception like depth perception, with developmental consequences for cognitive processes that require bi-hemispheric integration of sensory input for integrity of neural output, which Snowling related to central auditory processing deficits (Snowling 2001, p. 5), but would apply to vision in the same way.

The following review of literature relates to visual factors in LD, specifically in terms of o-m function which is rarely addressed when assessing visual status. Vision can refer to acuity, as health of the eye and lens shape. The eye is healthy if internal and external structure of the eye is normal and vision is clear for small letters at twenty feet i.e. 20/20 vision, or rated 6/6 at 6 metres. What is overlooked in standard optometry tests is that clarity of vision may also be adversely affected by o-m dysfunction that disrupts accommodation/convergence link for near work; or causes abnormal eye posture resulting in binocular foveal fixation failing to be centred adequately on the point of interest to register fine detail, of print, which is critical for establishing literacy.

It is within the central macular area of the retina that the most detail-sensitive area, of the fovea is located (Emsley, 1977; Palmer, 1999). This is the critical point of this thesis because, unlike peripheral vision, the fovea is specialized for response to colour and edge-discrimination for fine detail like print, so access to foveal fixation must be consistent and reliable if a child's access to print is to be optimal. Imbalance of eye muscles may cause visual abilities to be inadequate for some students, with otherwise normal eyesight, to cope with demands of schooling owing to one weaker eye, or poor eye muscle co-ordination. Effects of this o-m dysfunction may include weak binocularity, poor focus and insufficient convergence for near work or accurate movements. Any of which can interfere with speed of visual processing,
adequacy of visual perception and eye-hand co-ordination, as well as learning skills. The therapeutic perspective is that although visual problems may be statistically and clinically minor, this does not preclude the possibility that in a subtle way, dysfunction may upset pathways and contribute to developmental complications.

Support for the therapeutic perspective is found in Wiesel and Hubel (1965) who consider "abnormalities in neural functioning by subtle alterations of the sensory input ... depends not only on the amount [and quality - author's addition] of incoming impulse activity, but also on a normal inter-relationship between activity in the different afferents" (Wiesel & Hubel, 1965, in Bach-y-Rita, 1972, p.51-2). In both these ways, the quality of sensory input is the stimulus to growth that determines the 'architecture' of neural connectivity ... with practice only the most efficient networks are retained by 'pruning' through disuse (Purves, 1994, p. 45), which it can be argued, might also include unreliability of sensory input due to o-m dysfunction.

Fuster (2003) observed that neuroplasticity of rapid change is as a result of environmental stimuli ... expanded by internal emotional ... and previously constructed cognitive cortical networks, all changing the structure of the brain (p.116). This process is in positive directions in learning, but might also be in non-productive ways in terms of LD, from unreliable sensory input. The therapeutic approach has been to correct o-m dysfunction, to provide sensory-integrative exercises, followed by a bridging word skills programme. Progress notes combined with pre- and post-tests of literacy and memory is an on-going review of the efficacy of the Educational Therapy practice. This thesis is part of that evaluation process.

3.2.1 Visual function for reading, spelling and writing

Basic visual skills are essential for "the child's ability to get meaning and understanding from what he sees by skilful and efficient uses of both eyes" (Hig & Ames, 1955, p. 271). This observation is just as relevant today because there is a serious lack of consensus about the role of visual function in LD. This is probably because causation is difficult to prove in such a developmentally complex situation in the neuro-development of a growing child. What is not disputed in the literature of optometry is that visual function in terms of stamina, speed and accuracy of o-m function under working conditions, is an integral aspect of the dynamics of reading and eye-hand co-ordination for writing. Presumably a mature and well co-ordinated visual system provides for greater reliability and fluency in the learning process of phonics, word attack skills, reading and writing, than visual dysfunction could. Howell and Peachey (1990) commented that reading disability is related more to instability and inability to compensate for lack of co-ordination than simple acuity problems, or the severity of visual
dysfunction. They state, "Visual dysfunction interrupts the processes involved in acquisition and processing visually presented information" (Howell & Peachey, 1990, p. 12-19).

a) O-m function

In the initial stages of deciphering words, very fine and precise detail is required for discerning the internal details of words, particularly for spelling. It is apparent from students' feedback and progress during controlled conditions of vision training that it is imperative for both eyes to be in correct position to achieve binocular foveal focus on the print. This is a pre-requisite o-m function, for reading and eye-hand co-ordination needed for writing, otherwise the image of words may be intermittently blurred and perceptually confusing. Consequently, clarity of vision is more than just acuity, as it also involves accurate aiming and focus of the two eyes, co-ordinated in timing and motion to provide clear and fused foveal images (Shilcock, Ellison & Monaghan, 2000).

The following description is the therapist's notional 'task analysis' of o-m function for reading (see Glossary of terms, 1.5). In order for an individual to perceive adequate detail, o-m function of eye muscle co-ordination, stamina and balance must be adequate to maintain optimal phoria of eye posture, because as well as visual acuity it is necessary to aim central vision, as opposed to peripheral vision, at the point of interest, for optimal clarity. Macular vision and most particularly the fovea of central vision includes colour and detail specific areas for fine detail. Eyes need vergence to move in contra-motion simultaneously, to converge inwards and diverge outwards respectively for near and distance viewing from desk to blackboard. Accommodation muscles provide lens adjustment for accuracy of focal length needed for clarity of vision. Eye teaming movements are matched and moving in unison to maintain identical retinal images, while tracking along a line of print from left-to-right. Saccades are subjectively undetectable jumps between pauses, as movements to the next point of fixation, which allows the reader to focus and register sufficient detail to match what is being seen against memory traces, in the remarkable perceptual / memory integrative process of recognition (Emsley, 1977; Palmer, 1999).

Although these individual aspects of vision are described as separate, this does not mean they function independently, but rather as an interactive dynamic flow of stimuli, action and reactive feedback. For example, accommodation and vergence are intimately related such that vergence difficulties frequently reflect an underlying accommodative disorder (Howell, 1986; Palassis, 2004, private communication).
**h) Binocular vision**

Also of concern is the teaming of the two eyes, to provide binocularity in all aspects of vision. Emsley states that “Binocular fixation and depth perception have to be learned during childhood, from education and experience ... and a complicated mechanism such as binocular vision is more easily deranged than a simple one ... and those most recently acquired faculties are more easily upset, and the more susceptible to modification or development by training” (Emsley, 1977, p. 30); or conversely, to be modified in a mal-adaptive manner in response to abnormal sensory input and o-m dysfunction.

Both eyes and their respective visual cortices are integrated to provide binocular fusion for depth perception, that is, stereopsis / three-dimensional vision /3-D vision. The same may be said to be true of bi-hemispheric integration of visual input in literacy, whereby both left and right visual cortices contribute to integrating form detail within spatial context, for o-m feedback to inform visual co-ordination. Emsley (1977, p. 47, Vol. 2,) states that binocular vision depends on o-m balance, to fulfill a requirement of “presentation of two suitable unilocal impressions and projection, and fusion of these into a single binocular percept”. He points out that “vergence / accommodation conditions in the visual apparatus may interfere with the o-m system, in which case the subject is unable to achieve simultaneous macular vision [in which the fovea is centrally located – author’s addition], owing to faulty binocular fixation” (p. 47). The ability to converge the eyes inwards is one aspect of the accommodation / convergence ratio of movements required to aim both eyes clearly, accurately and reliably on print in order to sustain foveal binocularity.

c) Foveal vision and fusional reserves in binocular vision

As defined in Section 1.5, binocularity involves the co-ordination of both eyes in order to focus on an object. The ratio of vergence to accommodation is finely tuned until fusion occurs and the object can be seen as one perceptual image. According to Emsley (1977, p. 29, Vol. 1), if “due to any cause, retinal images do not fall on the two foveae, the resulting afferent impulses transmitted to the cortex do not ‘correspond’...the object is seen as double (diplopia) ...The brain will make great efforts, if necessary, to overcome this confusing condition and obtain single vision”. This may be the mechanism preceding the suppression of one foveal pathway when the visual system is under vergence stress. It is a key issue uncovered in vision training and incorporated into the Developmental Model of LD, in Chapter 9.

During vision training, the progression into eventual suppression of one eye can be observed using an anaglyph (a transparent screen that has images consisting of both red and green parts).
and wearing stereoscopic red/green glasses. These lenses make not only 3D images, but also discriminate between what is seen by each eye. This is invaluable information, as a student’s report of what is being seen informs the therapist of how clearly and sustainable is the focus of each eye, not only for the broad images, but also the fine detail of letters seen in foveal vision. In summary, it is being argued that if eyes are not co-ordinated adequately in time and motion to retain balanced binocularity, the visual system’s attempt at making ‘corrective signals’ becomes dysfunctional, owing to functionally ‘mismatched’ eyes.

d) Foveal Suppression
In effect, the visual system may be unable to adapt adequately to abnormal circumstances over which it has little control. In the case of insufficient convergence or accommodation, blurring, double vision and even foveal suppression can occur if the visual system is stressed in convergence and can not sustain a binocular image when working at near. Three levels of responses occur in vergence eye exercises using red/green lenses with red/green images on an anaglyph to produce 3D images, which provide information about the visual status of each eye at any given moment, in parts of the display that are monocular for either eye. If the student has inadequate convergence, as the slides are moved apart to challenge convergent and divergent movements, at first the student reports blurring, then some separation of the image. If this is not controlled, by increased accommodative and vergence effort by the student and if the exercise is continued, then the student may report a second effect, of double vision as fusion is lost. When instructed to ‘get the single, floating (3D) image back again’, if the student reports no further double image, this is a positive result if binocularity is regained. However, it is mal-adaptive if the visual system has resolved perceptual confusion of double vision by suppressing foveal vision of the weaker eye, presumably in the interests of clarity of vision. The student still has global depth perception by seeing a large circle as a 3D ball, but the finer details of letters that require edge discrimination of foveal vision have disappeared in words seen by the weaker eye. This suppression of foveal pathways from one eye is in spite of there being anatomically parallel pathways from both left and right fields of vision, in each eye, to each hemisphere.

Saccadic suppression (masking) is generally understood to be an unconscious strategy used by the perceptual system to avoid blurring during saccadic jumps between fixation points (Wikipedia, accessed 2006 Dec). The American Optometric Practice Guidelines (1998, online) state that many children with LD have accommodative and vergence problems. It can be argued that in the case of anomalous accommodation or fixation disparity of retinal images, suppression might be a strategy used to minimise blurring as the eyes move, from conditions other than normal ‘saccadic’ movements. In Educational Therapy, during vision training with
stereoscopic glasses, the loss of detail seen by one eye is referred to as a ‘drifting’ eye to prompt the student to regain control, as anti-suppression therapy. The therapist’s assumption of foveal suppression is generally checked by having the student report the details of what is being seen. If fine foveal detail of words and parts of the image seen by the weaker eye are missing in binocular vision, if these missing parts return when the ‘stronger’ eye is covered momentarily, then foveal suppression is suspected. If, with the return to binocular viewing, the previously missing words disappear again, foveal suppression can be assumed to be the strategy adopted by the visual system to maintain one clear, but monocular, image. Loss of binocularity can be considered as a third stage of mal-adaptation to binocular stress due to insufficient convergence, or competition between ‘unmatched’ signals from either eye.

Support for the concept of foveal suppression may be inferred from other research. Stein (2001, p. 12) notes that the visual magnocellular system uses signals from any poorly-timed or unintended movements to bring the eyes back on target, if there has been movement that “leads to images moving off the fovea”, which Stein refers to as ‘retinal slip’. Resulting retinal disparity may cause blurring, which if not remedied from magnocellular feedback, may trigger suppression. The high incidence of instability of binocularity found in dyslexics (Evans, Drasdo and Richards, 1994, cited by Stein 1999, p. 59; Galaburda, 1999) might likewise be considered as having a similar effect owing to poorly co-ordinated eye tracking movements. Lorusso (2004, p. 2420) found that unlike normal readers’ access to foveal vision, poor readers accessed peripheral vision for letter recognition. Shilcock and Monaghan, (2005, p. 44) proposed lack of synchrony between the hemispheres, associated with weak foveal fusion, with a tendency of poor readers to fixate to the left of centre. The findings of Lorusso (2004) and Shilcock (2005) might also be attributed to foveal suppression of the right foveal hemi-field vision. The conjectured dynamics of foveal suppression are discussed further in the Discussion chapter.

Care is taken during eye exercises to avoid mal-adaptive strategies becoming embedded, as has been found with some older students who have had more years of ‘near vision’ stress, resulting in foveal suppression of one eye, or alternating dominance has become established. Foveal suppression as a mal-adaptive adjustment is discussed further in Chapters 7, 8 and 10. These clinical findings align closely with those of Stein and Fowler, (1993); Stein and Talcott, (1999); and Stein, (2001) as their theories of unstable binocular control and magnocellular deficits, affecting binocular focus and co-ordination, were found to adversely affect reading, spelling and orthographic skills.

Against the remarkable capacity of the eye to respond to a myriad of stimuli from the environment, in literacy, an advanced perceptual ability to discern detail is needed for pattern
recognition of letters, words and phrases which depends on foveal fixation according to Juttner (1997). ... Perception and internal representations underlying pattern recognition ... arise at distant cortical levels... and are developed within an extremely narrow visual field essentially restricted to the fovea. Learning speed for classification learning... was drastically reduced in dyslexics in relation to foveal vision (Juttner & Rentschler, 1997, p. 55). It is apparent from the review of the literature that 'vision for learning' is far more complex than 'eyesight from seeing', as the visual system informs and is modified by the senses at different levels and pathways of neural function (Fuster, 2003; Luria, 1973; Palmer, 1999; Purves, 1994; Shatz, 1992).

3.2.2 Four hypotheses: visual dysfunction linked with LD
In his review of visual processing problems, Robinson (2002) acknowledges that visual anomalies are becoming an accepted area of research, as possibly part of the problem in LD (Robinson, Sparkes, Roberts & Conway, 2002, p. 2). Three of these hypotheses, discussed by Robinson are the Irlen Syndrome, magnocellular deficit, and biochemical anomalies. These current theories are discussed in some detail in order to provide a context for the theoretical framework of the Intervention Studies discussed in Chapters 6, 7 and 9.

1) The Irlen Syndrome
The Irlen Syndrome (IS) of LD associated with visual dysfunction is not normally assessed by optometrists. Symptoms of IS include visual-perceptual dysfunction found in some dyslexics, with “doubling, blurring and shadowing of letters and words, merging or movement of print, restriction of span and sustaining focus, with eye strain” (Irlen, 1991; Meares, 1980, cited in Robinson, 2002, p. 2). Many controlled studies have supported the IS, with various explanations being given, one of which is that IS may be due to retinal abnormalities of receptor distribution, “with evidence of extra peripheral cones competing with foveal vision to produce these effects” (Grosser & Spafford, 1990, cited in Robinson, et al. 2002, p. 2). Other researchers found a higher incidence of binocular instability and eye movement problems in people with IS in spite of “conventional optometric intervention of spectacles and orthoptic exercises”, whereas these people have reported improvement with the use of coloured filter lenses (Evans et al., 1999; Robinson & Foreman, 1999, cited in Robinson, et al., 2002, p. 2).

What is not certain is whether o-m function was included in the vision tests used in these studies. Accommodation micro-fluctuations were found to be greater when subjects were not wearing their prescription colour lenses (Simmers et al., 2001, cited in Robinson, 2002, p. 2). In the Educational Therapy practice, Irlen lenses were not adopted. The holistic approach of vision training, together with low level magnification to take strain off the accommodation...
system, was found to be a therapeutically advantageous way of addressing the associated cascade of difficulties experienced by these students, rather than simply ameliorating the visual effects described as the Meares-Irlen Syndrome. Evans (2005, p. 363) found that in three test cases, patients suspected as having the Irlen Syndrome, had other causes to their symptoms, including uncompensated convergence weakness exophoria, astigmatism and posterior cataract.

2) Magnocellular deficit theory

The second hypothesis of visual dysfunction associated with LD discussed by Robinson, centres around the magnocellular system (Robinson, 2002, p. 2). Robinson notes that accumulating evidence suggests deficits in the magnocellular pathways may occur in approximately 70% of cases of dyslexia (Whitely & Smith 2001, cited in Robinson, 2004, p. 3). The overlapping of visual images found in the Irlen Syndrome has been hypothesised as being due to an overlap between consecutive eye fixations when reading (Williams & Lovegrove, 1992, cited in Robinson, 2002, p. 2).

Anatomically, there are a number of parallel visual pathways between the two separate eyes, as each eye has left and right fields of vision, with two hemi-fields in the fovea, as well as two functional visual systems of peripheral (magnocellular) and foveal (parvocellular) pathways, all integrated within the visual system and associated with the other sensory modalities. Behavioural Optometrists explain that the magnocellular pathway of peripheral vision provides a global overview and can be conceptualised as a fast "where is it?" type of processing which allows the brain to decide what is the point of interest. The second stage of processing and decoding information is provided by a slower parvocellular pathway that allows eyes to be aimed accurately for central foveal vision, to establish "what is it?" Poor correlation between the speed of magnocellular and parvocellular processing has been found to cause reading delays and persistent after-images which can be perceived as blur by the reader (Palassis, 2004, private communication). These perceptual anomalies are likewise some of the evidence on which much of the Irlen theory is based.

Lovegrove (1985, p. 4) states that "it has been proposed by contemporary researchers ... that in building percepts we obtain a general image first and then add further detail into the general image later. In reading, the high spatial frequency channels are likely to be involved with detailed central viewing and the low spatial frequency channels with collecting general information from peripheral vision". Lovegrove (1985) described the magnocellular system as a "transient" system processed by a low spatial frequency channel that provides a "general form", whereas the "details" are transmitted by high frequency channels, in a "sustained"
system of parvocellular pathways which proceed at a slower pace. Lovegrove (1980) tested contrast sensitivity using a gradient of different frequencies, with drifting and flickering gratings, in which a subject reports when a change of direction of moving dots is perceived (Lovegrove, 1985, p. 5), as a measure of part of the visual system that processes global vision (moving or transient stimuli). Lovegrove et al. (1990) reported experimental evidence of a deficit in the transient, magnocellular system, which is sensitive to coarse patterns/discrimination of low spatial frequency, in subjects with LD (Lovegrove, Garzia & Nicholson 1990, p. 137). It was theorised that a deficit in the magnocellular system causes reading difficulties through a failure to suppress the activity of the parvocellular system at the time of saccadic eye movements. In later work, Lovegrove et al conclude that “poor magnocellular process may exist on a continuum in the population, with performance related to visual components of word processing, but not phonological processing skill per se (Lovegrove & Conlon, 1990, 2001, p. 2).

At present there are conflicting opinions amongst researchers of the viability of the magnocellular theory to reading difficulties, some of which are reported in the following summary from Abstracts to the Essex University symposium “Sensory bases of reading and language disorders. Talcott et al. (2001a) found the largest sub-group of dyslexics had impaired accuracy sensitivity to both dynamic visual and auditory stimuli (Talcott et al., 2001a); and visual motion detection was a strong detector of orthographic skill (Talcott, Witton et al., 2001b, p. 9). Ben-Yehudah and Ahissar found “coherent motion direction detection under severe conditions” was consistent with the magnocellular theory, but only for sequential [left hemisphere function - author’s addition] presentations. They conclude that “dyslexics have a basic impairment in retaining and comparing perceptual traces, regardless of the magnocellular related performance” (Ben-Yehudah, & Ahissar, 2001). This point may account for a vulnerability to SIS deficits in students’ inability to register sufficient detail for a reliable spelling vocabulary (see p. 47). Amitay and Ahissar (2001) found magnocellular deficit linked only with eye-hand coordination, in a subgroup of dyslexics. They question whether the magnocellular deficit can account for variability of reading and spelling, or whether it occurs in normal readers.

Support is provided for the magnocellular deficit hypothesis of “delayed visual evoked potential for poor readers along the magnocellular pathway in response to moving stimuli” (Brannan, Solan, Ficarra & Ong et al., 1998, p. 280). This variable or diminished stimulation may account for “the lateral geniculate nucleus being smaller and more disorganised in post mortem dyslexic brains” (Livingstone & Galaburda, 1991 cited in Robinson, 2002, p. 2). This latter finding is supported by two functional imaging studies, both of which found reduced
activity of the V5/MT area of the visual cortex which is sensitive to visual motion and is dominated by magnocellular input (Eden et al., 1996; and Denh et al., 1998, cited in Robinson, 2002, p. 2). Omitzigt et al. (2001) state that magnocellular input is involved in locating (target) information relative to other (distractor) information, and this "localisation may be important for optimising subsequent form processing by the parvocellular stream" (Vidyasagar, 1999 cited in Omtzigt 2001, Abstract p.1; Pammer & Cornelissen, 1998, p. 32).

Pammer, Lavis and Cornelissen (1999) provide an overview to this discussion by suggesting that contextual reading may depend upon two separate and functionally distinct visual encoding mechanisms – one central, important for the spatial discrimination of letters within words, and the other, a spotlighting mechanism important for spatial localisation within a body of text. While both mechanisms may constrain reading efficiency, neither mechanism enforces an absolute limit on reading ability (p. 2). Their description of "spatial discrimination of letters within words" seems to describe foveal discrimination, together with shape/word recognition (Del Rene, 2003, p. 32), and echoes the Behavioural Optometrist view of the parvocellular system function of "What is it" discrimination. Pammer’s description of a "spotlighting system for spatial localisation" might relate to right hemisphere spatial sensitivity, and the magnocellular system of detecting the ‘Where is it’ aspect of perception.

Evidence of neurological deficit in dyslexics was found in decreased activation of the cerebellum during motor learning, which includes spelling and writing (Fawcett & Nicholson, 2001, 1999, cited in Robinson, 2002, p. 2). However, Skottun states that negative findings from many studies have unanimously found it is the magnocellular, not the parvocellular system, which is suppressed during saccades. Other studies found no evidence of a magnocellular deficit in dyslexia (Victor et al., 1993, cited in Skottun, 1997), therefore can not account for the magnocellular deficit or Irlen Syndrome of “overlapping of images” disruption to the reading process. Skottun (1997) regards the magnocellular deficit theory in dyslexia as “having done much to legitimise the study of visual deficits in dyslexia” but his review found there were difficulties reconciling new findings to this theory. This topic is discussed further in Chapter 10 in relation to the findings of this study.

3) Biochemical anomalies associated with sensory-motor-neurological integration
A third theory, related to nutrition, complements both Irlen and magnocellular causal hypotheses of LD. Robinson (2002) reports growing evidence of an association between deficiencies in long chain highly unsaturated fatty acids (HUFA) and a variety of learning and behavioural problems as symptoms in the sub-type of dyslexia, including deficits in visual
processing. The Irlen and magnocellular deficit hypotheses relate primarily to symptoms, as factors contributing to visual dysfunction, however Robinson considers they are without a cohesive theory to explain the overlap of a number of conditions which are found, to varying degrees and in different combinations, in any group of individuals with LD (p. 12).

According to Robinson, essential fatty acids (EFA), in particular the Omega 3 and 6 groups, “play a primary role in most cell signalling systems in the neurones, and are fundamental to neuronal structure growth, remodelling and function” (Robinson 2002, p. 3). Stein (2001) states that the magnocellular pathways and retina are dependent on EFAs, consequently a deficiency may compromise visual function (Stein 2001, cited in Robinson 2002, p. 4). EFAs improve “maturation of rod photoreceptor function and visual acuity” (Neuringa et al., 1994, cited in Robinson 2002, p. 4), and the “development of mature synapses” (Willatts & Forsythe, 2000, cited in Robinson 2002, p. 4). Studies have reported reduction in attentional difficulties and general behavioural problems with highly unsaturated fatty acid (HUFA) supplementation (Richardson, et al, 2002 cited in Robinson 2002, p. 15), although this conclusion is questioned by Mitchell (1987) who states that a simple deficiency in EFA’s as the cause of the problem is unlikely “or there would be more signs of ADD in other disease states where DGLA is low, such as cystic fibrosis” (Mitchell et al., 1987 cited in Robinson, 2002, p. 15).

Robinson (2002) warns that although HUFA supplements may improve the status of visual function for people in this wide range of diagnostic categories, the effectiveness is likely to “depend on the original cause of the anomaly”. The sources of the symptoms need to be identified in order to establish if that was due primarily to EFA deficiency, or whether this “increases vulnerability to environmental factors as infection and stress” before EFA status can become a method of early identification of visual and LD (p. 16).

(4) Multi-deficits in reading difficulties addressed in “Cellfield” intervention study
Prideaux, Marsh and Caplygin (2004) use computer-based tasks that required simultaneous visual, auditory and phonological processing to address multiple deficits related to reading impairment. The visual aspects of their programme were influenced by evidence of impaired neural development in the visual system (Galaburda & Livingstone, 1993 cited in Prideaux et al., 2004, p. 10) and brain scanning evidence of under-activation in the angular gyrus (Shaywitz, 1998, cited in Prideaux et al., 2004, p. 10) which they believe “highlighted the need to enhance auditory, visual and visual to auditory processing”. Ocular measures included foveal position, foveal stability and contrast sensitivity recorded for each eye. Vision training involved increasingly the load on the magnocellular system with “high demands on visual focus, eye tracking, on language processing and on eye/hand coordination” (Prideaux, Marsh &
C!plygin, 2004, p.12). Results of their ten-session, integrated approach to therapy showed an "accelerated gain of two entire grade levels" within two to four weeks that it took students to complete the course, in reading-related skills, and oral reading proficiency (p. 30). Ocular measures of foveal position and foveal stability, and contrast sensitivity abnormalities had come within normal range for a significant number of subjects following treatment (Prideaux, Marsh & Caplygin, 2004, p.36).

3.2.3 Conflicting research findings and theoretical explanations pose further questions
These apparently conflicting findings in research studies raise a number of questions. Specifically of whether the o-m function is normal in subjects of these studies, or whether the o-m system serving foveal binocularity and fixation capacity may be implicated. From a developmental perspective, the Irlen Syndrome of "visual-perceptual dysfunctions, restriction of span and sustaining focus, and eye strain" also describes effects of o-m dysfunction, from 'defective eye teaming'. Students attending Educational Therapy generally display deficits to some degree in orthophoria, of eye posture at rest; imbalance of accommodation between the two eyes, and/or fixation disparity; inadequate range of convergence and divergence; and limited fusional reserves resulting in an inability to maintain normal binocular vision. From a clinical, as opposed to an experimental perspective, it can be conjectured that variability of results from research findings may reflect the variability of the subjects’ visual function. Results of any tests might be dictated by where, along the 'stress continuum', the optometric measures are taken. Results might depend on the level of eye teaming, how a weaker eye might adapt to the challenge and how changeable thresholds from poor motor co-ordination might impact on integration of peripheral and foveal vision pathways, as shown in the Lovegrove test of contrast sensitivity.

Theoretically, any deficit that intermittently interrupts binocular pathways, prevents accurate feedback between the parvo and magnocellular systems, and / or diminishes foveal fixation may predispose an individual towards LD if it disrupts the visual pathway to the language area of the dominant hemisphere. Nutritional biochemical anomalies which may adversely affect neural function within the retina, cerebellum and myelin sheaths can certainly be regarded as a primary cause of neural 'immaturity' that might result in secondary, developmentally adverse effects.

3.2.4 Summary – Fovea fusion as the key to literacy
The key o-m function appears to be the ability to maintain focus of the foveal hemi-fields on the point of interest. Foveal vision includes edge discrimination needed for the perception of
details of shapes, like for example, letters. In order to read fine detail with foveal vision, the eyes must convergence in and downwards, in concert with the accommodation system. A normal reading distance is about two-thirds of an arm’s length, consequently as the angle of fixation is increased, greater convergence is required to maintain foveal binocularity, more so for small, finer print. Palmer (1999) describes the anatomical structure of the fovea as being “densely packed with cones ... The visual angle covered by the fovea is about 2 degrees (the size of a thumbnail at arm’s length) where colour and spatial vision is most acute” (Palmer, 1999 p. 31). The optic nerve carries retinal impulses to the optic chiasm from which the nasal side of the fovea of each eye crosses over to the opposite side of the brain. The density of the fovea and its generous neural representation is a measure of its importance, “with a disproportionate representation of central visual field” (Palmer, 1999, p. 35). In this way, the ‘dominant literacy pathway’ is from the foveae to the left hemisphere language area (see Section 9.4.1).


The subtle nature of o-m dysfunction is highlighted by Cuiifreda (2002) who states that assessment of both static and dynamic accommodative and vergence disorders may be overlooked, because “o-m bases are generally found to be relatively minor, as output is derived from the specific blur or disparity stimulus itself, within its own negative feedback control loop... and since accommodation at near is not usually sustained... the adaptive loop would not be activated”. Cuiifreda stresses that assessment would need to incorporate “blur discrimination techniques, with monocular and binocular flipper therapy to force accurate accommodation” (p. 743). The difficulty inherent in correctly attributing causal factors and effective treatment are also applicable to the broader problems in dyslexia. Stein and Walsh
(1997) in their paper, “To see but not to read” suggest ‘impaired temporal processing’ may explain the disparate deficits of dyslexia, “weak phonological processing and spelling, clumsiness, poor spatial organisation and untidy writing, distractibility and forgetfulness” (p.151). Stein and Walsh speculate, “a subtle underlying thread... may eventually be found at a lower level than the perceptual and cognitive systems that have been the main focus of research effort to date” (p.151). This supports the author’s critique of the Paediatric and Ophthalmologist’s position statement (1998) that asserts there are no links between visual function and LD, as possibly based on ‘incomplete’ vision screening (see Ch 1, p. 2).

3.2.5 The importance of foveal binocularity

According to Emsley (1977) retinal images need to fall equally on the two foveae to provide a single, fused image, but if the images differ the impulses transmitted to the cortex do not ‘correspond’, resulting in double vision which is confusing (p. 29)...“fusion becomes possible only with extra effort, or discomfort” (p. 66) ...and “depends on the o-m system’s adaptation capacity “forced by the fusion impulse” to make the requisite movement (p. 67). Emsley (1977) notes different levels of function; between binocular vision (both eyes have normal vision), binocular fixation (both eyes fixate on the same point of interest, with or without fusion), fusion (the two retinal images blended into one image, with or without stereopsis), and simultaneous macular vision (central vision including fovea, fixated on the point of interest (p. 67).

Three levels of suppression in global or foveal vision

Suppression is assumed to be a visual strategy to retain clarity of vision and avoid double vision while retaining clear, binocular global vision. However, it appears to be at the expense of foveal binocularity and so becomes a ‘mal-adaptive adjustment’ in terms of the demands of memory and literacy skills. Three levels of visual suppression have been uncovered in vision training.

a) One simple example may occur when looking at a bead on a string that is held at the nose (Brock string). Two crossed strings were perceived, but as the bead was moved closer, with insufficient accommodation or convergence, one string may disappear. If each eye is then covered in turn, the student becomes aware of the lost image and could then work to overcome the suppression.

b) A second level of foveal suppression is manifest during vision training when viewing anaglyph slides through red/green lenses (Section 6.4.3). This equipment allows the student to
discriminate between what each eye is seeing. It becomes apparent to the student when one eye is unable to maintain foveal fixation and part of the image blurs, or images do not match. This may occur due to insufficient convergence, anomalous phoria, accommodation or long sightedness. It is reasoned that as convergence demand is increased during eye exercises, detail is lost as foveal fixation slips out through the macula area onto the peripheral retina. In this way, whichever eye fixates, the other eye is displaced and the image blurs and is lost. Or words appear to "switch on and off", as eyes alternate in a ‘bird’s eye effect’ which does not appear to create problems, providing alternation is fast enough for the images to blur into one.

c) Foveal suppression is discussed in detail in Section 9.4.4, 9.4.5 and 9.5.3.

Networks strengthened by stimulation, feedback and maturity

Neural networks are strengthened by reliable sensory input, but it can be argued that the converse may be true. Networks may be weakened, or disrupted if the same stimuli are repeatedly encoded differently by unreliable input, due to o-m dysfunction. Hebb (1945) proposed the principle that “whenever one cell (A) repeatedly takes part in the firing of another (B) ... some growth process of metabolic change takes place in one or both cells, such that the efficiency of the first cell in firing the second is increased. In this way, synapses play a central role in making connections within cognitive networks (Hebb 1949, cited in Fuster, 2003 p. 42).

It is well established that stimulation modifies and develops functional pathways. According to Purves (1994) the quality of sensory input is the stimulus to growth that determines the ‘architecture’ of neural connectivity ... with "qualitative and quantitative accuracy of neural connections based on intercellular recognition [italics added]" within associative networks. Over time, excess connections are ‘pruned’ allowing for greater maturity in neural efficiency and functional co-ordination (Purves, 1994, p. 45). Shatz (1992) wrote that “foundations of the mind are laid down ... as neurons form appropriate connections and patterns ... Neural activity and stimulation ... are crucial in completing this process” (Shatz, 1992, p. 35).

In terms of the anomalies observed when supervising vision training, the therapist considers that a physical anomaly like a weaker right eye frequently displayed in eye exercises (see Chapter 7 for evidence of this observation), may upset neural development along latent pathways, if intermittent and changeable input into the visual system mistakenly connects to different ‘destinations’, then “this dissonance would lead to the weakening and ultimate removal of that connection” (Shatz, 1992. p. 39).
3.2.6 Inter-relationship of visual ‘immaturity’ and o-m dysfunction

Level of perceptual tolerance in complex tasks

Palmer (1999) states two major functions of eye movements are “fixation to position target objects of interest on the fovea where visual acuity is highest; and tracking to keep fixated objects on the fovea despite movements of objects or observer’s eyes or head ... as spatial and chromatic resolution are much higher within one or two degrees of the centre of the retina ... if detailed information is needed then eyes need to move so relevant objects fall sequentially on the fovea” (p. 520). Timing is critical because according to Emsley (1977), “stimuli must not be repeated too rapidly if they are to be perceived as separate, ... yet in reading the eyes travel over the printed matter at a rate of forty or more letters being seen and interpreted in one second. The fovea thus recovers from one impression sufficiently to be appreciably stimulated by a succeeding impression “with remarkable speed and precision, even allowing for the feats of interpretation executed by the brain as the result of long and continuous experience” (p. 31).

These observations have particular relevance for foveal fusion in the highly complex skills involved in literacy, as this necessitates visual links to the language area. There may be much less perceptual ‘tolerance’ in literacy, from o-m inaccuracy upsetting speed and synchrony of foveal input, than there might be for less complex tasks of daily living where peripheral resources may share the visual load.

‘Mal-adaptive adjustment’ and ongoing ‘immaturity’ of the visual system

The remarkable ontological plasticity of neural growth and development can be interpreted as becoming ‘mal-adaptive adjustment’ in the visual system’s attempt to ‘accommodate’, that is, to use normal adaptive processes in the unnatural situation of on-going variability of sensory input from o-m dysfunction. Thus ‘immaturity’ of the visual system, as poor co-ordination, might be perpetuated in the manner of immature neural systems, as described by Purves (1994) in failing to provide sufficient, constant perceptual ‘schemas’ that are necessary to allow for the pruning of excess connections that are used less and less, in a process of improved co-ordination. O-m dysfunction may maintain these ‘excess’ connections by extraneous input, thereby delaying visual maturation. As a consequence, it may take longer for normal milestones to be achieved, with delay in the integration of associative networks and co-ordination as part of the developmental process.

Certainly, uncoordinated jerky eye movements of students with o-m dysfunction doing eye tracking exercises are reminiscent of eye movements of very much younger children (clinical observation EGB – author). It can also be seen clinically with monocular foveal suppression
when vergence is not adequate to sustain binocularity for near vision (EGB). Likewise in Duane’s syndrome (abnormal retinal correspondence from a deviating eye, Emsley, 1977, Vol.2, p.130), where it appears one eye becomes ‘fixed’ it is assumed to compensate for a ‘wandering’ eye. Both eyes usually respond well to eye exercises, because as the drifting eye comes under control, then the compensated eye ‘loosens up’ to a full vergence range and fusional reserves (EGB).

In principle this type of functionally ‘mal-adaptive adjustment’ to abnormal conditions appears to be a survival imperative, in order to maintain clarity of vision, and minimisation of perceptual confusion. They are mal-adaptive in the sense that although maintaining optic clarity, they might also, as suspected, contribute to intermittent or chronic interruptions to bi-hemispheric integration of visual information, and most critically, prevent auditory/visual signals becoming bonded into a dyadic unit, as phonics. Once normal visual function is restored, then literacy skills tend to progress with greater speed and ease.

3.2.7 The major assumptions of the thesis

Notion of ‘neurologically determined eye dominance’

It can be inferred, from the review of the literature, that reliability of visual input is the focal point of questions underlying this research. In theory, the important role played by foveal binocularity in the recognition of print can be reflected in foveal content for encoding graphophones. These are mapped through the associative networks onto, and bonded to, the auditory signals in the angular gyrus in the left hemisphere, as dyadic phonics, having bonded visual and auditory components. This supposition would indicate that if the language area is located in the left hemisphere, then the contra-lateral pathway, from the right hemi-field of the right eye to the language and form recognition area, is the dominant pathway for literacy. Likewise, the left hemi-field to right hemisphere provides the spatial feedback to support o-m co-ordination. The other parallel pathways that need to match, synchronise and integrate are the magnocellular (peripheral) and parvocellular (foveal) pathways. Consequently it can be argued that any acquired physiological anomaly that interrupts these latent connections may make it harder and take longer to acquire the highly evolved skills required for literacy, predisposing the individual to what is termed ‘LD’.

Implications for vision testing

Standard vision tests may be adequate to detect acuity problems affecting activities in everyday life, including already established reading skills in adults. However, current tests may not be sensitive enough to detect anomalies that may intermittently disrupt sensory input in early
childhood and the first years of schooling. It is apparent that early visual experiences are important for stimulating neural networks, but these established pathways need to be reliable for efficient learning, retention and recall in reading and spelling. Even mild o-m dysfunction may compromise this developmental process if the dominant pathways are compromised.

3.2.8 When is a visual anomaly a sensory deficit?
Kiely, Crewther and Crewther (2001) note there is little consensus among researchers about a link between eyesight and learning, and their research found no correlation between visual parameters and ocular function for children with differing reading ability ... except for 30% of subjects with low accommodation [italics added] - "possibly the most efficient diagnostic tool for binocularity" as they concede that accommodation is a point of major clinical impact, so binocular anomalies should always be assessed (Kiely, et al., 2001, p. 352).

The Kiely paper is interesting as it encapsulates difficulties associated with establishing scientifically workable results, from a clinical point of view. On one hand they state there is no statistical link between vision parameters and reading, and then suggest their finding of diminished accommodative facility as possibly being causally linked with binocular anomalies. Yet physiologically, efficient reading necessitates language and word recognition as left hemisphere processes, linked with spatial, right hemisphere processes to provide feedback loops for accurate eye movements. Binocularity may be a key pre-requisite for efficient learning in the neurologically complex task of literacy. The problem is not the severity of the dysfunction so much as variability of eye balance and movement (Howell & Peachey, 1990, p.16) which appears to have the most negative effects on perception, memory and learning. Presumably because the visual system can adapt to even severe anomalies, so long as the condition is constant, and consequently does not cause perceptual confusion.

The implication is that inconsistency of sensory input is the destabilising element. The apparently perverse clinical situation provides some support for Howell's observation, namely that apart from a lack of depth of field perception and poor driving skills, functionally, monocular vision of the right eye does not appear to create the same LD as intermittent binocular dysfunction. Stable monocular vision does not appear to create these problems, presumably because it provides a constant environment to which the brain can adjust. Several siblings from two families of students attending Educational Therapy were likewise assessed as having functional monocularity, but generally their academic standards were above average, regardless of which eye was dominant (clinical observation EGB).
The demands of reading versus biology

Bimbaum (1989) places the concept of visual dysfunction outside the medical concept of 'anomaly', into an evolutionary perspective, when he states: "Technology and culture have created a task demand, for information processing through symbols at nearpoint, which is inconsistent with our biology" (p. 25). Bimbaum argues that the attention and mental effort involved in reading amounts to autonomic arousal with the result that accommodative stress tends to result in over-convergence, so that "integration of accommodation and convergence, essential for efficient nearpoint function, is incompatible with our own physiology... such that various refractive, binocular and accommodative deviations may arise adaptively in order to resolve this mismatch and facilitate efficient nearpoint visual function". He equates nearpoint visual stress as being parallel in effect to that of stress-induced systemic illness (pp. 25–35).

3.2.9 Symptoms of clinical significance – Behavioural Optometry

Behavioural Optometry has been forging a route through these disparate views with their vision training results. Howell, (1986), a leading academic and clinician in the field of Behavioural Optometry states “optometrists need to ensure the visual system is available to receive and process with meaning, the maximum visual information per unit time with the minimum of effort” (p. 20). His stated position is that although it is difficult to prove a causal relationship between LD and visual problems, these certainly contribute to reading difficulty and visual perception problems. In their monograph, Howell and Peachey (1990 pp. 12-19) identify eye movement deficits associated with short-term memory. Unstable eye dominance associated with control of fixation and perception of location which is in turn significantly correlated with reading age (Stanley, Howell & Marks, 1988). Binocular dysfunction of convergence insufficiency; and accommodation disorders associated with reading and learning. "...many seemingly different visual development difficulties have a common underlying cause... not readily apparent as they have become embedded" (Howell 1986, p. 24).

Of particular interest is Howell and Peachey’s point that a source of confusion arises from an expectation that the "degree of reading disability would be contingent upon the severity of o-m dysfunction" (Howell & Peachey, 1990, p. 16). Strabismus (turned-eye) "is clinically severe but does not necessarily impact on reading if it is stable and can be compensated... but... a less obvious acute or intermittent binocular dysfunction would make it more difficult to develop compensatory abilities" (Howell & Peachey, 1990, p. 17). Howell and Peachey note the cumulative effect of fatigue can also be overlooked. That is, if abnormal effort is required to overcome vergence / accommodative stress which “over time can interfere with comprehension”. They conclude that "o-m dysfunction interrupts the processes involved in
acquisition and processing visually presented information ... and can occur in the absence of an ocular [acuity] problem” (Howell & Peachey, 1990, p. 19).

Clinical insights and encouraging results, including therapy gains reported in this research, arising from vision training guided by Behavioural Optometrists is proving to be an important foundation for the successful treatment of under-achievers with areas of o-m dysfunction. Palassis (2004) comments that “the problem is not the classification but the outcome of treatment ... nothing is static in the visual system, we can vary the outcome depending on the nature of treatment, which is why behavioural optometry works with therapeutic lenses to shift the visual system and not compensating lenses that embed the difficulties” (Palassis, 2004, personal communication). This developmental view reinforces the opinion of Fletcher (2002) who suggests the most productive development of effective research and management strategies would involve a move towards “intervention-oriented definitions of LD” based on the results of intervention studies (Fletcher et al., 2002, p. 64). Research driven by results from the field rather than the laboratory, is considered to be more effective in evaluating what works and in building a theoretical model.

3.3 Primacy of Perception in Learning

3.3.1 Optical information as the foundation of vision

Piaget (1971) presents a cognitive view of learning, “To present an adequate notion of learning one must first explain how an individual manages to construct and invent, not merely how he repeats and copies” (p. 27). In this way, perception is the manner in which an individual assimilates impressions and tests a sense of reality of the world. Palmer (1999) states that the biological importance of vision is that it evolved to aid in survival:

Optical information, from the light emitted or reflected from environmental objects and events, is the foundation of all vision ... (p. 5) ... ‘knowledge’ being a cognitive activity ... signifying something about the nature of external reality ... enables the perceiver to act appropriately in a given situation, in an evolutionarily adaptive manner. All senses participate in this survival ... vision is the most accurate, however perception differs as it is a ‘constructive act’, so does not necessarily reflect external reality in its truest sense (pp. 5-6). Objects we perceive are actually hypothetical interpretations based on the structure of images rather than direct registrations of physical reality (p. 9) ... a remarkably economic solution to the problems of how to achieve stable and accurate knowledge of the environment (p. 12).

Included in a concept of ‘vision enabling the perceiver to act appropriately’ can be added the observation that it also influences what is learned. In effect, the quality of vision also
determines what is laid down in memory, to be integrated into the totality of learned experience, which to the individual may be uncertain because perceptual memory is an interpretative process of raw sensory impressions. Purves (2002) notes that in colour and light discrimination there is “an inherent ambiguity of the real world origins, of any spectral stimulus” (p. 609). Auditory pitch discrimination is likewise a matching process that “relates inevitably ambiguous sound stimuli to their probable natural sources” (Schwartz and Purves, 2004, p. 31).

3.3.2 Attention
In the case of blurred vision, from poor acuity, focus or accommodation, or lack of foveal ‘visual definition of detail’, the subsequent ‘blunt awareness’ can be modified to some degree by heightened attention. Conversely, a convergence of attention can also reduce awareness of other aspects of a task, which can increase error rates. Consequently, o-m dysfunction can be stressful and tiring, and associated with discouragement.

William James (1890, cited in Palmer 2002) expressed attention’s critical attributes as consisting of the mind’s focus, selectively and exclusively on one object or train of thought ... not necessarily consciously. Ullman (1984) referred to ‘visual routines’ which “operate only with the benefit of focused attention to a single object or group... for analysing complex properties of incoming visual information” (Ullman 1984, cited in Palmer 2002, p. 589). Palmer (2002) expands on the concept of visual routines as operating “on visual images retrieved from memory, such as generating and transforming images for a variety of tasks, including visual imagery” (p. 589). For example visualising and recalling spelling patterns and generalising across to an unfamiliar but similar sounding word. In Educational Therapy foveal fixation is regarded as the functional partner in selective attention, as awareness of fine detail and sequence of common letter group, is part of spelling (EGB).

According to Fuster (2003) in working memory, the “selective activation and attention on the cognit (unit of information) is sustained by continued re-entry of excitation within that network”. Attention is presumably complemented by being able to ignore irrelevant stimuli through “the exclusionary inhibition of networks to the task at hand” (p. 159). It can be considered that the brain’s intelligent initiative of ‘exclusionary inhibition’ may not work effectively if the sensory input stream is confused and/or intermittent, resulting in loss of attention, and distractibility of ‘attention deficit disorders’.

Serences and Yantis (2006) state that perception depends of two separate systems, that of ‘bottom-up’ involuntary sensory input and ‘top-down’ voluntary selective attention, at “all
levels of the visual system from the retina, to regions of parietal and frontal cortices”. The two stages consist of earlier receptions whereby sensory properties of the stimuli are coded as “basic image features”. These then interact with later neurons that “code abstract features such as behavioral relevance”. Selective attention then coordinates the activities of both sets of neurons, to resolve competition and link perceptual representations from different parts of the brain (p.3). Tree, (2003) states that “A voluntary deployment of attention to a location or feature, and their relative impact varies more or less continuously as incoming information ascends the cortical hierarchy” (p. 469).

The primacy of voluntary control is suggested by Serences et al. (2005) who found “recent evidence for a reconfiguration signal originating in post parietal cortex that does not vary as a function of the sensory properties of the stimulus”. He suggests this might be due to “some neural signals being classified as pure sources of attentional control operating independently from the current sensory input” (p. 36).

Sireteanu et al. (2006) found dyslexic children presented with selective deficits in visual attention. Although their performance in feature detection tasks was similar to the control group, they were slower and had a greater error rate (p. 85). Generally, poor o-m co-ordination and tracking skills are also found in autistic and ADD students attending the ET practice, and while not all aspects of their difficulties can be corrected, vision training is found to make a difference to their attention and retention rates (EGB).

When working with children with L.D. it is common to find they are slow to integrate information, but compensate with fast, but ill-conceived responses in a trial and error strategy, ‘before they forget’. Students can portray a general air of perplexity when faced with perceptual challenges associated with poorly developed visual perception like deficits in size judgement; spatial awareness; position / direction awareness in patterns; discriminating figures against a background; three-dimensional awareness in over-lapping edges; shape recognition including comparing and contrasting shapes, and completion of shapes from minimal clues. Most of these elements of perception are crucial for letter and word recognition and writing.

Deficient three-dimensional perception is apparent when teaching ‘running writing’ to young and older students, as elements like angles are missing from the visual array, consequently they are limited to ‘stick and ball’ shapes of printing, which is inefficient (EGB). For these children it appears that complex visual displays are not as meaningfully self-evident as it is for children with normal o-m binocularity and visual perception. In addition to a perceptual deficit is an increased error rate from rushing into tasks ill-prepared. All of which suggests that their
perceptual model of the world is slower to take shape. When constancy and dependability of sensory input is unreliable, this not only upsets the ‘down-line’ processing of memory traces and retrieval, but may even adversely affect the way in which ‘information processing’ networks develop.

The Intervention study will investigate the effects of improved visual function and whether this makes a difference to literacy outcomes, which by implication, would include increased speed and efficiency of work habits and reduced error rate.

3.3.3 Perception and Memory

The following Figure 4 is a conceptual representation of the ideal perception and memory interaction within the limits of the Sensory Information buffer of half to one second duration time for visual information.

**Ideal Perceptual analysis**

![Ideal perceptual analysis within Sensory Information Storage limits](image)

Words and phrases are familiar clumps of visual information that are recognised from minimal cues, when reading at a normal pace. Lawrence (1988) makes the point that ‘sensory memory’ can be described most aptly as a ‘perceptual capacity’ because it has a limited capacity, and furthermore it is not a memory until it is recorded (p. 152). Palmer (1999) states that perceptual information is retained in a functionally active state in the auditory, echoic sensory information store (SIS) for up to thirty seconds as sound is ephemeral, and between a half and one second in visual, iconic sensory information store, depending on lighting conditions (p. 574). During this initial stage, information is very vulnerable to loss either by interruption of the analysis by masking, that is, displaced by attention to new material, or other distractions (Riding 1980, cited in Lawrence, 1988, p. 151); or if there is a failure to match incoming stimuli with existing traces, it is stored as a new classification (Bower, 1969, cited in Travers, 1977, p. 260); these
interruptions to the sensory stream constitute a subtle loss of signals, and “is the fundamental determinant of learning capacity for symbolic material for some children” (Lawrence, 1988, p. 152).

The following Figure 5 shows how intermittent sensory input might result in not only incomplete, ambiguous images, but additional extraneous elements constituting ‘random noise’, that creates further perceptual confusion. Variability of images might likewise cause confusion between ‘known’ and ‘novel’ items, or multiple images of the same object or letter. Stable memory traces sufficient for literacy would evolve over time from trial and error, or extra repetition.

![Perceptual deficit model](image)

**Figure 5  Perceptual deficit model**

As stated previously (Palmer 1999), auditory Sensory Information storage is longer because sound is ephemeral, which in theory would provide a larger error tolerance for visual signals to be bonded to auditory signals as phonics. However, it can be argued that if ocular-motor function is slowed or uncoordinated such that the signal arrives at the left angular gyrus outside this temporal limit, or is suppressed momentarily, then the visual signal would may be lost (see Section 3.2 Weisel & Hubel, 1965).

This form of deficit might be considered as sensory deprivation, with distractions leading to S.I.S overload, leading to a loss of accurate selective attention and behaviour labelled as ‘distractibility’. From a neurological point of view, there might also be an associated reduction of potential dendritic and synaptic growth, resulting in perceptual ‘immaturity’. The implication is that perception, specifically of reliable feature detection capacity, may be a limiting factor for children with LD. Support for this notion is that adequate acuity of vision and o-m function is
necessary to provide the level of discrimination needed for a clear and reliable symbolic memory (Palmer 2002, pp. 5-6), as converting spoken language into symbols of language, in print. Memory is determined by the number of attributes, or characteristics of experience that are accurately presented to memory through the perceptual analysis process (Bower, 1969; Riding, 1980; Lawrence 1988).

3.3.4 Memory as neuronal firings

Gibson (1963) conceptualised memory as a familiar sequence of neuronal firings, with perceptual processes organising data into patterns, in effect imposing an order, in what could be described as ‘reduction of uncertainty’ (Gibson, 1963, cited in Marshall, Eds. Stanley & Day, 1977, p. 26). Remembering, recalling and recognising is “the retrieval of memory as re-activation’ of the network that represents it... Conscious awareness [may vary the] reactivation of its connective pattern of the associated component parts that define and sustain a memory” (Fuster, 2003, p. 132).

Memory is also anticipatory, but if perception is too hazy or unreliable, and a student is not expecting to see much detail, and fails to attend adequately, not enough essential elements are perceived to retain a complete memory of it. In this way lack of attention to detail may compound an already weak feature detection system arising from unreliable o-m function. This is certainly the impression given by students with o-m dysfunction, which may be at variance with the level of intelligence shown in their well developed language skills and social awareness. As visual skills improve, parents frequently comment on the associated changes as “showing more initiative and having more confidence”, the contrast confirms how perceptually ‘lost’ their child had been previously.

3.4 Memory as the Basis of Learning

Careful (clinical) observation and subjective evaluation of perception, memory and learning has an honourable precedent set by the Greek philosopher Aristotle (384-322 B.C.) the “founder of formal logic and scientific method” (Guthrie, 1970, p. 590). Aristotle believed intelligence is dependent on the quality of memory, which relies on adequate encoding of repeated, accurate and reliable visual signals, a view validated by current research and theory. Aristotle wrote:

> We prize sight as a source of pleasure... as a guide for action... because sight gives us the most information and reveals many specific qualities. All animals are provided with sensations... [but] with some, memory does not result from their sensations .... Hence animals with memories are more intelligent and able to learn... In man, memory gives rise to experience, since repeated memories of the same thing acquires the characteristics of a single experience (Aristotle 350 B.C).
3.4.1 Stages of memory

Palmer (1999) defined visual memory as “the preservation of visual information after the optical source of that information is no longer available to the visual system” (p. 573). Baddeley (2002) presents a memory model as having initial visual, auditory and haptic (in this context can be defined as tactile, kinaesthetic and proprioceptive senses) input from the environment registered in a Sensory Information Store (SIS). Attention then facilitates transfer to short-term, temporary working memory (STM) where controlling processes consist of rehearsal, coding, decision and retrieval strategies. Responses are part of this process, a two-way interaction between electrical STM and chemical Long Term Memory (LTM), feeding information into LTM and in turn being guided by it (Baddeley, 2002, p.3). The difficulty with earlier models of memory was that learning did not automatically occur from holding information in STM, so Baddeley and Hitch (1974) proposed a multi-component working memory in three interactive stages:

a) Sensory information store (SIS)

The initial SIS is in both visual ‘iconic’, and auditory ‘echoic’ modes as brief ‘buffer’ memory stores before information is accessed consciously (Sperling 1960 cited in Palmer, 1999, p. 574). The characteristic duration for which visual information is held in the SIS is approximately half a second (Averbach & Sperling, 1960, cited in Palmer, 1999, p. 576), so attention and motivation must be adequate for patterns to be registered within this time. The other characteristic of SIS is information content, capacity, maintenance and loss through decay or interference (Palmer, 1999, p. 576).

One explanation for the purpose of SIS is to allow processing of information during saccadic eye movements, when visual information is suppressed in order to avoid movement blur (Palmer 1999, p. 523). It may also be allied with the unconscious visual system, involving the superior colliculus, which allows ones attention to be drawn to novel or important objects or events, without being conscious of seeing it (Weiskrantz, 1986, cited in Palmer, 1999, p. 635).

The following Figure 6 shows the critical role of the SIS. Input from both left and right fields of vision of both eyes across contra-lateral pathways provide bi-hemispheric integration of information. This ensures a link with the left hemisphere to the auditory system’s angular gyrus for the bonding of phonics. It also provides feedback regarding spatial processing from the right hemisphere to guide eye movements. The timing of signals into the SIS can therefore be considered as critical, for both the integration and quality of sensory input into associative networks and subsequent perceptual processing.
Intermittent visual input into the Sensory Information Store

It can be argued that the optimal condition for perception is two eyes, focussed and aimed accurately on the object of interest, with interpretations as plausible reconstructions, and errors modified by subsequent visual exposure. The early learning processes of a child’s neural growth and connectivity can then build on reliable, clear images for unambiguous memory traces. It fact, children may suffer from developmental deficits in critical stages of neural growth owing to o-m dysfunction causing intermittent breaks in the flow of information. Particularly if foveal details of images, like print, do not always appear the same. As outlined in Chapter 1, p. 4, in Educational Therapy the common pattern of visual anomalies is found to affect binocular co-ordination of movements, and eye posture as the eyes converge for near vision or diverge for distance vision, or do not operate in concert with accommodation, owing to lack of balanced muscle tone between the eyes.

It can likewise be argued that selection of relevant information demands a level of alertness which may be undermined by ‘faulty reception’ at retinal level owing to poor eye teaming from o-m dysfunction causing delayed processing time. Dyslexics have been found to have “a basic impairment in retaining and comparing perceptual traces” (see Section 3.2.2:2, Ben -Yehudah & Ahissar, 2001). This is an effect that may compound problems in the feedback loop, from an associated attention deficit, of not ‘expecting to notice’, owing to an ongoing experience of helplessness that confused perception might create. It would seem the SIS might be a weak link for individuals with LD, being as it is the unconscious interface between sensory reception and
conscious perception. This vulnerability to loss of sensory input prior to memory encoding may determine whether the individual falls into an 'at risk' category for literacy skills.

b) Baddeley’s 1974 model of Short-term memory and Working memory

In brief, the Short Term Memory (STM) is electrical, with a limit of about seven items and this stage also fades fast. However, details such as the sequence of phonemes in the symbolic memory system can be held by selective attention and rehearsed until it can be transformed into long-term memory. Stages of memory involve *encoding* to register information; *storage* maintaining information over time; and *retrieval*, accessing information by recognition, recall or implicitly by performing a task better for having done it before. The STM is conceived as being a link between the limited SIS system and long-term memory.

Baddeley proposed a number of systems within the STM. The working memory he considered as being a “broader construct that emphasises the STM in ‘executive control’ processing, in virtually all cognitive tasks” (Baddeley, 1986, cited in Palmer 1999, p. 584). This includes a ‘central executive’ or attentional controller utilising two subsidiary systems. These are firstly, the ‘phonological loop’ in order to store phonetically encoded traces for a few seconds, coupled with sub-vocal rehearsal process, or secondly, visual information in a ‘visuo-spatial sketchpad’, while STM is working (Baddeley, 2002 (a) p. 5). From the teaching point of view, the interactive nature of this system makes it appear to be central to the process of matching and mapping the sound of phonemes into their visual equivalent, as grapho-phonemes, or letters, which are the foundation of literacy.

A third system, called the supervisory attentional system (SAS) was proposed by Norman & Shallice (1986, cited in Baddeley, 2002 p.6) to account for intentional ability to “over-ride well-learned habits and schemata that are guided by environmental cues”, and so “allow novel actions in response to new challenges”. The SAS model has accounted for absent-mindedness (Reason, 1984, cited in Baddeley 2002, p.7), and for individuals with LD, it explains how easy it is for them to ‘unlearn’ past lessons, leading to lack of confidence in their own memory.

A key aspect of trampolining exercises is raising students’ awareness of the working memory, coaching them to take conscious responsibility for accessing and using it in an efficient manner. When introduced to her ‘mental screen’ one eight-year old was quite distressed, “I can’t do that, it is cheating” which illustrated to the therapist just how limited the ‘learning tool-kit’ can be for these students.
Lack of attention or absent-mindedness is often noted as a common trait associated with LD. It is possible that supervisory aspects of the attention are diminished owing to 'learned helplessness' (Seligman, 1975), as insecurities arising from the unreliable nature of visual signals with o-m dysfunction. Rayner et al., (1978) proposed a form of memory that supports "a coherent perception of a unified scene from multiple fixations" called trans-saccadic memory (Rayner, McConkie & Erlich (1978) cited in Palmer 1999 p. 585). In a sense, this is a micro-scene of symbolic (as opposed to experiential) memory, but it might likewise be associated to the macro-scene of daily living, called 'disorganisation' and procrastination'. Generally, it can be considered that o-m dysfunction can be considered as being particularly detrimental to this specialised memory system.

c) Long-term memory
In brief, long Term Memory (LTM) is chemical, organised, stable, and relatively permanent depending on how often information is refreshed by being retrieved. It is believed to have two component systems, i.e. episodic memory of events, and semantic (Tulving, 1972 cited in Baddeley, 2002, p. 8) termed exclamatory memory, for the meanings of words and abstract concepts, which are explicit memories available to consciousness. Implicit memory is unconscious, automatic, learned skills.

Symbolic memory is an aspect of semantic memory that is the main concern of this paper as it relates to symbols with which we do our thinking, namely language and concepts, mathematics and sequential operations, like letters in words and words in sentences. Vital to symbolic memory are demands for visual accuracy and perceptual processes of feature detection, as well as ability to organise these into patterns and blocks of information in the memory. For example, a K is always a K, regardless of its script style or orientation. Words and phrases are familiar clumps of visual information that are recognised from minimal clues, when reading for meaning at a normal pace (EGB).

Like STM, LTM has an explicit component which is declarative - facts and events that can be expressed and retrieved directly; and implicit component which is non-declarative - skills, priming (cued by preceding action), conditioned and non-associative learning of implicit knowledge without words (Baddeley, 2002, p. 7). Episodic memory has strong emotional and sensory components, whereas normal recall consists of a 'plausible reconstruction' process guided by intellectual thought organisers, like logical possibilities and value judgements. It is retrieved through an individual's level of reasoning and intellect, or as Piaget expressed it, "the schemata, the cognitive nucleus around which sensory information about the environment is
organised ... [is in effect] ... an organisation of memories for action” (Piaget, 1977, cited in Lindsay & Norman, 1977, p. 500).

It can be reasoned that students can have four levels of memory deficits, or areas of immaturity. They are: (i) primary perceptual and attention deficit at the SIS level; (ii) a secondary memory span deficit in the Working Memory; (iii) a tertiary deficit in the Long Term Memory schemata, of analysis and organisation require for storage and retrieval, which can not evolve into ‘memories for action’ if the memory store is patchy and obscure; (iv) and lastly, the Episodic Buffer of multi-modal integration.

d) Episodic Buffer
A fourth component of working memory, episodic buffer, was proposed by Miller, (1956 cited in Baddeley, 2002, p. 8) as a “multi-modal, temporary store of limited capacity capable of integrating information from subsidiary systems with that of LTM. This process allows the advantage of prior knowledge to be chunked into STM ... enhancing storage and retrieval”. Baddeley surmises this is “unlikely to be reflected in a single anatomical location, but that frontal lobes would be crucially involved” (Baddeley, 2000, p. 420). Chunking is a skill that enables a student to hold enough information in STM for categorisation of detail and generalisations to occur, as for example, perceiving and reproducing spelling patterns.

3.4.2 Memory storage
Information is stored in a number of ways in the memory. Mandler et al., (1971) suggests it is stored in serial order, categorised into groups or relational imagery, like linking words to pictures, metaphors and other “belongingness” (Mandler & Anderson, 1971, cited in Travers, p. 185). Bower (1969) suggests material is seen in terms of similarities and familiarity, matched to existing traces, it is then stored and repetition strengthens them.

As noted in Section 3.2.3, if images do not match, or are perceived as different, it is stored as a new classification (Bower, 1969, cited in Travers, p. 273). These separate images can then be moulded perceptually into a multi-faceted representation of an object. In discrete symbolic data however, recoding as a separate item leaves scope for error, or ‘unlearning’ if an ongoing o-m dysfunction results in different traces for the same object. Furthermore, if it is being integrated as stimulation that “modifies and develops functional pathways based on intercellular recognition” within associative networks (Purves, 1994, p. 45), then this suggests, in the case of o-m dysfunction and variability of memory traces, this route must be less direct or efficient, thereby affecting the rate of learning compared with an individual with normal visual function.
It can be argued o-m function is an essential aspect of visual discrimination needed for initial encoding, firstly for clear and reliable symbolic memory and secondly, sufficiently clear vision for later recognition of incoming input. The crucial factor in memory seems to be the number of attributes, namely, characteristics of experience that are presented consistently to memory through the perceptual analysis process.

3.4.3 Identifying letters and words

Literacy involves identification of letters and words while matching and mapping them to their linguistic equivalent. In effect, processing a retinal image that resonates with an established memory trace and is recognised as familiar. The process of developing networks and laying down memory traces in response to educational stimuli is postulated by McClelland and Rumelhart (1981, cited in Palmer, 1999, p. 453) as being an “interactive activation” process. The perceptual process of letter detection is difficult to explain, and according to Palmer (1999) “one ‘fuzzy feature’ approach is where much current research on this problem stands” (p. 455).

Palmer’s analysis shows that visual perception is quite remarkable. Furthermore, quality of perception is highly reliant on clarity of retinal image and o-m co-ordination for both eyes to function as one organ. Categorization is a key cognitive skill in both auditory and visual system. It is central to discriminatory skill of comparing and contrasting, ‘same or different?’, on which visual perception and memory storage depends. It is also a crucial aspect of any educational therapy work, from earliest auditory discrimination between short vowels like ‘i’ and ‘e’; rhyming endings; discriminating between letters and sequences of letter strings; eventually higher order analysis such as identifying key statements in texts for note taking; and levels of reasoning when refining essay writing skills.

3.4.4 Working memory related to LD

The various stages of the memory system show the steps and skills required to have information finally established into the long-term memory, where information is relatively stable, within a limitless capacity, depending on constancy of usage. Experiential LTM is largely unaffected in individuals with LD. Auditory and visual short-term memory on the other hand, have a limited functional capacity and are vulnerable to disruption during processing, consequently these episodes are recognised as deficits in working memory span, which is a characteristic that discriminates between proficient students and those with LD.

O-m function and auditory concerns were included in a ‘dual route model’ followed by Talcott et al (2001b) where putative sub-types of reading disability differed in sensitivity to dynamic
visual and auditory stimuli. It was found that, 19% of subjects had phonological and spelling problems within the lowest tenth percentile for their age group, as well as in visual motion tasks. The poor spellers were all impaired in processing time as well as auditory tone discrimination which is considered important in the development of phonological skills (Tallcott, Stoodley & Stein, 1997).

Crike (2001) comments that “working memory assessments in school can identify at risk children who are failing to achieve expected levels of attainment”. He suggests that although digit span is a key to cognitive maturity “it does not define and control adaptive innate intelligence”. He believes “auditory input registers as conceptualisation, with understanding of abstract ideas, principles and values ... whereas visualisation develops with eyesight and is how we begin to perceive reality, and use it in an abstract way” (p. 1).

Poorly matched visual input may provide more opportunity to build errors into the ‘iconic memory system’ (Baddeley, 2002a, p. 5), given the complexity of the associative modalities inherent in the working memory. It might be conjectured from observing atypical ‘learning behaviours’ that an individual with LD may be seeing the same thing differently often enough to misjudge familiar words, or ‘forget’ what they know already. Invariably they have a diminished memory span so that word recognition depends on the overall gestalt of a word, as informed guessing. This strategy tends to preclude the student registering adequate detail of letters and their sequences to be recorded in LTM, consequently capacity to recall the details of a word for spelling does not develop naturally from reading exposure. Overall these children take longer to integrate data and need more repetition consequently their rate of progress is slower, compared with their intellectual peers (EGB).

3.4.5 Lateralisation of memory.

Tulving proposed a model (1994, in Poldrack, 1998) of “hemispheric encoding / retrieval asymmetry” as “lateralization of memory”, with verbal memory being related to the left and non-verbal, to the right prefrontal cortex. However, Poldrack (1998) suggests “the actual encoding of a memory, undoubtedly involves multiple cognitive processes, including assembling a representation of the stimulus, detecting that the stimulus is novel, relating the stimulus to existing knowledge and laying down a lasting memory trace, of the assembled representation” (Poldrack, et al., 1998, p. 1092). Memory may be likened to a hologram, reflecting the sum of experiences of whole brain function and as such, is the medium through which learning is acquired and expressed.
According to Fuster (2003), memory like other cognitive functions, is subject to a degree of hemispheric lateralization "where one cerebral hemisphere can acquire memories and motor skills independent of the other (Sperry, 1974, cited in Fuster, 2003, p. 125) ...with left hemisphere specialisation for language, ... the content and abilities being unequally represented in the two hemi-cortices (Rubens, 1977, cited in Fuster, p. 125) ... leading to the inference of left-sided specialisation for logical reasoning and calculation, whereas the right cortex would specialize in non-verbal ideation, as well as other functions of visual imagery and memory, postulated from neuro-imaging evidence" (Fuster, 2003, p. 125).

Studies of dichotic listening (with different inputs in each ear) show that below the age of three-years, the right-ear advantage is for phonetic discrimination and left ear for musical discrimination. Right hand preference is also apparent. Imaging and stimulation studies point to "wide and idiosyncratic distribution of language in operation", (Fuster, p. 187) "with greater contribution from the left hemisphere of basic language and implicit linguistic competence, as essential to grammar. Meta-linguistic knowledge is provided by the right hemisphere ...[with] explicit components of language largely acquired by learning and education" (Paradis, 1998, cited in Fuster, p. 189).

From lesion studies it has been established that parts of language are distributed in different areas, "verbs and action words represented in the frontal cortex, whereas nouns are in the posterior associative area" (Goodglass, 1966, cited in Fuster, p. 195), "extending into the sensory conversion area that has been associated with naming" (Geschwind, 1967, cited in Fuster, p. 195). According to Dehaene, in primates, form recognition is located in the left hemisphere, as this area has been adapted by education to become the word recognition area in humans (Dehaene, 2003, p. 32).

In general, memory can be regarded as bi-hemispheric processing through which learning occurs. Perception and memory span can determine how much is perceived and processed at any one time, how complete an image may be and how fast information can be integrated, allowing for speed of processing and 'pattern recognition'. Reading and writing are saturated with multi-modal 'data', so speed of processing and rate of learning is reflected in developmental maturity, not necessarily related to adaptability and problem solving as aspects of intelligence. The description of functional memory also demonstrates the adaptability of neural architecture. Conversely, it also shows how this neural plasticity might easily become mal-adaptive if there is intermittent o-m dysfunction due to weaker muscle tone on one side of the face. Adaptation is a normal process, but under abnormal situations may become mal-adaptive if it upsets bi-hemispheric integration and dominance pathways.

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The Developmental Model provides a framework to understand that alterations at the various neural 'junctions' may contribute towards differences between children. One child whose physical development and cognitive maturity simply evolves as it should and another child, matched in all other respects, except o-m dysfunction and developmental LD. In this respect, o-m dysfunction can not be considered as the 'cause' of LD, but from the direction of this literature review, it can certainly be considered as a primary contributing factor.

3.5 Cerebral laterality

3.5.1 Laterality refers to asymmetric cerebral organisation.

The left dominant hemisphere [in right handers] begins to play an essential role not only in the cerebral organisation of speech, but also in the cerebral organisation of all higher forms of cognitive activity connected with speech – perception organised into logical schemas, active verbal memory, logical thought... Absolute dominance of one (left) hemisphere is not... always found, and the law of lateralisation is only relative in character (Luria, 1973, p. 78).

Laterality is 'task specific', and "nearly all right-handers (96%) are left-hemispheric for language", (Milner, 1975) or 99% (Rossi & Rosadini, 1967, cited in Corballis, 1991, p. 193). Corballis (1991) found that with "a lack of consistent lateralisation there may be increased risk of LD ...such as developmental dyslexia and stuttering" (p. 195) ..."and also dyspraxia, a disorder of skilled, voluntary movements, as left hemisphere appears to also contain 'movement formulas' for organising actions as an aspect of sequencing (p. 196). Corballis speculates that the left language location... "has to do largely with praxis, because the organisation of purposeful, sequential actions, in which spatial [right hemispheric-specific awareness] constraints imposed by the environment are minimal,... favouring selection... of both manual and vocal praxis to be left-hemisphere" (p. 213).

Handedness and cerebral asymmetry for language may be genetically determined, predisposing the left hemisphere to play a dominant role, but in the absence of dominance being established, may leave the direction of both asymmetries open to random influences [italics added]. Apparently, handedness and language have enough in common to make it an advantage to have both represented in the same hemisphere, yet they are distinct enough for this not to be obligatory (Corballis, 1991, p. 195).

Walsh (2000) found that "the left hemisphere contains an 'interpreter' that ... is part of an ensemble of behaviour-centred capacities ... needed for selecting actions ... and to make sense of events in the world ... and can be considered as dictating the very narrative of our lives" (Walsh, 2000,p. 461). He found problem solving patterns showed the left hemisphere's choice was to make predictions based on "frequency-matched pattern", whereas the right hemisphere
mechanism’s approach was that of “maximising behaviour” (i.e. what has been successful in the past – author’s addition). In effect, the ‘interpreter’ selects whichever hemisphere’s strategy is superior in context of the nature of the task. Presumably, access to a balance of the two strategies within the brain’s resources, would offer optimal information processing and adaptive intelligence.

3.5.2. Hemispheric specialisation

Cognitive Sciences have established the nature of different specialisations of the two hemispheres (Springer and Deutsch, 1998). The right hemisphere has a visio-spatial orientation, which provides the gestalt for holistic, creative, divergent reasoning, looking for overall patterns and inductive thinking. The right hemisphere understands language but does not have the expressive mechanisms of the left hemisphere. Traditionally the left hemisphere is regarded as ‘dominant’ as it contains the primary speech and language areas and manual dexterity in right handedness. As well as verbal functions, it is involved in sequencing behaviour and detailed linear tasks, as in deductive logic. Presumably the left hemisphere also analyses the pieces that make up the whole, such as patching letters together to make words, and sentences from key words from the germ of an idea.

Within the language area is Broca’s area which is involved in expressive speech and “self-generated behaviours” (Shallice et al., 1989, cited by Walsh, 2000, p. 462). Walsh (1987) found that most, but not all, women generally have Broca’s area in both hemispheres as they can suffer a greater degree of brain damage before showing significant levels of speech problems. This finding may be of particular relevance when trying to understand why there is a 5:1 ratio of males to females affected by these LD. It has been observed by the therapist, that girls’ problems are generally of the ‘deep dyslexia’ variety (SalTran, 1980, cited in Coltheart, 1980, p. 5).

3.5.3 Dominance

Superiority of manual dexterity is considered to indicate a dominant hand, but can be partly attributed to experience, so that a ‘preferred’ hand is determined by superiority of function, and does not necessarily match the dominant arm. What Corballis (1991) termed ‘random influences’ may include constitutional problems like o-m dysfunction affecting eye-hand coordination, which in the case of weak binocularity, depends on which eye is the most proficient at synchronizing eye movement, to focus on hand movements. For example, it is assumed that a weak or drifting right eye may upset the natural dominance pattern, at an age when a child first shows laterality preference, when learning to feed with a spoon.
Latent dominance is considered to be indicated by Luria's folded arm test, where the dominant hand is uppermost (see Section 1.5 Definition of terms) from the Luria-Nebraska Neuropsychological Battery (1966) which was used prior to neuro-psychology having access to live brain imagery, with fMRI. A discrepancy between latent arm dominance and preferred writing hand is referred to as 'crossed' or 'not established' dominance, with o-m dysfunction a possible pre-determining factor.

Denckla (1979) found “nearly two-thirds of dyslexic children were right-handed, right footed, and left-eye dominant” when she was attempting to disprove Orton's assertion that mixed dominance is part of the pattern associated with developmental dyslexia. However, Orton had qualified this assertion with the proviso that “it may be only certain patterns of mixed lateralisation that gives rise to difficulties” (Denckla, 1970; Orton, 1937, cited in Corballis 1991, p. 200). In this study it was important to discover whether a 'compromised' right eye makes a difference to literacy skills. In this way, unreliable visual and auditory sensory input can be considered as 'environmental' factors that can cause a developmental deviation from genetically determined pathways.

Eye dominance can be considered as being at the perceptual end of a developmental continuum, whereas hand/arm is more central to development as it is established early in life. Carter (1998) reports “Handedness is well established at birth ... at 15 weeks a foetus shows a preference for sucking the right thumb” (Carter, 1998, p.78), so eye dominance develops later.

As Wiesel (1982) established, this is subject to environmental conditions. “Abnormalities in neural functioning ... [are influenced by abnormalities in — author's addition] not only the amount of incoming impulse activity, but also on inter-relationships between activity in the different afferents” (Wiesel & Hubel, 1965, cited in Bach-y-Rita, 1972, p. 51-52). It can be argued that if hand preference matches the already established pre-natal networks, particularly if this matches eye dominance, this would seem the most natural and efficient pathway, which if upset by ‘environmental’ factors may pre-dispose a child to LD.

3.5.4 Timing and hemispheric differences in auditory - visual networks

It has been well established that auditory and visual pathways are dominance-specific. This was expressed by Luria (1973) as “diminishing modality specificity and increasing functional lateralisation” (Luria, 1973, p. 79). Cornelissen (1999) observed that “behavioural and neuro-imaging data suggest a dissociation between left and right hemisphere processing of the global and local attributes of complex visual stimuli” so that during “early processing of letter-strings, the two hemispheres compute a combined identity space code in parallel”. The difference is
that the left hemisphere specialises in the "local attribute of letter identity", whilst the right hemisphere deals with the "global attribute of spatial position" (Comelissen, Salmelin, Tarkiainen, & Helenius, 1999 p. 482).

These results were replicated by Putter-Katz, et al., (2001) who used auditory event related potentials (AERPs) in auditory discrimination tasks of short vowels or syllables. These are more difficult to discriminate as it involves processing rapidly changing auditory cues. Their results showed significantly different brain processing patterns between competent readers and dyslexic children. The characteristic pattern of the latter group involved anterior frontal lobe processing, with slower reaction times and slower brain processing, as phonological demand is increased. The more frontal auditory processing was considered to be compatible with phonological impairment (Putter-Katz, Kishon-Rabin, Sachartov, Weiz & Pratt, 2001).

These findings are supported by Hari (2001) who found impaired processing of rapid sound sequences due to "sluggish" attention shifting ... and the dwell time for visual attention was 30% longer than normal-reading adults", with stimuli from the left visual hemi-field processed more slowly, which she interpreted as a sign of left sided "mini-neglect" (Abstract). Habib (2000) in his review of the neurological basis of developmental dyslexia summarises the general finding with his comment, "one attractive interpretation of available evidence points to dyslexia as a multi-system deficit possibly based on a fundamental incapacity of the brain in performing tasks requiring processing of brief stimuli in rapid temporal succession. The "temporal processing impairment" theory of dyslexia could also account for at least some of the perceptual, motor and cognitive symptoms very often associated with the learning disorder, a coincidence that has remained unexplained so far (p. 2373).

3.5.5 Neurological growth

At a most basic level, the neural structure is genetically endowed, but as the preceding review has made clear, development of the visual system and its complex connections depends on the quality of sensory stimulation, in a process of maturation. According to Shatz (1992) the initial states of axon outgrowth and pathway selection are thought to occur independently of activity but are genetically determined with a basic network in the embryo. Once the advancing tips of the axons arrive at the appropriate, predetermined 'address', choice of target location is influenced by nerve impulses originating within the brain genetically, or stimulated by events in the external world. Synapse formation during critical periods of development may depend on the axons that are activated appropriately (according to the genetic code) being favoured when establishing networks. Connections are formed as "axons are guided to their appropriate targets in the visual and other systems" (Shatz, 1992, p. 34). This pre-determined process can be said
to incorporate impulses from associative pathways into a synergy of auditory and visual signals to create a dyadic, two-sided item in phonemic memory.

Phonics are regarded as elemental foundations of literacy. This synergy of auditory and visual signals has cultural values of enabling spoken language to be converted into visual symbols of print that can be recorded and accessed by others, in other places, over time. The associative auditory and visual signals are synchronised to find their ‘appropriate targets’ which presupposes that the speed and accuracy of sensory input must be matched for the perceptual system to patch the connections together as phonics. Logically, the efficiency of the whole is determined by the weakest link.

We learn from experience how to gain control over our movements, and what sensations mean by matching these against memories already formed. Fischbach (1992) states that “physical and mental functions depend on the precision and overall stability of neural ‘wiring’ ... and a number of neurons must be activated before recognition occurs ... these electrical impulses (action potentials) not only encode information but alter the circuits over which they are transmitted ... although we lose thousands of neurons every day, the memories are not lost” (p. 30-31).

3.6 An Interpretive Summary from the Literature Review

As this Literature Review illustrates, there are different, but not necessarily contradictory theories between researchers about causal factors of LD, all of which might be subsumed under Luria’s Model of Neural Function. Functional brain tomography studies show anomalies in the brain of dyslexics that some researchers attribute to genetic factors owing to the apparent heritability of the problem, leading to a medical model of a pre-existing condition. However, a growing number of researchers are taking a more developmental approach of left hemisphere mini-neglect. Evidence of lateralisation and specialisation of tasks between the hemispheres raises the possibility of natural pathways disrupted by visual dysfunction as a pre-disposing factor in LD. As far as causality of LD is concerned, it can be argued that lack of hemispheric integration may be attributed to subtle imbalances and discontinuities of auditory and/or visual, and/or motor-sensory input during critical stages of development. It can be argued that intermittent otis media and/or visual dysfunction in early childhood, may not be considered significant later into school years, or even detectable in adulthood, but may in fact have left a
legacy, by preventing efficient pathways being laid down in the neural architecture, at a critical
stage of a child's development.

This review has been synthesised from the literature into a model that suggests integrity of
multi-sensory inputs as a pre-condition for developing 'an economy of neural resources' through
optimal growth and development of bi-hemispheric function. Not only in terms of left
hemisphere, language based skills, but also the right hemisphere which contributes creative
power to the brain (Luria & Simernitskaya, 1977; Lezak, 1995, cited in Fuster, 2003, p. 243),
and the "logical and linguistic capabilities of the left hemisphere have been shown to be
considerably assisted by the functional integrity of the right hemisphere" (Fuster, 2003, p. 243).
This growth is assumed to be pre-determined by genetic endowment and modified by
environmental influences, either positively or negatively, by the quality of vision and its
contribution to the memory system.
Overview of the three-part Research Plan

The proposed research is to be completed in three stages, following both quantitative and qualitative methodology. Part 1 is referred to as the School Survey and is an explorative, cross-sectional study of visual dysfunction, memory and literacy in a girls' school. Part 2 incorporated the training program and is referred to as the Intervention Study. This study will address questions arising from Part 1 by examining the effects of improved visual function on literacy results following an Educational Therapy intervention programme. Statistical analysis of data is from archived material in both Part 1 and 2 studies. Part 3 consists of two current, on-going case studies that highlight integrative therapy processes and developmental outcomes. Details specific to each study are addressed in Chapter 5, 7 and 8 respectively.

4.1 Reasons for setting up the Studies

4.1.1 School Survey

In the author's Educational Therapy practice LD usually co-occur with o-m dysfunction and outcomes of a word skills programme are greatly improved if eye muscle problems of balance and co-ordination are corrected with vision training. Current optometric tests generally identify and provide prescription lenses to correct acuity problems but not o-m dysfunction. Public Health nurses test for acuity when conducting school vision screening and report "anything suspicious" [nurse's comment] to the ophthalmologist in charge for any medical intervention that might be needed. It has become increasingly apparent over the years that these assessments are insufficient to address issues of subtle and often intermittent eye muscle imbalance or fatigue that might be developmentally associated with LD. Behavioural Optometry, however, achieves positive results with vision therapy, and this has become an important aspect of Educational Therapy practice under these specialists' guidance. The author had been working earlier with a group of twelve pupils from Years 8 to 12 that the School Counsellor had selected for the Educational Therapy programme because they were seriously disadvantaged in their schooling. These girls were possibly suffering from the same pattern of visual dysfunction seen in the Educational Therapy practice, so visual assessment was requested.
A 'Vision Awareness Week' provided free vision screening by optometrists. The idea was adopted and extended by the School Counsellor with the Principal's support, resulting in a quarter of the school being screened by a team of five co-operating optometrists. Their assessment protocol was expanded to include o-m tests not usually part of standard paediatric optometry assessment, but which none-the-less may impact negatively on visual function. The intention was to investigate the incidence of visual dysfunction in a school population, to determine whether these visual problems are more common in students with LD.

4.1.2 Reasons for the Intervention study
The reason for the intervention study was to determine whether LD diminished when visual dysfunction is corrected. The study involved eye exercises to correct o-m dysfunction, followed by a short word skills programme. Before and after tests were compared to measure relative changes in each student's literacy skills and memory. Two case studies are included in the Intervention Study to provide more detail regarding the impact of visual dysfunction on two 16 year old males.

4.1.3 Current on-going case studies
Assessment and case notes of two current students have been expanded and added as on-going case studies. These exemplified physical difficulties experienced by students, as expressed in the Developmental Model of LD. They also highlight the assessment and treatment of physical anomalies and the impact of this integrative therapy on improved outcomes in current practice.

4.2 Methodology
4.2.1 Data
a) Quantitative data
Data collection and findings were based on numeric, quantitative methodology (Babbie 2001, p. 36). In the School Survey, observations and explanatory concepts were tested in subsequent statistical analysis, in an ongoing exploration of how visual dysfunction may impact on learning. In the Intervention Study, outcomes are reported in two stages, firstly with outcomes for the whole group reported as simple comparison between pre- and post-tests, and secondly the same data were analysed according to two groups, based on whether stable eye dominance had been established or not following vision training. This was used to determine whether there was a difference in literacy and memory outcomes between the two groups which could be related to eye dominance.
b) Qualitative style and descriptions
The broad, therapeutic / educational nature of the topic requires a more detailed qualitative
description of the therapeutic background in the interpretation of findings. The Educational
Therapy practice, on which both studies are based, can be described as having an inductive
logical perspective, similar to that of a Grounded Theory conceptual framework (Babbie, 2001,
p. 284), in practice, principles and purpose. That is, it is a rigorous inductive approach that
builds theory from the data, rather than the other way around. Although the inductive nature of
Educational Therapy has parallels with Grounded Theory, the research methodology was not
framed as such, and so for the purposes of this thesis, Grounded Theory is used as a metaphor

4.2.2 Working theory and therapeutic logic
As explained in Section 2.2.2, assumptions on which this therapeutic working model is based
are not implicit in current scientific theory of LD, but these do represent part of the thinking
process leading to the key factors being addressed in this study. These notions include possible
casual assumptions and treatment options which are only provisional and open to change until
tested. Palmer (2002) states that this “usually valid... rule-of-thumb” heuristic process
involves “uncertain probabilistic inferences in which many different pieces of evidence can be
integrated into a conceptual framework” (Palmer 2002, p. 83). This approach can justify using
results of previous successful intervention practices as a starting point from which to construct
a causal theory of LD. These LD can be of any kind that co-exists with o-m dysfunction, and in
the absence of pre-existing morphology, that can diminish learning performance (Fletcher, et
al., 2002, p. 64).

a) The Author's background – 'know thyself'
A therapist's personal profile becomes part of the therapeutic working model, particularly when
involved as a 'participant researcher'. Therapy, by its nature, is subjective in that it depends on
the therapist's personal awareness, professional experience and observational integrity of
maintaining openness to avoid pre-conceptions. In the author's case there is a degree of
empathetic awareness owing to her own history of early reading difficulties, as school reports
show her to be a disorganised and distractible child. While studying at university she was
aware of short term memory limitations, specifically of note taking in lectures and difficulty
handling a lot of data in order to synthesis math concepts, as well as her ability to analyse and
follow complex instructions, even though her general grasp of principles and understanding of
implications was fine. She had difficulty building and maintaining a technical word vocabulary
and her recall was slow or unreliable, as memory files for nouns in particular seemed 'hard to
access' when expressing generative ideas. She has a divergent thinking style so bi-hemispheric
processing of sequential data within a convergent logical structure requires extra concentration and discipline.

Her awareness acts as a ‘working model’ when supporting a student who is acquiring new skills, where the focus is not on the expected outcomes but on the cognitive processes, in order to track where within that process the student is currently engaged, or blocked. An awareness of ‘what is possible’ allows the therapist to ‘hold the space’ while the student’s brain is gathering its resources to make connections. This awareness communicates to the student as trust that they will be able to manage the task, so their ‘locus of attention and control’ is internalised and better able to focus on problem solving. In this carefully controlled environment, the only external influence is occasional verbal prompts from the therapist as supportive feedback encouraging the student’s perceptual processes. Eye exercises are an example of this process.

b) The review of therapy practice as a form of ‘field research’

Educational Therapy practice can be conceptualised as a form of ‘field research’, such as in Grounded Theory which is employed here as a working metaphor. The parallel between this methodology and therapy is discussed as a means of providing background to the therapist’s thought processes and probabilistic reasoning. Grounded Theory is defined as “a naturalist approach to deriving theories from an analysis of patterns, themes and common categories discovered in observational data” ... “which is periodically reviewed” (Babbie 2001 p. 284). Grounded Theory terminology can be adapted to describe the therapeutic practice of record keeping used in the Intervention study (Glaser & Strauss 1967, p. 105-113). For example, an “audit trail” records responses from each of the visual and auditory exercises that are used to track progress and constitute the data set. “Bracketing” of perceived deficits in visual function, memory and literacy is used as a guide to therapy activities by building a notional model of how visual dysfunction or auditory processing problems may impact on concentration and memory access. “Constant comparative analysis” is an ongoing informal assessment as part of the therapeutic process. Comparisons are made between the students with LD and students of similar age and ability in a normal school, observed during the therapist’s teacher training. This sets a benchmark as a guide from which to set realistic goals, since it takes into account the amount of time and activities needed for each individual to overcome particular learning blocks.

In this way, Educational Therapy can be seen as a form of field research, in observing the evolving pattern of students’ learning behaviour and adaptability, with the therapist ‘teasing out’ possible connections and explanations to direct remedial action. Substantiation can be
assumed if the therapeutic activity achieves the desired outcomes, that is by diminishing the
degree of deficit being addressed. In other words, education therapy attempts to replicate
success, guided by a synthesis of careful observation, therapeutic experimentation and
examination of outcomes, with theorising as an interpretive act. As such it can be considered as
an inductive process as background to empirical analysis that may contribute to the ongoing
developmental theory.

c) Therapy processes and Research Studies parallel Grounded Theory

**PART 1. School Survey as an empirical study**

The School cross-sectional study had a naturalistic approach, in the sense that it was an
empirical method of study by which the researcher introduces no outside stimulus, instead
witnesses behaviour as it naturally occurs in the environment. The study involves assessing a
representative group of students (25% of the school) under normal school conditions in order to
derive explanatory insights about visual dysfunction and LD from common patterns discovered
in the data (Babbie 2001, p. 284). As in Grounded Theory, data collection and analytical
procedures must be rigorous to avoid biased assumptions in the encoding or reading of the data
(Babbie 2001 p. 284). In both the Survey and Intervention the data was quantitative. Tests were
generally standardised instruments with numeric data and statistical analysis that objectively
indicated the probability of differences or associations between groups being significantly
different (not due to sampling error owing to particular characteristics of the group).

**PART 2. Intervention study as a quasi-experimental method**

Following Babbie’s description of qualitative style criteria (Babbie 2001, p. 209), the following
points apply in the Intervention study. Firstly, sampling was simply a ‘convenience selection’
of subjects attending the practice over an eighteen month period for whom a full data set was
available; secondly, collection of data was part of treatment over a normal period of time;
thirdly, treatment was conducted in a normal educational therapy setting where there was no
researcher-controlled environment or teaching conditions; and lastly, assignment into two
groups was not determined by the researcher, but rather on the outcome of the participant’s eye
exercises and the effect of these on eye dominance status. The description of assessment
procedures and interpretation of outcomes likewise follows the qualitative style to provide the
reader with a sense of what visual dysfunction feels like, and its effect on a student’s school
performance.

Briefly, Educational Therapy is an integrative programme to develop the basic abilities required
for school readiness. The programme is eclectic, with some existing programmes modified and
original exercises devised by the therapist and added in response to specific LD as they manifest during treatment. It consists of initial vision training followed by a week-long word-skills programme once optimum progress from eye exercises is achieved. (This programme is detailed in Section 2.2, ‘Matching educational therapy to students’ specific needs). The data, from eye exercises and pre- and post tests of literacy, are analysed to determine if there is a difference in literacy tests between those participants who achieved normal visual function and stable eye dominance, and those whose eye dominance remained unchanged, with either mixed or unstable dominance in spite of eye exercises.

PART 3. Current Case Studies as ‘Extended case method’ for ongoing research

The ‘Extended Case’ Method of Burawoy (1991) is presented as a means of discovering flaws in, and modification of, existing theories (Burawoy cited in Babbie 2001, p. 285). In effect the outcomes of these two case studies are extended into therapeutic practice if visual dysfunction, due to eye muscle imbalance, is found to adversely affect binocularity and the acquisition of literacy. This would be evidenced by the individual’s improved methods of addressing problems, thereby contributing to current theories included in the Literature Review.

4.3 Method - Research design

4.3.1 Outline of School Survey

In brief, the School Survey consisting of a team of five optometrists, provided a 7 to 10 minute screening to assess visual function specifically for acuity, o-m function, and eye/hand dominance (see Table 1 for tests used). The sample consisted of 272 pupils from Grade 1 to Year 12 at a private girl’s school from whom parental consent forms had been received. Spelling, reading comprehension, and reasoning skills tests were undertaken to establish academic standards. In addition some criteria-referenced, class-based exercises to assess maturity of visual perception were used. A further sub-group of 144 participants in this sample were randomly selected by the School Counsellor, who was administering the study, for assessment by the researcher of memory and phonological skills and latent arm / hand dominance.

Visual data were evaluated clinically by the Optometrists, into three levels (normal, borderline, or anomalies) and encoded as a dichotomous scale (namely, ‘normal on all tests’, or ‘any visual dysfunction). Visual perception and dominance test results were also dichotomous. Raw scores for reading comprehension, spelling, and three memory tests were used as interval scales, as well as dichotomous values (above or below average) for use in different analysis tests. A
fourth memory scale had a four point interval scale indicating degree of memory deficit, and
was ordinal in value, as ‘triple deficit’ (i.e. auditory, visual, and phonemic memory); double
deficit (two memory modes): single deficit; or normal memory span. In all three modes,
dichotomous values and interval scales were used in t-Tests and gamma coefficients of
association.

These data were evaluated for evidence of an association between visual dysfunction, and
deficits in visual perception, memory, spelling, reading, and reasoning skills. In effect the
purpose was to examine the contrast in performance profiles between competent students and
those with LD in order to determine if these differences were associated with poor acuity or o-m
dysfunction. Any association found between visual dysfunction and LD was tested by
removing o-m dysfunction as a variable in the follow-up Intervention Study. The intent here is
to evaluate what improvements might be made in learning rates and standards of literacy once
visual risk factors had been eliminated with vision training and the establishment of stable eye
dominance.

4.3.2 Outline of Intervention study
In brief, this study investigated how weak binocularity and unstable dominance might affect
learning skills, specifically spelling and reading. It also sought supporting evidence to validate
the School Survey that might allow predictions to be made relating to the effect of o-m
dysfunction on learning. In general terms, the purpose of the Intervention Study was to
determine how much importance might be placed on the professional observation that visual
dysfunction co-occurs with LD, and to review the nature of the practice in the light of these
findings. The Intervention Study was integrated into normal Educational Therapy practice. A
detailed description of the research design and method is presented in Chapter 6.

4.3.3 Assessment principles for both studies
The assessment strategy was designed to gauge the types and incidence of visual dysfunction,
to identify ‘at risk’ students whatever their level of academic performance. For example, some
students may need further assessment in order to identify special needs. This could include
students who may have a high reading comprehension score, and yet have low levels in
spelling. Areas of weakness associated with o-m dysfunction or memory problems would
provide justification for further investigation. In the case of a “good all-rounder”, he /she
would not be expected to have any weakness of visual function (except perhaps myopia – short-
sightedness), or memory span. Stress levels were not investigated in this study. However, it is
reasonable to assume that an intelligent, under-achieving student with visual dysfunction may be under unnecessary stress.

Rationale for assessment criteria
A therapist's concern regarding assessment criteria is that averages in standardised tests may mask subtle indicators of problems, and may also under-estimate what can be expected in students with no neuro-psychological problems. In this thesis, the interpretation of 'natural' is: what is possible when 'visual function is optimal' including normal acuity, full range of binocularity in accommodation, and vergence control. Such optimal function would enable students to complete close work for the long periods required in school. This is in contrast to 'normal parameters' that are based on a normal distribution in the population, from worst to best. One difficulty in interpreting individual responses from norms obtained from massed data is that when used to evaluate individual performance, 'average' may be understood to mean 'no problems' when in fact an individual with a degree of functional disadvantage might be performing below his/her potential. Another individual may be performing above average through high intelligence, diligence, and perseverance, but stress may undermine energy and health with long term consequences.

Basis of judgement of 'normal' in dichotomous codes in the data set
From this therapeutic perspective, a standard of excellence becomes 'natural' when the o-m system is working properly and where integrated auditory / visual and bi-hemispheric processing becomes possible. In this way, 'natural' exists in a realm of possibilities rather than reflecting a 'normal' statistical incidence within a given population range. Behind the principle of remediation is the observation that vision training can improve sensory sufficiency and more efficient processing for new skills. It may also provide the individual with better access to a wider range of cognitive resources. This would enable him/her to use what is 'known' already, but hitherto has had difficulty manifesting in schoolwork. Only those subjects in this study with 'normal' rating on all visual variables were rated as normal, and the remainder rated as below standard.

4.4 Target Population
The target population was approximately one thousand pupils from Years 1 to 12 at a private girl's school. In terms of gender, it is considered that results from these girls may be generalised to a mixed school population because according to Shaywitz (1990) the percentage of actual reading difficulties between the genders is about equal. However, boys are more often
identified with specific LD, with a ratio generally quoted as 5:1 of boys to girls respectively (Shaywitz, 1990, p. 999).

4.4.1 Sample group: a) School Survey
The School Counsellor arranged a controlled sample group of 272 pupils, all of whom had parental consent to participate in the study. Names were selected from every fourth available student, on the alphabetically ordered school register. The sample group comprised approximately 25% of each school year, with junior school numbers being 27% of the total sample.

All participants undertook optometric screening, 207 of those completed reading, spelling, as well as analytical reasoning tests and a deductive reasoning exercise (see Section 4.5.1 for more details). Approximately every second pupil from the sample group was further assigned by the Counsellor into a group of 144 participants for assessment of memory, phonological skills, and latent arm/hand dominance. This assessment was conducted by the researcher. Visual perception exercises were also incorporated in art class exercises.

Sample group: b) Intervention Study
Sample selection – three elements
Potentially all the students who completed the Educational Therapy programme over an eighteen month period were part of a ‘convenience’ sample, but when compiling the spreadsheet, missing data reduced the number to 31 subjects aged 6 to 21. When it was decided to divide the sample into two groups for Phase 2 statistical analysis, three of the oldest students were eliminated in order to create a roughly equivalent mean age for the two dominance groups. This sub-group (LD) was from a wide range of schools, referred by parents of past students. Two groups were formed by natural selection according to whether stable eye dominance was established as a result of eye exercises. Although 24 students is a relatively small sample, collectively they provided an in-depth exploration of the link between visual dysfunction and LD and the gains achieved through therapy.

4.5 School Survey
The School Survey was carried out over a contiguous period of ten days. It was designed to explore any associations between visual dysfunction and LD in an empirical, explorative survey. The survey provided a ‘snap-shot-view’ of a cross-section of skills required of students in a general day’s schooling. Data collection, analysis, and reporting of results followed a
quantitative methodology (see Section 4.2.1), and qualitative observations are provided to describe the impact of o-m dysfunction on learning. It should also be noted that although the premises underpinning these studies have been developed from therapeutic practice, the research in this area is still at an early stage.

4.5.1 Assessment categories
This cross-sectional study incorporated five categories of assessment, namely visual, academic, memory, visual perception, and dominance. This protocol was designed to provide a 'proficiency profile' to determine: a) which subjects would benefit from vision training; b) how many subjects had visual dysfunction; and c) if there was an association between this and LD.

Summary of Tests and Measures – School survey
Table 1

a) Vision and oculo-motor screening by five optometrists (approx. 10 minutes)

<table>
<thead>
<tr>
<th>Optometric tests School Survey</th>
<th>(see APPENDIX AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Acuity - objective assessment - Retinoscopy</td>
<td></td>
</tr>
<tr>
<td>2. Muscle balance - Maddox ring</td>
<td></td>
</tr>
<tr>
<td>3. Strabismus - binocular fusion - Random dot test</td>
<td></td>
</tr>
<tr>
<td>4. Near point convergence - Brock string and bead measured as nearest point double vision occurs</td>
<td></td>
</tr>
<tr>
<td>5. Pursuits &amp; saccades - professional judgement</td>
<td></td>
</tr>
<tr>
<td>6. dominance, eye-hand – near distance aiming test professional judgement</td>
<td></td>
</tr>
<tr>
<td>7. amplitude of accommodation nearest point at which clear vision can be maintained.</td>
<td></td>
</tr>
<tr>
<td>8. Far / near convergence / accommodation cycles - focus changing at fixed points with lens flipper</td>
<td></td>
</tr>
</tbody>
</table>

b) Academic psycho-metric Tests, supervised by the School Counsellor

<table>
<thead>
<tr>
<th>Literacy and reasoning</th>
<th>Standardised tests</th>
<th>Statistical Value 272</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spelling (Schonell, 1952)</td>
<td>Age norms minus chronological age</td>
<td>Interval scale</td>
</tr>
<tr>
<td>GAP Reading Comprehension (McKirdy, 1976)</td>
<td>Chronological age</td>
<td>Interval scale</td>
</tr>
<tr>
<td>Abstract Reasoning test (Tobin, 1983)</td>
<td>Ranked 1 – 4 in each school years (≤ Yr 6)</td>
<td>Ordinal scale</td>
</tr>
<tr>
<td>Deductive reasoning exercises (Harnadek, 1977)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

c) Phonological and Memory skills, conducted by the therapist / researcher,

<table>
<thead>
<tr>
<th>Memory span</th>
<th>Standardised tests</th>
<th>Statistical Value 144</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory memory digit span (WISC-R, 1974)</td>
<td>Age norms - 7 digits</td>
<td>Interval scale</td>
</tr>
<tr>
<td>Test of Auditory Analysis (Rosner, 1979)</td>
<td>Age norms</td>
<td>Ordinal scale</td>
</tr>
<tr>
<td>Phonemic memory exercises (Taylor &amp; Bender, 1972)</td>
<td>Year level</td>
<td>Ordinal scale</td>
</tr>
<tr>
<td>Visual memory span</td>
<td>Age norms - 5 items</td>
<td>Interval scale</td>
</tr>
<tr>
<td>Arm / hand dominance (Luria-Nebraska test)</td>
<td>Crossed arm test</td>
<td>Nominal scale</td>
</tr>
</tbody>
</table>

d) Visual perception (depth of field), exercises in Art Classes, Years 1 - 10

<table>
<thead>
<tr>
<th>Chain link still life – depth of field exercise</th>
<th>Ranked 1 – 4</th>
<th>Ordinal scale 130</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Optometrist's rating</th>
<th>Statistical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. severe</td>
<td>Dichotomous scale</td>
</tr>
<tr>
<td>2. borderline</td>
<td>1. any anomalies</td>
</tr>
<tr>
<td>3. normal</td>
<td>2. all tests normal</td>
</tr>
</tbody>
</table>
I. Visual terminology (see Description of terms, Appendix A).

The screening protocol for this study was expanded beyond standard acuity tests (where head, eyes, and target are stationary), to include eye muscle movement and co-ordination.

O-m dysfunction can also comprise clarity of vision and theoretically may adversely affect multi-modal sensory integration and neural development. The term acuity refers specifically to clarity of vision through lens shape, o-m function is muscle strength, balance, and teamed, integrated movement of both eyes, while visual dysfunction refers generally to any 'visual risk'. The 7-10 minute Optometrists' vision screening involved tests of acuity, fusion (stereopsis), vergence control, near point convergence, accommodation, phoria, pursuits, saccades, and motor eye dominance. The latter was an eye/hand monocular sighting test of 'preferred' eye, which does not indicate the 'leading' eye in terms of acuity or direction. It is for this reason the tranaglyph was used in the Intervention study, as it served both as a therapy and as testing equipment with records used as data. Other dominance tests employed complex equipment that was found by the optometrist colleague to be no more reliable than the tranaglyph used in the Intervention study (see Section 6.5.1).

Professional screening was conducted by five optometrists, who classified their clinical findings into three levels: 'normal', borderline, or anomaly (requiring further assessment and possible treatment). For the purposes of this study these levels were encoded as dichotomous values by collapsing the borderline and anomaly levels into one visual dysfunction value, as a clinical 'visual risk' group. This grouping was considered necessary because there were relatively few anomalies, but more importantly, the functional variability of the borderline category can be most problematic for learning. The category 'borderline', for which there is no clinical baseline or evidence of clinical significance, was rated as 'dysfunction' on the advice of the consultant Behavioural Optometrist. He considered that balanced binocularity is of prime importance "as it expresses the integrity of the whole visual system, in that any o-m dysfunction can be symptomatic of a more serious underlying anomaly, as well as reflecting cumulative effects of minor o-m dysfunction", (Palassis 2004, personal communication). The risk is that seemingly different visual difficulties generally have a common underlying cause, and can become "embedded" (Howell 1990, p.12-19).

From the above perspectives, there are two aspects of vision. One is general, "How clearly can I see?" and is addressed with acuity tests. The other is developmental, which examines "How reliably does visual input contribute to multi-modal integration and neural development?". Consequently, the consultant Behavioural Optometrist considered this 'borderline' group needed careful investigation as having possible associations with LD. Conceptually, such
findings could support the impact of unreliable visual input on the development of neural networks, associative sensory connections, and lateralisation of pathways (Luria’s model of brain function, Section 2.1).

Visual test levels
For statistical purposes, tests were rated as factors independent of each other, although functionally the visual system operates as an integrated whole. Visual factors do not have quantifiable relationships and so cannot be assigned an ordinal value. Consequently the eight optometric tests have been encoded as dichotomous values.

2. Selection criteria of standardised tests of literacy
The GAP/Gapado Reading Comprehension test was chosen because, as a 'cloze' technique (finding appropriate words to fit words deleted from the text), it reflects intelligence as a measure of language and grammar development, and social/cultural comprehension, as well as a test of word recognition. The GAP Reading Age standardised scores are norm referenced, with reading ages in three sections, the middle 80% rated as within 'normal' range, while the lower and upper 10% tails of the sample parameters represent 'retarded' / 'superior' readers respectively. Reliability has been reported by MacLeod (1976) and validity comes from widespread use in schools.

The McLeod criterion was found to be too severe for statistical analysis in this study owing to small numbers in cells of interest. When trialled, the range and variety of difficulties observed in practice were not fully represented. As a consequence, a more individualised encoding system was used with reading and spelling age scores. The Schonell Spelling test (Schonell and Schonell, 1952) commonly employed in schools was used in this study to maintain continuity with results from the Educational Therapy practice. The Tobin Test of Abstract (mathematical) Reasoning provided a measure of academic competence other than literacy (Tobin 1983); and Deductive reasoning was simply a range of reasoning puzzles from a series of Basic Thinking Skills exercises (Hamadek, 1977) as a fourth measure of intellectual competence.

3. Academic Rating – age linked rating for reading and spelling
Age was taken into account when rating reading comprehension and spelling, as there may be twelve months or more difference between the youngest and oldest student in a class. Standardised scores were individualised by computing the difference between reading/spelling ages and chronological age. In this way, a score of zero that indicates reading age is the same as
chronological age (RA = CA = 0) with negative and positive numbers indicating the reading age in years/months is decimalised, below or above chronological age. These scores were used as an interval scale for t-Tests. A dichotomous scale was extrapolated from this as positive and negative values represented above and below average respectively for gamma coefficients of association analysis. In the dichotomous scale, an individual score of 0 is normal so has a rating of 1. The cut-off point for reading is 17 years so this did not create the same ceiling effect as the age limit of the Schonell Spelling test which is 15 years. In order to avoid negative values for students older than 15 years of age, this was used as a cut-off level for ages as well.

4. Maturity-based memory span
Maturity-based auditory, visual and phonemic memory span were included to provide perspective on the relative strengths and weaknesses of each student's memory system.

Auditory digit span
The auditory digit test of WISC-R Wechsler (1974) consists of repeating a sequence of numbers. Cripe (2001) states that a sequence of 5 numbers is normal as long as right / left dominance is in place (Cripe, 2001, p. 2). However, some girls of 6 years managed 7/7, so this was used as the upper benchmark, with an ordinal rating scale 4 (top level) being a span 6 or 7/7; level 3 was 5/7; level 2 was 4/7; and the lowest level 1 was ≤ 3/7, for Year 3-5. From Year 6 upwards the dichotomous scale was 6 or 7/7 ‘normal’ and < 5 was rated ‘below standard’. The same criteria were used for Phonemic Memory.

Visual memory span
Taylor and Bender (1952) found a score of 5 out of 5 (reproducing a sequence of geometric shapes) to be the norm at 6½ years. So the visual memory ordinal rating scale 4 (top level) was a span 5/5; level 3 was 4/5; level 2 was 3/5; and lowest level 1 was 2/5. The seemingly severe rating scale was adopted because a drop from 5 to 4 or worse still, to 3/5, makes a considerable difference to the student's processing efficiency if they are unable to handle more than three visual features at a time. It necessitates chunking a smaller amount of detail, then putting that on 'hold' to return to gather up the rest of the information, which leaves them vulnerable to losing their place and information from the Sensory Information Store (SIS). This loss is apparent in an inability to discriminate between words with a similar appearance and length; or working with one letter at a time when copying words; or integrating enough features of a picture from one glance to make sense of it. Insufficient memory span means individuals do not have sufficient capacity to 'upgrade' to the more efficient strategy of chunking.
Phonemic memory span

This consists of the Test of Auditory Analysis (Rosner TAAS, 1979) and a number of phonemic exercises which involve recognising given sounds in a word, starting with two phoneme words and removing, exchanging or adding a given sound to make a new word. In effect, phonemic integration exercises involve several levels. In the first part students were required to 'say the sounds' (not name) of letters indicated on the Fidel phonics chart (Gategno, 1962) representing all the different spelling options for each sound. The student then 'sounded out' a sequence of letters pointed to on the phonics chart, starting from two and up to seven phonemes in simple but uncommon words, and multi-syllables in the upper grades. The student needs to hold the sequence of sounds in the working memory until it is blended and the student says the given word and spells it back to the examiner. This simple exercise clearly identifies areas of weakness in the transformation process from visual to auditory, sequencing, memory and attention span components, with sound-blending as part of phonological awareness.

Records were kept of each response and phonemic memory span was judged by the number of phonemes that could be managed without loss or error, together with speed and ease of processing. Age norms in terms of how many simple phonemes can be processed in each word were provided by equivalent words on the Schonell spelling test and auditory digit span test (Wechsler). Coded values were based on an interval scale of 7 phonemes said correctly and without hesitation, with an allowance made for age; "deficiency" was rated in Years 1-3 as being ≤ 3 phonemes; in Years 5-7, ≤ 4 phonemes; and Year 8 - 12, ≤ 5 phonemes.

5. Visual perception - performance based assessment

Performance measures of perceptual skills were based on a number of visual perception 'puzzle-solving' pencil and paper exercises, which were completed in art lessons. The reasons were firstly, to provide some pre-test familiarisation in drawing specific perceptual features to eliminate the effects of lack of experience, and secondly to extract examples for evaluation of depth perception representation, which is directly related to binocularity. Binocular retinal images are a pre-requisite for perceiving depth in three dimensional features of a scene. In near vision, defined as the space between the eyes and fingertips of the outstretched hand, three-dimensional-vision is constructed by the perceptual system from information about angled lines for which binocular vision is necessary. It allows angled lines in two dimensional pictures, images or diagrams to be interpreted as three dimensional. It also provides the ability to draw angled lines of perspective accurately as in perceptual exercises, and to read and write angled script, instead of verticals and circles of printing. In global vision, beyond the finger tips, perceptual cues of size, overlapping edges, and tonal gradients contribute to depth of field, perceptual experience and interpretation.
Preliminary exercises in visual perception included reversals - drawing another face, looking in the opposite direction, and spatial shape awareness - geometric designs, drawing in pieces to fit (Thurstone, 1946); Right / left direction discrimination - mentally dividing a geometric pattern into four and colouring the four matching shapes in each quadrant (Silvy & Pasternack, 1977); Graded tones, shading a continuum of a row of 7 boxes from black, through grey to white; depth of field exercises, completing a design of lampposts and chimneys (Freeman, 1983); overlapping edges of a family of four figures, by outlining each figure in a different colour, with the smallest figure in front (Frostig, 1954); and a still life 'chain links' exercise, with graded examples shown in Figure 2. The chain links exercise was of key interest as it directly related to reliability of binocular vision and depth of field perception. It was employed in statistical analysis as it involves two-dimensional drawing from a three dimensional shape. These exercises were sorted into four levels for each school year group (see Chain link exercise Figure 3).

6. Dominance

Latent dominance - mixed arm and hand preference

Mixed arm / hand dominance is a discrepancy between latent dominance whereby the dominant hand is that which is uppermost when the arms are folded, compared with the preferred writing hand. Latent dominance may be determined by using Luria's 'crossed arm test'. The term 'crossed' was used if laterality preference differed, or the term 'not established' was used if the individual had difficulty deciding on preference, or dominance was changeable (Section 1.5, Terminology).

Eye dominance

Eye dominance is traditionally a motor test to indicate the preferred eye in monocular tasks. For example, tasks include aiming along a pointed finger at a distant target, or looking through a small hole for near viewing. (see Section 4.5.1(i)). Such motor dominance does not necessarily indicate the neurologically dominant eye, as a weaker latently dominant eye may cause the naturally recessive eye to become advantaged, that is, 'perceptually privileged', and therefore 'dominant by default' (detailed in Section 4.5.1).

Eye / hand dominance

Eye/hand dominance is the preferred eye matched to the writing hand.
4.5.2 Collection of data and grading procedures

The School Psychologist administered the psychometric tests and Art teachers incorporated perceptual exercises into their normal lessons. Standardised Literacy tests; assessment of memory function; and visual perception exercises were evaluated by the researcher who is professionally qualified as an occupational therapist and art teacher.

Assessment of visual perception was ranked in four levels of maturity in each school year, scored 1 - 4 from lowest to top maturity. Having one examiner was a simple way to control for variation in the evaluation of work and the subjective aspects of memory tests, namely reaction times, and ease of response. Therefore, consistency was maintained with no need to calibrate results. Examiner bias was controlled because details of subjects were not known to the rater. The aim of this survey was to provide insights into aspects of visual dysfunction that may be adversely impacting on a subject's schoolwork. Hence, the testing instruments and method of evaluation, although based in part on subjective professional judgment, provided an 'every-day' criterion-referenced approach to evaluation of performance, as an appropriate way of estimating the reality of each student's situation.

Encoding visual data

The eight optometric tests were rated as independent variables and encoded as dichotomous values, with 'borderline' and 'anomalies' encoded as 'visual dysfunction'. In this way, the rating of dichotomous values was rigorous in that a 'normal' rating is used only for those subjects for whom every test is 'normal', whereas subjects with any o-m dysfunction whatsoever are rated 'dysfunctional'.

4.5.3 Summary of Statistical analysis

One purpose of the School Survey was to establish the incidence of visual dysfunction within the school and to identify individuals in need of further o-m assessment. The research question asked if there was a link between visual dysfunction and LD, so variance between 'above' and 'below' average reading and spelling groups was checked against each of the visual variables. Three types of statistical analysis were employed:

(i) Frequency statistics – these provided the distribution of key variables within the school; namely which problems were the most common, and to determine the age distribution of visual dysfunction, reading and spelling competence at each year level.

(ii) T-Tests were used to determine differences between the above and below average groups in reading comprehension and spelling, visual function, perception, and memory.
(iii) Gamma coefficients of association were used to determine whether there was lineal progression and direction between groups, as representing a consistency of profile between the variables associated with memory.

The total sample size was large enough to provide a robust p rating. Significance levels were set at .05 or less probability. As eye tests were only a 7 to 15 minute screening, and not a full assessment, values of gamma above 0.3 were accepted as significant except where the probability of association exceeded .05. A full description of statistical analyses is provided within each section of the Results chapter, and is supported by an explanation and interpretation of findings.

4.6 The Intervention Programme

4.6.1 Rationale of the Intervention study

This was an explorative study, with 24 participants attending the Educational Therapy practice, set up firstly to establish efficacy of the vision training and word skills Intervention programme. The second purpose was to answer the question arising from the School Survey, namely to evaluate the impact of newly established right eye dominance on literacy, as a second stage of statistical analysis.

4.6.2 Research Design

Each participant completed vision training prior to commencing the week-long word-skills bridging workshop. Records were archived until analysed for this thesis.

The Intervention study can be described as _quasi-experimental_ (Babbie 2001, p. 339) in that:

(i) The Educational Therapy programme is itself the Intervention procedure. It is controlled in that all subjects received similar vision training and word skills programmes over a 4-6 month period.

(ii) It is a convenience sample as all students attending the practice at the time were included in the Educational Therapy programme. An attempt has been made to remove selection bias, as students were from many schools, including both single sex and co-educational schools in rural and suburban settings. For these reasons, the sample is considered to be a representative sample from a target sub-group of LD, within a general school population.

(iii) Selection of the two groups for the Stage 2 analysis was determined entirely by the results of eye exercises as regards dominance status, namely whether stable eye dominance had been
achieved or not. In this way, selection was not from screening and was independent of the researcher.

Comparison between the dominance groups was established by assessing differences, if any, in spelling, oral reading, and reading comprehension. This followed the five-days of the word skills programme, when those who had established right eye dominance (Group 1, n = 15) were compared with those who had not (Group 2, n = 9). If literacy gains in Group 1 were significantly different from Group 2, then a prediction might be made that "if right eye dominance is not established within balanced binocularity, then memory and literacy skills may be compromised in terms of speed and accuracy of learning". This prediction related to the second research question: What difference might newly established right eye dominance have on speed and ease of learning in reading and spelling? (Section 1.4).

Unmatched sample
In a small Educational Therapy practice there are a number of uncontrolled variables. One such limitation is that ethically all subjects must be treated equally and in their best interest at all times. Consequently this study could not follow an 'experimental' research design. Uncontrolled variables are also to be expected due to different ages and ability levels that influence the rate and amount of material that can be covered to mastery level in a week's work.

4.6.3 Measures
All measures were the same as those used in the School Survey (Section 5.6.1), which included the key o-m functions of binocularity and near foveal vision (assessed by a Behavioural Optometrist); with auditory, visual, phonemic memory span, spelling and reading conducted by the author. Post-tests were conducted by an independent assessor.

Data collection consisted of pre-tests to establish base-lines across 10 variables for each case. Firstly, analysis using post-tests measured literacy and memory span gains. In this case, each student was his/her own control (within-sample) in the before and after tests (Dawson & Trapp, 2001, p. 111). The same data was then used and the sample divided into two groups based on eye dominance status, to determine whether there was a difference in literacy and memory gains for those students who achieved stable eye dominance. Raw scores were used as interval scales for variables, namely three key visual measures of eye tracking, convergence, and divergence range. Standardised literacy tests of spelling, word recognition, oral reading, and reading comprehension were administered; and also visual, auditory, and phonemic memory tests.
In the Stage 1 analysis, paired-samples t-tests were used to compare the outcomes of post-tests of the word skills programme. In Stage 2, students underwent the word skills programme under the two research conditions. Group 1 included those with newly established right eye dominance, whereas those classified in Group 2 had no change of dominance in spite of having access to the same eye exercise regime. An independent-sample t-test was conducted to determine whether any difference in literacy or memory gains was found between the two dominance groups using the pre-test results as the co-variate.

4.6.4 General overview of the Educational Therapy programme

a) Eye exercises and word-skills workshop

All subjects underwent the same basic abilities training and cognitive skills programme over a 4-6 month period, which included vision training followed by a week-long word skills programme. Although the practice is client-based and activities depend on the needs of the individual, this programme is generally the same for all students because of their common deficits. Depending on age and educational level, the Educational Therapy programme includes vision training for stability of dominance, binocularity, and foveal fixation; sensory-motor co-ordination and sequencing; phonological and visual perception; letter / sound recognition, blending, word making; spelling patterns and rules; reading comprehension particularly related to prepositions (as a language extension of visual perception); topic sentences and note taking; logical analysis; study and exam strategy. Some of these activities are ongoing skills training, and the later stages consist of mini-lessons and exercises.

b) Levels and standards of memory and literacy

The word-skills programme was designed to bridge the difference between participants' performance and expected school-year parity, or at least perform within their perceived ability level. All students tend to display areas of immaturity, because in spite of the age range (6 – 18 years), even senior students are found to function at Primary school level in pre-literacy skills of phonological awareness, memory span, and visualisation. These deficits are addressed because every student undergoes the same visual, memory, and word skills programme. The only difference is age appropriate content and activities. Allowance is made for differences in energy, intelligence, and level of maturity in grouping students for the word-skills workshops.

c) Vision training

An hour-long acuity and o-m assessment of each student is done by a Behavioural Optometrist prior to commencement of eye exercises. Eye exercises provide ongoing assessment during the course of therapy, so exercises are formative as well as informative for the student in setting
goals; for building from basic skills upwards; and to establish patterns of more efficient function. All responses during eye exercises are recorded for monitoring so these are available for reports as required by the student's optometrist and these records provide the data base for this study.

Eye exercises provide a form of bio-feedback as the student works to maintain clarity of vision and binocularity, while expanding the range of vergence control, eye posture, and accommodation. For example, a dichoptie eye tracking exercise on computer uses red / blue lenses to track red and blue targets on the screen. This effectively separates the input to each eye, and ensures bi-hemispheric feedback to permit tracking of a diagonally moving target.

d) Equal opportunity

Equal opportunity was provided by allowing each student as much time and repetition as needed to achieve full range of o-m function, or until a plateau in results indicated that no further improvement was possible. The length of time needed for corrective eye exercises reflects the severity and the duration of o-m dysfunction that has been limiting an individual's ability to sustain clear binocular vision for fine detail. Results of the School Survey showed an increased incidence of o-m dysfunction with age (see Section 6.2.3, Table 3), which might be attributed to increased stress of longer hours spent in concentrating on smaller print at near range. In this case, for example, +0.50 lenses increased magnification sufficiently to take stress off the accommodation system and relax convergence. Exercises to re-establish full binocularity may then be a relatively minor matter if success is only a question of reclaiming what has been lost through acquired eye muscle imbalance.

Individuals with chronic conditions that have existed since earlier childhood may require work from a 'deeper baseline'. For example, an individual of any age who does not have basic levels of visual tracking or binocular focus may need to learn to attend to, fixate, and hold concentration on a small moving target and sustain this. Such training would begin with broad following movements. With 'a little bit often' practice at home, eventually smooth tracking, and controlled saccadic movements are achieved, with an accommodation / convergence ratio that is sufficient for refined foveal fixation of both eyes simultaneously. This would lead ultimately to access to fine visual detail inherent in bi-hemispheric processing in literacy. The length of time needed to achieve normal visual function generally depends on the depth of dysfunction. Consequently an open ended treatment facility provides equal opportunity to students with different levels of competence to catch up in both the visual domain as well as
word-skills. Ongoing therapy would ethically be available if needed after the study time-frame had elapsed.

4.7 Time Scale

School Survey

Timing and duration of the survey was set by the availability of optometrists for free vision screening during Vision Week. The Survey was set up in ten days, and data collected over the following ten school days, with minimal disruption to the school. The simple criterion-referenced activities did not present any difficulties in implementation or acceptance by the students, so it was a simple survey to run. As noted previously, this explorative study represents a practical snapshot of a range of activities required of every child in a normal school day, rather than a scientifically designed research plan. The initial proposal regarding vision screening had been suggested for the initial group of twelve students, but was extended to include a quarter of the school population.

Intervention follow-up Study

i) Eye exercises and Educational Therapy (n = 24 subjects) were conducted over an 18 month period. This was an intensive schedule, of between 15-30 one-hour, individual eye exercise sessions and 30 hour/week in a group situation for the word skills programme. The length of treatment was open-ended and depended on the rate of progress to establish foveal binocularity and right eye dominance. For some subjects, eye exercises were discontinued once this goal had been achieved and were usually held for 3 to 4 extra sessions. With others, if progress had reached a plateau beyond which no further progress was achievable in the opinion of the student and therapist, then exercises were also discontinued.

ii) Records were kept of the activities and results of each therapy session, over three years including the incidence of feet and posture problems requiring orthotics to correct anomalies in the bio-dynamics of gait (n = 64 subjects). The findings from this collection of data are reported briefly in Section 9.1.1. It has become increasingly apparent from these data that as well as visual dysfunction and LD, students have a common pattern of physical anomalies of muscle tone creating neck and shoulder discomfort, plus imbalance of posture and gait. This combination of symptoms raises a possibility that visual dysfunction may be one aspect of a systemic problem. The case studies ML and LW in Chapter 8, and two current case studies RW and GK in Chapter 9 describe patterns of physical and cognitive problems experienced by students with LD attending this practice.
iii) Two case studies of students currently under-going Educational Therapy. These individual cases illustrate the range of LD, the diagnoses, and advances in the management of LD.

4.8 Ethical considerations

School Survey
A letter-of-consent was arranged and administered by the School Counsellor (copy not available), to participating families. All tests and assessments were conducted within the school. Every endeavour has been made to address ethical concerns and ensure that in the archived material results are anonymous, with subjects and schools remaining un-identifiable.

Intervention study
As Educational Therapy must suit the vulnerable students’ needs, manipulation or timing of each student’s course work was avoided. The ethical challenge was to design a study that objectively divided the sample into two groups, without disadvantaging any student. In this private practice parents are present for assessment and vision therapy and were fully informed of the nature of the intervention programme, consequently the students’ inclusion in the study represents parental consent. Participant’s details are not identifiable from the data set.

4.9 Limitations of the study

4.9.1 School Survey
The weakness of a ‘snapshot’ Survey is that it does not indicate how accurately each measurement represents the subject’s ability, or how reliable the results might be. This aspect of dependability was mediated by the large number of subjects and variables, so both elements together helped to balance this risk. Thus, the reliability of results is evidenced in highlighting the incidence of visual problems within the school, and the profile of associated variables. For the school, it provided a ‘proficiency profile’, from which each student’s risk rating can be judged, and remedial action planned.

Confounding variables
Confounding variables were possible as this survey was conducted in a natural school setting, with conflicting timetables, missed appointments, and students failing to submit their work, all of which contributed to missed data. The large number of variables meant that some cells of the data set contained very small numbers. There was also a higher than expected number of students presenting with problems possibly due to a bias of parents who signed consent forms.
If 'concerned' parents recognised visual function as a possible problem, and parents of 'successful' students saw no need for visual assessment, both situations could have contributed to a skewed sample. Another explanation is that older, concerned girls may have begun self-selecting themselves for assessment when they heard what the other students were doing. It is also likely this private school might have attracted a higher proportion of exceptional, as well as disadvantaged, students.

**Validity, reliability and strength of the study**

The study remains important as it breaks new ground. If there is a proportionately larger number of educationally disadvantaged subjects, this would none-the-less provide an even more 'robust' sample to improve reliability, to prove or disprove any associations between visual problems and LD.

The strength of the study was its naturalistic view of basic learning abilities during ten school days. Firstly, gender was not considered a problem, because although girls are generally quoted as being only 20% of the sub-group with LD, fMRI research shows it affects boys and girls equally (Shaywitz, 1990 p. 998). Secondly, reading comprehension results have been matched against standardised tests, so these results can be considered as representing general, mixed school populations. This closeness of fit is shown in Table 5, which compares the samples’ median raw scores for reading comprehension with that of standardised GAP/GAPODOL raw scores. These scores can be considered as equivalent (having only a 2.3 point difference), so these findings may be assumed to be relevant to the school population as a whole.

### 4.9.2 Intervention study

This convenience sample had a range of intellectual abilities and varied deficits, together with o-m dysfunction, but no acuity or neurologic problems to account for their LD. Within this varied sample, as with any therapy based programme, it was difficult to take account of confounding variables and it was not possible to create matched groups, but neither was this necessary. The mean pre-test scores across all variables were remarkably even. An independent-samples t-Test was employed to compare the pre- and post tests of the two dominance groups.

The research design suited therapy principles and practice. It also made a clear distinction between those participants who achieved right eye dominance and the group whose eye exercises were unsuccessful. This facilitated the evaluation of any changes in post-tests. Conditions were as controlled as was possible in Educational Therapy practice, but given the
constraints and limitations of this design as a research study, it will be difficult to make
generalisations or predictions from findings. None-the-less, as a naturalistic study, it ought to
provide useful insights to guide further research and a more holistic management of LD.

This chapter has addressed the Methodology and overview of the three studies.
In Chapter 5 the School Survey method is discussed, with results and interpretation of findings.
Chapter 6 addresses questions arising from the School Survey. It introduces the considerations,
assumptions and Methods adopted in the Intervention study. Chapter 7 reports the findings of
the Intervention study, commencing with two matched case study studies as an example of the
experiential context in which these students participated.
Chapter 5

Results and Discussion of the School Survey

5.1 Introduction

This chapter focuses on the results of Part 1 - the School Survey. This 10 day survey was a cross-sectional study in which data were collected in a school over a two week period. The purpose was to explore the patterns discerned in a broad range of data related to perception, memory and literacy as a developmental hierarchy (ref. Luria's Model of Mental Function). Any pattern of results that emerged will determine what associations between variables need to be tested hence the statistical analysis reflects this eclectic approach. The computer programme used for the statistical analysis was SPSS (Student's Version 11.0 for Windows). In order for the reader to follow the logic behind the investigation, three aspects of the results are reported concurrently in each section, namely the statistical method, the actual results, followed by a therapeutic interpretation. Clinical questions arising from these interpretations will be instrumental in determining subsequent analytical processes.

The chapter concludes with a meta-analysis of the findings to uncover unanswered questions; justify further investigation; and to refine exploration-guided research questions for the follow-up Intervention Study in Chapters 6 and 7. The key research question undergirding this analysis of results is: "Is visual function (that includes both acuity and o-m function) associated with anomalies of LD, in terms of visual perception, memory, spelling, reading comprehension, and reasoning skills?"

5.1.1 Vision Screening measures

Visual variables as dichotomous values

A dichotomous 'visual function' variable was constructed from the eight measures of acuity and o-m function. The 'normal' category was comprised of cases where all eight visual elements tested as normal. 'Dysfunction' was identified when the results on one or more of the eight visual tests were rated as borderline or anomaly. 'Borderline' and 'anomalies' were collapsed into one visual dysfunction value, because functional variability of vision was the problematic element being investigated for its effect on learning. The term 'visual dysfunction' was used to incorporate the addition of o-m functions into tests that are normally limited to visual acuity. It also serves to convey 'visual risk' and for simplicity this term is used in the data analysis.
5.2 Frequency distribution

5.2.1 Frequency of specific visual dysfunction variables

As discussed previously, the visual system functions with all attributes interconnected within the visual system, so imbalance in one area impacts on the whole system to some degree. To determine the relative frequency of each variable, each one is treated as independent of the others. Table 2 shows the occurrence of ‘normal’ (described in Section 4.3.3) compared with visual dysfunction divided into specific variables in ranked order of frequency.

### Table 2

<table>
<thead>
<tr>
<th>Visual variables</th>
<th>Normal</th>
<th>Borderline</th>
<th>Anomaly</th>
<th>B+A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Phoria</td>
<td>207</td>
<td>77</td>
<td>50</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accommodation</td>
<td>214</td>
<td>80</td>
<td>50</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vergence</td>
<td>233</td>
<td>87</td>
<td>31</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pursuits</td>
<td>245</td>
<td>92</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fusion</td>
<td>247</td>
<td>92</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acuity</td>
<td>246</td>
<td>92</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near Point Converge</td>
<td>249</td>
<td>93</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saccades</td>
<td>252</td>
<td>94</td>
<td>11</td>
<td>4</td>
</tr>
</tbody>
</table>

**Note:** Visual dysfunction Variables ranked in descending order of the percentage of students who fell into Normal, Borderline or Anomaly categories. Total = 267.

Of greatest interest is phoria, accommodation and vergence control (in bold print).

Of the 277 subjects screened (10 missing data), some tested as having multiple visual problems so the Table 2 is not based on one-variable-per-subject. Of the visual dysfunctions, phoria was the most common problem (23%), together with accommodation (20%), and vergence control (13%). Each of these factors, either separately or interactively, can intermittently weaken binocularity which raises the question of which eye might be disadvantaged and differentially impact on the development of neural pathways, if it is the genetically dominant eye that is dysfunctional.

5.2.2 Visual Function – Incidence of younger students vs older students

Table 3 shows the incidence of normal and visual dysfunction is almost equally distributed across the school (50% normal, 47% dysfunctional and 3% missing data). Junior school students with some visual dysfunction are 32%, whereas the number is larger (52%) in the senior school.
Table 3
Visual Function distribution - Senior and Junior students

<table>
<thead>
<tr>
<th></th>
<th>Sample</th>
<th>Junior (N 76)</th>
<th>Senior (N 201)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>138 (50%)</td>
<td>52 (68%)</td>
<td>86 (43%)</td>
</tr>
<tr>
<td>Dysfunction</td>
<td>129 (47%)</td>
<td>24 (32%)</td>
<td>105 (52%)</td>
</tr>
<tr>
<td>Missing</td>
<td>10 (3%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>277</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Interpretation of 'Visual Function' Results

Table 3 shows an age discrepancy with senior students (52%) who are more prone to visual problems than junior subjects (32%). While this may be due to sampling, a plausible optometric explanation is that visual dysfunction may be due to eye muscle fatigue owing to abnormally long hours doing close work in the upper grades. Discrimination of fine detail like print involves foveal fixation which requires more accurate, sustained muscle co-ordination, control and stamina than normal global vision. Fatigue itself compromises muscle function and visual efficiency, together with increased stress on the individual from abnormal effort, resulting in problems of concentration, stamina and motivation impacting on learning. The probability of 50% of students having visual dysfunction with no LD is discussed further in Section 5.6.6.

From an educational point of view, the proportion of students with LD is generally quoted as between 10% and 20-30% depending on the definition used (DETYA report 2003, (2). p. 19). Consequently, figures in Table 3 can be extrapolated to support an argument that half of the 47% with visual dysfunction may not have literacy problems (owing to an advantaged dominant eye). However, the remaining 23.5% do qualify for more thorough investigation. As this outcome demonstrates, both the functional aspects of vision and neurological architecture of dominance pathways need to be taken into account when evaluating statistical outcomes.

Table 4 provides an overview of each school-year across the school population to show the relative distribution of above and below average levels of visual function, reading and spelling. Standardised reading and spelling tests were used, namely the GAP reading test and Schonell spelling tests. The main finding in Table 4 is a consistent and progressive increase in visual dysfunction with age, from Year 8 upwards, with the exception of Year 10 with 38 percent.
<table>
<thead>
<tr>
<th>Year</th>
<th>Sample Size</th>
<th>Visual Function</th>
<th>Reading Competence</th>
<th>Spelling Competence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>N %</td>
<td>N %</td>
<td>N %</td>
</tr>
<tr>
<td>Yr 1</td>
<td>8</td>
<td>Normal 7 68 At or above CA</td>
<td>6 75 7 88</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 1 12 Below CA</td>
<td>2 25 1 12</td>
<td></td>
</tr>
<tr>
<td>Yr 2</td>
<td>9</td>
<td>Normal 8 88 At or above CA</td>
<td>7 100 4 50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 1 12 Below CA</td>
<td>0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Yr 3</td>
<td>8</td>
<td>Normal 3 38 At or above CA</td>
<td>7 88 4 50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 5 62 Below CA</td>
<td>1 12 4 50</td>
<td></td>
</tr>
<tr>
<td>Yr 4</td>
<td>10</td>
<td>Normal 4 40 At or above CA</td>
<td>8 80 7 70</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 6 60 Below CA</td>
<td>2 20 3 30</td>
<td></td>
</tr>
<tr>
<td>Yr 5</td>
<td>7</td>
<td>Normal 5 72 At or above CA</td>
<td>4 57 5 72</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 2 28 Below CA</td>
<td>3 43 2 28</td>
<td></td>
</tr>
<tr>
<td>Yr 6</td>
<td>8</td>
<td>Normal 8 100 At or above CA</td>
<td>6 75 8 100</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 0 0 Below CA</td>
<td>2 25 0 0</td>
<td></td>
</tr>
<tr>
<td>Yr 7</td>
<td>26</td>
<td>Normal 17 66 At or above CA</td>
<td>18 75 12 48</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 9 34 Below CA</td>
<td>6 25 13 52</td>
<td></td>
</tr>
<tr>
<td>Yr 8</td>
<td>54</td>
<td>Normal 21 42 At or above CA</td>
<td>28 66 21 56</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 30 58 Below CA</td>
<td>14 34 16 44</td>
<td></td>
</tr>
<tr>
<td>Yr 9</td>
<td>38</td>
<td>Normal 17 46 At or above CA</td>
<td>21 84 6 26</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 20 54 Below CA</td>
<td>4 16 17 74</td>
<td></td>
</tr>
<tr>
<td>Yr 10</td>
<td>38</td>
<td>Normal 23 62 At or above CA</td>
<td>15 50 1 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 14 36 Below CA</td>
<td>15 50 30 # 98</td>
<td></td>
</tr>
<tr>
<td>Yr 11</td>
<td>40</td>
<td>Normal 15 40 At or above CA</td>
<td>17 70 1 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 23 60 Below CA</td>
<td>7 30 23 # 98</td>
<td></td>
</tr>
<tr>
<td>Yr 12</td>
<td>31</td>
<td>Normal 10 36 At or above CA</td>
<td>4 30 0 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dysfunct 18 64 Below CA</td>
<td>9 70 # 100</td>
<td></td>
</tr>
</tbody>
</table>

Missing data is due to timetable conflict in the upper school, absences, and non-submission of work.

1 CA = chronological age

# Below-average ratings are inflated owing to ceiling effect of Spelling (15 yrs) and Reading (17 yrs) test cut-off points. Data has been adjusted to account for older students, but still many competent students in years 10, 11 & 12 are unduly penalised with negative ratings for minimal errors.

Total number of each group, above and below CA.

Note the inverse difference between reading and spelling.

5.2.3 Overview of visual and literacy levels within each school year

Comparison across Years in visual function, reading, and spelling.

Population data were not available for the spelling test, but the incidence of reading problems in the sample was similar to that deemed for the normal population (McLeod, 1976 GAP Reading Comprehension test). While the number of subjects in Years 1–6 is relatively small their
results represent a 'continuum of development' in the range of literacy typically achieved by younger students. The most useful data were derived from the larger and more consistent results from years 7, 8 and 9. The number of cases in Years 11 and 12 was smaller as care was taken not to be in conflict with the students' normal timetable. The literacy results for Years 10, 11 and 12 were artificially low due to ceiling effects from cut-off points in both spelling and reading comprehension tests of 15 and 17 years, respectively. This ceiling effect may account for the differences between reading and spelling in terms of group sizes.

Although it was expected that reading and spelling groups would be roughly equivalent, there were differences. In reading there were 141 competent readers compared with 67 below average readers. However in spelling this trend is reversed with 76 competent spellers compared with 126 below average spellers (7 missing in the spelling set).

The difference between the reading and spelling results shows that there were only 67 below average readers, but 126 below average spellers. This suggests that out of the 141 competent readers at least 58 (41%) have slipped into the below average spelling group. This may be due to inflated negative scores in spelling for the older students owing to the cut-off point of 15 years, so Years 10, 11 and 12 are eliminated to correct for this ceiling effect. A similar trend is again found as competent readers numbered 105 compared with 36 below average readers, and 74 competent spellers compared with 60 deficient spellers, meaning that of the 105 competent readers, possibly 31 (30%) were deficient spellers. From this it can be concluded that the ceiling effect has influence the numbers, but there is still a 30% discrepancy between reading and spelling that suggests these students are under-achieving. Further tests of association were needed to discover whether this discrepancy occurred in students with visual dysfunction.

*Increased incidence of visual dysfunction with age*

The observation that visual dysfunction increases with age supports the previously proffered argument that increased visual stress with fine detail of near work may undermine balance of the visual system as students enter higher grades. From a clinical point of view, the large number of subjects with dysfunction was a concern as 'normal' visual function can be achieved with vision training, given that there are no physical, constitutional complications to impede progress. Although these figures suggest visual problems may not be affecting literacy levels of some students, the question remains as to why visual variables like phoria, accommodation, vergence, and uneven acuity are adversely affecting some students and not others.
5.2.4 Lack of trends in Visual Function

Visual dysfunction is only one of many factors, observed by the therapist that ought to be considered as implicated in LD. In these results, the incidence of visual dysfunction determined the size of the problem, with trends indicating only the numerical feasibility of an association.

Apart from the difference in age distribution, no consistent pattern was discernible between normal or dysfunctional levels of vision, reading, and spelling in Table 4. For example, variability of results showed a similar percentage of normal vision and above average spelling in Years 5 and 6, but there was an inverse relationship in Year 7. The Year 6 sample had 100% normal visual function and spelling, but only 75% normal reading. Although normal vision is found in 62% of Year 10, this had not translated into a higher proportion of subjects with above average reading and/or spelling. Again the question pursued through this thesis is, "What makes the difference?"

A review of the range of results show high standards in reading comprehension achieved by some students in Years 5, 8 and 9. Year 4 data shows two nine-year-olds were already reading at a twelve-year-old level; in Year 6 one subject reading at 17 years; in Year 7, 38% (8/21) scored higher than 16 years; and in Year 8, 37% (16/43) reached 17 years Reading Age. This provided a perspective of what was possible at each age level, and against which expected standards can be judged. In effect, "normal" standardisation has lowered the threshold of expectations and has run the risk of under-rating students' capabilities.

As might be expected, spelling results did not show such a wide range. One student in each of Years 4 and 5 was spelling two years above CA. Likewise, 38% of Year 6, 12% of Year 7, and 6% of Year 8 students were high achievers scoring close to test limits, that is, at 15 years Spelling Age. Not all classes showed this pattern, in Year 9 no-one was spelling one year above chronological age. However 49% were high achievers with deficient spelling where they were reading two or more years above their age but lower in spelling.

Limitations of frequency statistics and dichotomous values

Limitations of frequency tables and problems associated with dichotomous values can be seen in Table 4, where this summary exposes two apparent flaws in encoding test scores. Firstly, a ceiling effect from test cut-off points on dichotomous values meant that the results were skewed against older subjects. Differences between reading and/or spelling ages and chronological age also diminished progressively in Years 10, 11 and 12 owing to a ceiling effect for those
students who are close to or older than the test cut-off point, namely spelling at 15 years and reading at 17 years. Appraisal of individual cases showed that many of the subjects had top reading scores and were reasonably competent spellers and yet small errors incurred greater negative ratings than for younger students.

Notwithstanding these limitations, data from older students were retained because they represent 39% of the total sample, and like the youngest groups represented the other end of a 'continuum of development' in the range of literacy typically achieved by older students. Years 10, 11 and 12 also contributed information on other associations of visual dysfunction in terms of memory function and LD. Furthermore, significant differences between groups were evident, in spite of limitations from the ceiling effect, and added further weight to the findings.

Secondly, dichotomous values did not indicate the degree of deficit, or competency, so failure to discriminate performance levels prevented detection of anomalies between an individual's results on the two literacy tests. A point of therapeutic interest was that anomalies indicating under-achievement in spelling and reading needed further investigation if associated with visual dysfunction.

5.2.5 Literacy Measures
Scores were individualised (described in Methods section 4.5.1c), because the assessment of literacy skills, using the standard scores derived from Gap / Gapado reading comprehension (GAP) and Schonell spelling tests, did not indicate the degree of deficit or competency where an individual's chronological age was taken into account. This limitation was corrected with an 'individualised' score, by transforming each subject's scores to the number of years / months above or below chronological age. The individualised, interval scale had a positive or negative value around a central value of 0 (Reading age minus CA = 0).

Encoding literacy results
These data were decimalised for statistical analysis on SPSS computer programme. Dichotomous values were derived from the resulting two groups, namely that High includes "0 and above" and Low is "-1 and below". Strictly speaking, these results related only to the girls in each year level in a private school, and not necessarily extrapolated to a general population of school children.
### Table 5

Sample median raw scores compared with GAP median raw scores

<table>
<thead>
<tr>
<th>A. Year</th>
<th>B. Age Range</th>
<th>C. Reading Range</th>
<th>D. Sample Raw Scores</th>
<th>E. Sample Raw Median</th>
<th>F. GAP Raw Median</th>
<th>G. GAP Median Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>1. 5.9</td>
<td>6.6</td>
<td>5.4*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2. 6.8</td>
<td>7.2</td>
<td>6.10*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. 7.5</td>
<td>8.4</td>
<td>8.2</td>
<td>6</td>
<td>25</td>
<td>15.5</td>
<td>9</td>
</tr>
<tr>
<td>4. 8.8</td>
<td>9.10</td>
<td>7.6</td>
<td>2</td>
<td>35</td>
<td>18.5</td>
<td>16.5</td>
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<td>5. 9.10</td>
<td>10.6</td>
<td>9.1</td>
<td>12</td>
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<td>23.5</td>
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<tr>
<td>6. 10.8</td>
<td>11.4</td>
<td>10.2</td>
<td>19</td>
<td>50</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>7. 11.8</td>
<td>13.0</td>
<td>10.0</td>
<td>18</td>
<td>50</td>
<td>34</td>
<td>32.5</td>
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<tr>
<td>8. 12.0</td>
<td>13.9</td>
<td>10.0</td>
<td>18</td>
<td>50+</td>
<td>34</td>
<td>33</td>
</tr>
<tr>
<td>9. 13.0</td>
<td>14.11</td>
<td>11.0</td>
<td>25</td>
<td>50+</td>
<td>37.5</td>
<td>35.5</td>
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<tr>
<td>10. 14.0</td>
<td>16.0</td>
<td>10.11</td>
<td>24</td>
<td>50+</td>
<td>37</td>
<td>37.5</td>
</tr>
<tr>
<td>11. 15.7</td>
<td>16.7</td>
<td>13.1</td>
<td>39</td>
<td>50+</td>
<td>44.5</td>
<td>40</td>
</tr>
<tr>
<td>12. 16.9</td>
<td>17.8</td>
<td>13.7</td>
<td>30</td>
<td>50+</td>
<td>40</td>
<td>42</td>
</tr>
</tbody>
</table>

**H. Mean of Medians**

|         |            |                  | 31.9     | 23.6     |

**Note:** * Reading ages supplied from standard school tests (Reading ages outside Gap limits).

Raw scores cut-off @ 50+ as this represents the highest Reading Age of 17 years.

A. Year
B. Age range (lowest / highest) in each year.
C. Gap/Gapool Reading Age range, in each year.
D. Raw scores of Sample group, quoted to match Gap NORMS which use raw scores.
E. Median Raw score for Reading in each year.
F. Gap/Gapool median matched to age range of each Sample school year.
G. Raw scores range in GAP test NORMS, lowest and highest raw scores matching age range within each school year, from which the median is computed for comparison with school median.
H. Mean of medians showing similarity between sample and norm referenced scores.

### Description of Table 5 and Figure 7

The columns show: (A) each school year; (B) age range; (C) sample group reading age range has been converted to (D) raw scores to match GAP norm-referenced raw scores. (E) is the *median* raw score value for the sample group sorted into each school year for comparison with (G) which is the GAP reading median, and (F) shows the GAP scores *median* (based on raw scores) at each school year level.
Sample Group scores compare with normal parameters

An issue addressed in Table 5 was to compare the median raw scores for each school year against the GAP raw score norms corresponding to the same age range. It was organised in this way to establish whether this school sample fell within normal parameters. The table showed that mean of medians were almost equivalent, with 31.9 for the school and 29.6 for the GAP standardised tests. The overall school reading comprehension results was only 2.3 points (8%) higher than normal school populations. A possible explanation could be the higher standard of reading ability in the lower school with small class numbers, with the difference flattening out by Year 7.

5.3 Variance between Groups in Reading and Spelling

This section reports the results of $t$-Tests based on interval scales for test variables of Reading Comprehension and Spelling with a $t$ value of 2.086 representing significant differences between groups. These were compared with the means of group variables, expressed as dichotomous values. The nominal measures of “normal” / “deficit” refer to either full range of memory span or memory deficits, respectively; either all normal optometric results or some visual dysfunction. Dominance “normal” / “deficit” refers to either established dominance or unstable and/or mixed eye or hand dominance, and in § Reasoning and § Perception it refers to either normal or below expected standards.
5.3.1 Reading Comprehension competence

A t-Test of variance Reading Comprehension was compared against the means of the Grouping variables expressed as dichotomous values representing 'normal' functioning and 'deficits' in each area. It was expected that competent readers and spellers were likely to be competent across all areas of literacy, memory and logic, which appeared to be the case.

Table 6 uses the 'individualised' results as describe in Section 5.2.5. The pattern of greatest interest in this table was that, in all but two instances, GAP Reading performance was higher for the 'normal' group, as on average they were reading above their chronological age. In other words, on average the mean difference was higher for the normal compared with the deficit group in all the group variables. The exceptions were phoria and eye/hand dominance, where case outcomes may depend on which eye is advantaged in the case of weak binocularity.

### Table 6  Reading competence levels in normal and deficit group variables

<table>
<thead>
<tr>
<th>Group Variables</th>
<th>Number</th>
<th>Reading (RA – CA)</th>
<th>t-Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RA-CA mean² (years)</td>
<td></td>
</tr>
<tr>
<td>VISUAL</td>
<td></td>
<td>normal³</td>
<td>deficits³</td>
</tr>
<tr>
<td>accommodation</td>
<td>167</td>
<td>0.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Visual risk</td>
<td>109</td>
<td>0.5</td>
<td>2.0</td>
</tr>
<tr>
<td>vergence</td>
<td>173</td>
<td>0.2</td>
<td>1.9</td>
</tr>
<tr>
<td>near point converge</td>
<td>190</td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td>pursuits</td>
<td>183</td>
<td>0.3</td>
<td>1.3</td>
</tr>
<tr>
<td>saccades</td>
<td>190</td>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>fusion</td>
<td>187</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>phoria</td>
<td>163</td>
<td>1.0</td>
<td>-0.2</td>
</tr>
<tr>
<td>acuity</td>
<td>183</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>PERCEPTION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>§ Perception 3D</td>
<td>49</td>
<td>0.1</td>
<td>2.7</td>
</tr>
<tr>
<td>DOMINANCE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hand /arm</td>
<td>66</td>
<td>0.1</td>
<td>4.4</td>
</tr>
<tr>
<td>eye / hand</td>
<td>118</td>
<td>-0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>MEMORY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>phonemic</td>
<td>51</td>
<td>0.3</td>
<td>4.0</td>
</tr>
<tr>
<td>auditory</td>
<td>94</td>
<td>-0.3</td>
<td>4.0</td>
</tr>
<tr>
<td>visual</td>
<td>66</td>
<td>0.4</td>
<td>2.7</td>
</tr>
<tr>
<td>ACADEMIC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spelling age</td>
<td>74</td>
<td>0.2</td>
<td>6.8</td>
</tr>
<tr>
<td>§ Deductive Reason</td>
<td>37</td>
<td>0.5</td>
<td>5.8</td>
</tr>
<tr>
<td>§ Abstract Reasoning</td>
<td>21</td>
<td>0.4</td>
<td>4.1</td>
</tr>
</tbody>
</table>

RA-CA mean indicates the difference in years and months between competent and deficient readers in the dichotomous group variables.

Visual risk (or visual dysfunction) is the composite value of any deficits in acuity and/or function.

¹ RA – CA mean = Reading age minus chronological age. A mean of 0/zero indicates RA and CA are the same. A negative value indicates RA is below CA.

² Mean = average number of years above or below students’ chronological age in terms of reading age.

³ For each group variable students are rated as 'normal' or as having 'deficits' in that area.

* p significant at or beyond the 0.05 level.
Profile of 'competent', compared with 'deficient' readers

The greatest difference amongst the group variables was in deductive reasoning \((t = 5.8, \text{df} = 80, p < 0.001)\). On average the 37 subjects with normal deductive reasoning were 2.4 years ahead of their chronological age in reading, while the 45 subjects in the deficient deductive reasoning group were on average one month below their age in reading. The significant differences were from competent readers who were more likely to be better at abstract (mathematical) reasoning with the mean difference between groups of 2.3 years \((t = 4.1, \text{df} = 88, p < 0.001)\); in spelling the normal readers were 1.9 years ahead of the deficient readers \((t = 6.8, \text{df} = 195, p < 0.001)\); in 3D perception there was a 1.8 year difference between the groups \((t = 2.7, \text{df} = 128, p = 0.009)\); and in arm/hand dominance, which is latent handedness compared with writing hand, there was a 1.6 year difference \((t = 4.4, \text{df} = 127, p < 0.001)\).

Memory variables also showed the competent readers ahead in auditory memory with a 1.6 year difference between groups \((t = 4.0, \text{df} = 129, p < 0.001)\); and in phonemic memory a 1.5 year difference \((t = 4.0, \text{df} = 129, p < 0.001)\). In the matched groups of visual memory there was one year reading age difference between the 66 with normal memory span, and the 65 with deficits \((t = 2.7, \text{df} = 129, p = 0.009)\).

Visual factors which are of particular relevance to the research question, in relation to a possible link between visual dysfunction and LD, include the difference between normal and deficient accommodation. The frequency of visual dysfunction was shown to be evenly distributed across the school, (as reported in Section 5.2.2). However, there was a difference between normal and deficit accommodation variable in terms of reading proficiency. The 167 subjects with normal visual accommodation were reading .9 months ahead of the deficit group \((t = 2.5, \text{df} = 201, p = 0.012)\); and in the composite variable of visual risk 109 subjects with normal vision were reading .6 months ahead of the 94 with visual dysfunction \((t = 2.0, \text{df} = 201, p = 0.049)\). There was no significant difference between groups in eye/hand dominance \((t = -1, \text{df} = 199, p = 0.945)\), where, in fact, the 'deficit' group performed slightly better on average than the 'normal' group.

Generally, these \(t\)-Test results suggested that binocularity and focus might have been a problem in the deficient reading group where there was a mean difference of about 7 months below the results of the competent readers. A clear distinction was shown between reading groups in both visual depth perception (which requires balanced binocularity) and accommodation. This was sufficient to constitute a visual risk. Visual memory span was likewise of interest because it reflected the number of visual and spatial elements that can be integrated in the working memory, to facilitate deductive reasoning.
The lack of a discriminatory difference in eye/hand dominance, quoted above, tended to confirm the possibility that this was a therapeutically inadequate test of eye/hand dominance. This was a conventional method of determining which eye is subjectively dominant, where the referenced or 'aiming' eye in monocular tasks is matched against the writing hand. This eye is not necessarily the neurologically dominant eye in terms of pathways to the language area.

5.3.2 Spelling competence

Differences between reading and spelling

In Table 6 it was found that mean spelling levels were lower than those of reading, as two-thirds of the grouping variables were negative, below 0 results. However, the size of the difference between the means of grouping variables remained much the same. Table 7 below followed the same principles as the Reading t-Test but with Spelling as an interval scale.

Table 7
Spelling competence levels in normal and deficit group variables

<table>
<thead>
<tr>
<th>Group Variables</th>
<th>Number</th>
<th>Spelling SA-CA mean (years)</th>
<th>T-tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>normal</td>
<td>deficits</td>
</tr>
<tr>
<td>VISUAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>accommodation</td>
<td>166</td>
<td>31</td>
<td>-0.5</td>
</tr>
<tr>
<td>Visual risk</td>
<td>112</td>
<td>85</td>
<td>-0.4</td>
</tr>
<tr>
<td>pursuits</td>
<td>180</td>
<td>18</td>
<td>-0.5</td>
</tr>
<tr>
<td>near point converge</td>
<td>189</td>
<td>9</td>
<td>-0.6</td>
</tr>
<tr>
<td>sacades</td>
<td>189</td>
<td>9</td>
<td>-0.6</td>
</tr>
<tr>
<td>fusion</td>
<td>184</td>
<td>14</td>
<td>-0.5</td>
</tr>
<tr>
<td>vergence</td>
<td>171</td>
<td>27</td>
<td>-0.6</td>
</tr>
<tr>
<td>phoria</td>
<td>162</td>
<td>36</td>
<td>-0.6</td>
</tr>
<tr>
<td>acuity</td>
<td>183</td>
<td>15</td>
<td>-0.6</td>
</tr>
<tr>
<td>PERCEPTION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Binocular 3D depth</td>
<td>50</td>
<td>79</td>
<td>0.1</td>
</tr>
<tr>
<td>DOMINANCE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand / arm</td>
<td>64</td>
<td>54</td>
<td>0.1</td>
</tr>
<tr>
<td>Eye / hand</td>
<td>112</td>
<td>83</td>
<td>-0.6</td>
</tr>
<tr>
<td>MEMORY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phonemic</td>
<td>49</td>
<td>71</td>
<td>0.2</td>
</tr>
<tr>
<td>Visual</td>
<td>83</td>
<td>58</td>
<td>-0.1</td>
</tr>
<tr>
<td>Auditory</td>
<td>82</td>
<td>29</td>
<td>-0.3</td>
</tr>
<tr>
<td>ACADEMIC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading</td>
<td>137</td>
<td>56</td>
<td>-0.1</td>
</tr>
<tr>
<td>Deductive Reason</td>
<td>36</td>
<td>38</td>
<td>0.0</td>
</tr>
<tr>
<td>Abstract Reason</td>
<td>21</td>
<td>61</td>
<td>0.1</td>
</tr>
</tbody>
</table>

SA-CA mean is Spelling age minus chronological age.

* p significant at or beyond the 0.05 level, for Group variables.

Mean is the average number of years above or below students' chronological age in terms of spelling age.

Visual risk (visual dysfunction) represents any deficits in acuity and/or function.
Results showed the distribution of cases with normal and deficit reading (137 and 58 respectively) and spelling (74 normal and 123 deficit spelling) was reversed. It was not consistently distributed as competent students would normally be expected to be competent in all academic variables of reading, spelling, mathematical (abstract) reasoning, and deductive reasoning. However, this table showed that under half of the competent readers were possibly deficient spellers, and/or had been adversely affected by the ceiling effect of the 15 year cut-off point in the spelling test, as discussed in Section 5.2.3 in relation to Frequency Table 4.

The most significant difference between groups was in reading \((t = 7.9, \text{df} = 193, p < 0.001)\) with competent spellers being 1.6 years ahead of the deficient group. Other differences were for arm dominance, where the writing hand is not congruent with latent dominance as shown in the folded arms test (Luria 1966) \((t = 4.1, \text{df} = 116, p < 0.001)\) with 1.1 years difference between the competent and deficient spellers. Each of the three memory modes showed a difference between groups as phonemic memory groups showed a 1.1 year difference between groups \((t = 4.1, \text{df} = 119, p < 0.001)\); visual memory 0.8 months difference \((t = 2.9, \text{df} = 119, p = 0.003)\), and auditory memory likewise 0.8 months difference \((t = 2.6, \text{df} = 119, p = 0.012)\). Reasoning skills also showed a difference between groups in spelling levels with abstract reasoning with a 1.1 year difference \((t = 3.0, \text{df} = 80, p = 0.004)\), and deductive reasoning 0.9 months \((t = 4.2, \text{df} = 72, p < 0.001)\).

One unexpected difference between reading and spelling results was that unlike reading, spelling showed no significant differences in any of the visual function variables, including accommodation, and depth of field perception. In every other respect, spelling mirrored that of reading, namely, group variables of arm dominance, all the memory and academic variables showed significant differences. Such a significant discrepancy between spelling and reading would justify these students having a more thorough visual assessment than the simple screening test.

5.4 Examining associations between variables

Given the findings so far, this section goes into a deeper analysis to examine the associations between phonemic memory and each of the variables used to measure visual function, literacy, perception, and reasoning. As mentioned previously, the term visual dysfunction encompasses both acuity and dysfunction, but it is the latter that is not typically included in standard eye tests, and may contribute to visual risk and associated LD.
Main research question:
The research question asks, "Is there a link between visual function, literacy, and memory?" However, owing to the complexity of the subject and diversity of results, the question was divided into six sub-questions which were integrated into the section of Gamma associations. In this search for associated variables, the organising focus was on aspects of visual variables; binocular depth perception, dominance and academic variables, with the key dependent variable being phonemic memory identified in previous findings.

5.4.1 Gamma co-efficient measure of association - Memory Deficit
Phonemic memory (the dependent variable) is an ordinal level variable, whereas the measures of visual acuity and function, perception, memory, literacy, and logic were recoded as dichotomous variables. Gamma was chosen as the measure of association since, according to de Vaus (1995, p.170), if one of the variables is dichotomous, its level of measurement can be ignored letting the other variable (in this case, the ordinal variable) determine the choice of coefficient. Since Gamma is a proportional reduction in error (PRE) measure, the coefficient can be interpreted as "the percentage improvement in predicting correct values of one variable on the basis of another variable" (de Vaus, 2002, p.257).

5.4.2 Phonemic memory
Phonemes are central to the discussion as these are the basic units of words. This phonemic memory exercise was devised as a composite of the transformations that individuals must developed in the process of establishing literacy skills. Details of phonemic memory exercises and age norms were outlined in Section 4.6.1.4. Neurologically these transformations involve the conversion of auditory to visual signals (and vice versa) in the associative area between the visual cortex and auditory area, in the angular gyrus. Functionally, phonics become bonded as one dyadic item, with inter-changeability of verbal and visual input. Like two sides of a coin, this allows for automatic responses of visual or auditory signals when encoding and decoding words. Automatic identification of both auditory and visual aspects of grapho-phonemes is vital in early stages of learning to read and spell. That is, phonological awareness is required to identify individual sounds and link these with written letters for spelling, and to blend them when learning the phonetic aspect of reading.

The gamma co-efficient was calculated to determine whether the competent readers had a wider memory span than deficient readers. Gamma as a measure of association indicated whether there was a relationship between them.
Table 8
Phonemic memory by visual function, perception, dominance and literacy

<table>
<thead>
<tr>
<th>Grouping variables</th>
<th>Phonemic Memory</th>
<th>Measure of Association</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severe Deficit</td>
<td>Deficit</td>
</tr>
<tr>
<td>VISUAL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near Point</td>
<td>Dysfunction</td>
<td>9</td>
</tr>
<tr>
<td>Convergence</td>
<td>Normal</td>
<td>131</td>
</tr>
<tr>
<td>Visual Acuity</td>
<td>Dysfunction</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>123</td>
</tr>
<tr>
<td>Saccades</td>
<td>Dysfunction</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>128</td>
</tr>
<tr>
<td>Accommod'n</td>
<td>Below average</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Above average</td>
<td>114</td>
</tr>
<tr>
<td>Visual Risk</td>
<td>Dysfunction</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>76</td>
</tr>
<tr>
<td>Pursuits</td>
<td>Dysfunction</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>124</td>
</tr>
<tr>
<td>Fusion</td>
<td>Dysfunction</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>129</td>
</tr>
<tr>
<td>PERCEPTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Binocular Depth</td>
<td>Deficient</td>
<td>85</td>
</tr>
<tr>
<td>DOMINANCE</td>
<td>Competent</td>
<td>36</td>
</tr>
<tr>
<td>Arm / Hand</td>
<td>Mixed / not est.</td>
<td>70</td>
</tr>
<tr>
<td>Dominance</td>
<td>Established</td>
<td>63</td>
</tr>
<tr>
<td>Eye / Hand</td>
<td>Mixed / not est.</td>
<td>60</td>
</tr>
<tr>
<td>Dominance</td>
<td>Established</td>
<td>79</td>
</tr>
<tr>
<td>ACADEMIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading</td>
<td>Below average</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Above average</td>
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</tr>
<tr>
<td>Abstract Reasoning</td>
<td>Deficient</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Competent</td>
<td>12</td>
</tr>
<tr>
<td>Deductive Reasoning</td>
<td>Deficient</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Competent</td>
<td>23</td>
</tr>
<tr>
<td>Spelling</td>
<td>Below average</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>Above average</td>
<td></td>
</tr>
</tbody>
</table>

1 Phonemic memory measured on an ordinal scale from 1 to 7:
   Severe Deficit ≤ 3; Deficit = 4; Weak = 5; Competent ≥ 6
* Significant at or beyond the 0.05 level
Results ranked in order of gamma values, within visual, perception, dominance, academic categories.
Visual risk is a composite value representing any deficits in acuity and/or function.
The percentages within each bi-variate table indicated both the strength of the relationship by means of the differences between the numbers, as well as the direction of the relationship. Table 8 shows four levels of phonemic memory as ordinal values which were cross-tabulated with nine dichotomous grouping variables, namely visual function, perception, dominance, and academic variables of reading, spelling, and reasoning.

Phonemic memory results

Gamma analysis results showed that reading (gamma 0.623, p < 0.001) had the strongest association with phonemic memory, and yet contrary to expectation, the association with spelling was weak (gamma 0.241, p < 0.077), as it was rated fourteenth in the list of sixteen variables. It was also outside the set probability level of 0.05. The percentages in reading comprehension showed a consistency of position, where students retained their position in the four levels. For example, students at the lowest level retained that position across all variables as the nature of the below average readers particularly showed a consistent linear trend.

Therapist's interpretation

There was a perplexing pattern of a higher percentage of subjects with defective (4/7) memory compared with weak (5/7) memory particularly amongst the competent readers. Admittedly, 5/7 can be regarded as the lower end of a range that can still support reading competence, but the percentage of defective memory span is not much lower than those subjects with competent (6-7/7) memory span. This observation may be linked to the notion of readers with limited memory span relying on just three features to recognise words. In spite of this anomaly, the Gamma analysis of results presented a strong association between phonemic memory, reading, reasoning, visual function, and to a lesser degree, visual perception of depth of field as a 'distant' measure of binocularity.

From the therapist's perspective, reading and spelling are the two sides of literacy involving different processes which may have accounted for their different levels of association with phonemic memory span. Both involved symbols representing language, but at a functional level, spelling was perceptually the more demanding task. This was because it required not only deconstruction of sounds of a word in sequence, but also a reconstructive process of letters from the memory's grapho-phonie data bank and complex sensory-motor networks involved in writing.

Although reading is a very complex cognitive and linguistic operation, at a functional level it is based on word recognition. With sufficient interest and exposure to print, reasonably
competent reading can be achieved by recognition of the unique shape of a word and several key letter features, without a sense of the internal details. Analysis of errors by predominantly left-eyed students suggested this is the way they read. This accounted for their tendency to confuse and therefore miscall words. Possibly this is one reason they are frequently deficient spellers. This aspect of the investigation is addressed in the Intervention study.

5.4.3 Auditory memory

The auditory memory measures shown in Table 9 were based on the auditory digit span test (Wechsler WISC-R, 1974) that has students repeat a verbal sequence of up to eight numbers. Results range from an optimum memory span of 6-7 digits down to a limit of 3 digits.

Results showed that after Year 3, the range of memory span was similar to older students as half of the seven-year-olds managed a top score of 7 phonemes, while many students in High School had low memory spans of 3 or 4 digits. The gamma co-efficient was calculated to determine whether a relationship existed between normal and deficient auditory memory span in the two dichotomous groups of reading, spelling, visual perception, and visual function factors. The gamma analysis showed a degree of association in both the strength and direction, shown in trends and differences between numbers.

The results in Table 9, showed the independent variable auditory memory was associated with only four variables. The strongest variable was hand / arm dominance (gamma = 0.628, p = <0.001), followed by visual acuity (gamma = 0.608, p = 0.006). Visual accommodation was associated to a lesser degree (gamma = 0.400, p = 0.035), and reading comprehension was the fourth variable (gamma = -0.467, p = <0.008).

From the therapist’s perspective this gamma analysis has provided a fine discrimination of points of interest to the research question. In contrast, previous tests showed visual acuity was ranked as the last of the dependent variables in t-tests with reading and spelling as independent variables. The acuity variable also showed a similarity of frequency counts in each group, so both analyses indicated that acuity was not significantly linked with memory. However, the gamma statistic suggests a strong association, supported by the overall trend. These results would possibly have been more linear if auditory memory had been divided into three instead of four levels.
Table 9

**Auditory memory by visual function, perception, dominance and literacy**

<table>
<thead>
<tr>
<th>Grouping variables</th>
<th>Severe Deficit</th>
<th>Defect</th>
<th>Weak</th>
<th>Competent</th>
<th>Measure of association</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VISUAL</strong></td>
<td></td>
<td></td>
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</table>

1. Auditory memory measured on an ordinal scale from 1 to 7:
   Severe Deficit ≤ 3; Deficit = 4; Weak = 5; Competent ≥ 6.
   Variables ranked in order of gamma values, sorted into each category.
   * Significant at, or beyond the 0.05 level
   Visual risk (visual dysfunction) a composite value, any deficits in acuity and/or function.
Although it might be assumed that visual factors are more likely to be associated with visual memory the converse seems to be the case, as it is auditory memory that is associated most strongly with visual function. Considered together, the co-occurrence of clarity of vision and focus with auditory memory supported the Luria (1973) model of sensory-perceptual-memory associative networks, such that both are a necessary part of simultaneous transformation of auditory / visual signals in the chain of neural processes, when encoding and decoding words in the memory system, and ultimately reading.

5.4.4 Visual memory

The visual memory measure shown in Table 10 was based on having the students reproduce up to five geometric shapes from a choice of twelve that were perceptually correct in shape, sequence and spatial position (Taylor & Bender, 1954). There was an optimum score of 15. The Wechsler test gives seven years of age as the norm for achieving a visual memory span for five shapes but, just as with auditory memory, there was little difference between junior and senior school results. However an age allowance was made for up to and including Year 6 students, with a score of 3/5 rated as a deficit. Whereas, Year 7 students who were upwards 4 or 3/5 were rated as a deficit and if 5/5 they were rated as normal.

Table 10 shows gamma co-efficient of association between visual memory and five variables. Just as in auditory memory, visual memory is most strongly associated with arm / hand dominance (gamma 0.367, p = 0.008). Visual variables of near point convergence (gamma 0.624, p = 0.039) and visual acuity (gamma 0.434, p = 0.055) were just within range of 95% probability, and both were essential for discerning fine detail of print for near vision. Deductive reasoning (gamma 0.421, p = 0.042) might be said to contain visual imagery, and binocular depth perception (gamma 0.343, p = 0.050) could be regarded as a bi-hemispheric representation of visual information, that is of ‘what is it?’ and ‘where is it?’ associated with visual memory.

Neither reading nor spelling were included as a component of visual memory as might be expected from a therapist’s task analysis. None-the-less, these results suggested there were sufficient numbers of subjects managing well enough to fall within the above average literacy category, without a full visual memory span. These complex expressive skills may have provided sufficient scope for adaptation and compensatory learning for such links to be indiscernible.
Table 10

Visual memory by visual function, perception, dominance and literacy

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1 Visual Memory span measured on an ordinal scale from 1 to 3:
   Deficit 3/5 = 1; Weak 4/5 = 2; Competent 5/5 = 3;

* Significant at or beyond the 0.05 level. Variables ranked in order of gamma values, in each category.
Visual risk (visual dysfunction) a composite value, any deficits in acuity and/or function.

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5.4.5 Are degrees of memory deficit and LD associated?

It was reasoned that degree of learning disadvantage may depend on the degree of memory deficit. Dysfunction is part of this process as it has already been found to be associated with each memory category, namely phonemic memory (accommodation, vergence and acuity), auditory memory (acuity and accommodation), and visual memory (near point convergence and acuity). Reading and spelling had shown no differences between visual function groups in the preceding t-Tests (Tables 6 & 7), but what was uncertain, was the influence of memory deficit on reading and spelling. Consequently a fourth memory category was needed to account for the fact that the data sheet showed many students had multiple memory deficits that were probably contributing to deeper levels of LD.

Degree of memory deficit

The new category ‘memory deficits’ was ranked at four levels:

- **Normal memory** included full range in auditory, visual, and phonemic memory span.
- **A single deficit** denoted either auditory or visual deficit (less than 5/5 items).
- **Double deficit** rating was two deficits out of the three memory modes.
- **Triple deficit** rating meant limitations in all three memory modes.

These four levels were rated from 1 for a triple deficit up to 4 for a normal memory span in each mode for statistical analysis.

Table 11 showed results of cross tabulations in bi-variate analysis, with the gamma co-efficient as the measure of association that included arm/hand dominance (gamma = 0.662 p = <0.001), reading (gamma = 0.583 p = <0.001), and spelling (gamma = 0.581 p = <0.001). Visual variables were well represented in this memory deficits variable, with depth perception (gamma = 0.496 p = <0.001). The following visual attributes that were instrumental in allowing clear image of fine detail, such as visual acuity (gamma = 0.500 p = 0.008), accommodation (gamma = 0.442 p = <0.001), visual function risk (gamma = 0.303 p = 0.016), and saccades (gamma = 0.540 p = 0.019). Abstract reasoning skills (gamma = 0.510 p = 0.029) association with memory status suggested that for individuals with this profile, competent or deficient, it might be reflected in mathematical ability.

These results showed memory deficit as being the most discriminatory variable of all as it included both literacy variables as well as some significant visual functions.
Table 11
Memory Deficit by visual function, perception, dominance and literacy.

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1. Memory DEFICITS measured on an ordinal scale from 1 to 4: of phonemic, auditory and visual memory
   * Triple Deficit = 1; Double deficit = 2; Single deficit = 3; Normal range = 4 (full range in all three modes).
   * Significant at or beyond the 0.05 level
   Variables ranked in order of gamma values, sorted into each category.
   * Binocular Depth is the pre-requisite for depth perception (3D) in angled lines in a 2D drawing exercise.
   * Visual risk (visual dysfunction) a composite value, any deficits in acuity and/or function.
5.4.6 Hand / arm dominance

The consistent occurrence of hand / arm dominance being associated with the most variables, suggested it was also a key variable (gamma = 0.346, p = <0.005). In this case there was a moderate level of association with phonemic memory, as is depth perception (gamma = 0.346, p = <0.020). The term ‘Binocular Depth’ in Table 8 referred to depth perception. The prerequisite of which is binocular fusion which provides not only 3D vision (stereopsis) but is also reflected as angled lines of perspective in a drawing. Two dimensional representations of a three dimensional scene were used in the perceptual exercises.

5.4.7 Reasoning

Deductive reasoning (gamma = 0.425, p = <0.017) and abstract reasoning (gamma = 0.494, p = <0.027) were likewise similar in association, even though only a small number of students completed the exercises (61 and 65 respectively) and even fewer (18%) reached expected levels of mathematical reasoning. These results showed competent subjects are more likely to be high achievers in reading comprehension as demonstrated in t-Tests (Table 6). Positive associations were found between phonemic memory and several of the visual variables. The strongest were accommodation (gamma = 0.450, p = <0.004), vergence (gamma = 0.465, p = <0.008) and visual acuity (gamma = 0.473, p = <0.030), which together were strong enough to register as visual function risk (gamma = 0.337, p = <0.005).

The broad association between phonemic memory and this wide range of variables suggested that reasoning is a key variable in the learning process. Of particular relevance to the research question, phonemic memory was associated with three visual variables, accommodation, vergence and acuity. Together, as part of the dynamics of visual function, each is critical for discriminating small detail in near work, as in print reading and eye-hand co-ordination for writing.

Results of this bi-variate analysis suggested two key issues that warrant further exploration. The first was the association of normal phonemic memory with competent reading comprehension, compared with deficit phonemic memory associated with deficient reading comprehension. Secondly was the importance of visual factors of (accommodation, vergence, acuity, and visual perception) associated with phonemic memory. If taken together as a model of integrated processes, it suggested an indirect link between memory (as the medium of learning), to reading and reasoning (as a product of learning), which has been shown to be associated with visual function, and therefore relevant to the research question.
Sensory-neural-cognitive processing as an integrated whole – Therapist’s perspective

As with all cognitive activity, memory ought not to be considered in isolation, nor should its various modalities be seen as operating as independent elements. Not only are neuronal signals integrated as parts of a total pattern, with both incoming and outgoing messages, but the mode of encoding signals as well as perceptual and logical operations have features common to each mode. None-the-less, by dividing memory according to sensory input modalities, differences and associations were found as shown in preceding tables. Clinically, this information has provided some insights for further research to inform therapeutic directions which is the qualitative bias of this thesis. What these results have failed to do is to provide a perspective as to the degree of deficit experienced by the individual. This is of importance as there may be a critical threshold of deficit beyond which an individual’s efforts and compensatory capacity can not reach. Thus, the individual becomes labelled at the severe end of the continuum, (i.e. as being learning disabled), as opposed to having LD; or just an under-achieving, hard-working, stressed, and/or discouraged average student.

5.5 Visual Perception

A number of pencil and paper perception exercises (Section 4.5.1.5) was provided to all student Years 4-7 and Years 8-10, who completed the tasks in art classes over the two week period of the School Survey. The most challenging exercise was a ‘chain links’ which consisted of sketching a large, rusty chain stretched along the length of the art table. This object was within easy view of each student. It was chosen as a controlled exercise of sketching many aspects of a single repeated shape. It incorporated all perceptual elements, of shape, size, direction, tonal shading, depth of field with overlapping edges, and angles, that convey perspective for which depth of field is needed.

General perceptual findings from Art exercises

Table 6 showed that of the 130 subjects whose art work was assessed (by the researcher/therapist who is a qualified Art Specialist), 49 (38%) had age appropriate perceptual ability, whereas 81 (62%) had problems with depth of field vision, that suggested weak binocularity and fusion.

Results of t-Tests of depth perception had shown a difference of means between the two reading comprehension groups ($t = 2.7$, df 128, $p = 0.009$), but not in spelling. The gamma coefficient of association confirmed that both phonemic ($\text{gamma} = 0.346$, $p = 0.020$) and visual memory ($\text{gamma} = 0.343$, $p = 0.050$) were associated with depth perception; and likewise, in ranked memory deficits ($\text{gamma} = 0.496$, $p = <0.001$).
Iconic evidence of various stages of perceptual development, in Years 4, 7 and 9.

**Mature rating,** students have studied the subject carefully and drawn the phenomena they are actually seeing and drawing accurately from a well-developed sense of size, shape, solidity, interconnectedness and three dimensions, and sophisticated use of angled perspective lines.

**Average rating,** lacks a third dimension as angled lines. The links are a 2D design pattern rather than 3D links which are interconnected and move in 3D space, so the drawing is of a general idea with limited perceptual analysis.

**Deficient rating** shows immature perception and suggests limited visual inspection, so drawing is of a ‘canonical projection’ of what they believe it would look like if they were looking at it, with no perceptual qualities other than a string of hollow, rounded ‘doughnut’ shapes with transparencies.

*The three perceptual levels relate to maturity of reading and memory, irrespective of age.*
In general, it may be asserted that deficient depth perception, binocularity, and fusion are linked with a greater level of memory deficit and reading comprehension.

Binocularity is of particular relevance to the findings of this thesis, not only in questions of the primacy of perception, but it might also be implicit in bi-hemispheric processing of foveal vision. Specifically, that means for fine detail like print to be registered and synchronised to link with the appropriate auditory information, to bond as a dyadic unit of phonics.

The students' Chain Link exercise (Figure 8) was designed as the appropriate measure because it represented the most perceptually demanding, two-dimensional depth of field drawing, and as such was directly related to reliability of binocular vision. The students' work was graded for each year level, falling naturally into four different stages of perceptual maturity. What was significant from a qualitative analysis of the drawings, was that when viewed en masse, similar levels of perceptual development occurred across all Years 4 – 10, irrespective of age as shown in Figure 8.

The 'chain' depth of field perception exercise (Figure 8) might be seen as an integral part of perceptual processes, as an indirect measure of binocularity. From a therapist’s perspective, weak binocularity and fusion may have diverse and possibly adverse affects on perceptual judgement of depth of which the individual is unaware. However, weak binocularity and lack of fusion do not necessarily affect academic progress or literacy skills as this may depend on which eye is advantaged, and whether visual links with the language area are optimal.

5.6 Answering the Research Questions – meta-analysis

This preliminary 'theory refinement' has been the result of applying the Gamma coefficient of association. This further analysis helped to draw together elements of findings in relation to the Research Question, which was divided into six sub-questions (from Section 1.4, p. 10). This enabled further therapeutic implications to be drawn.

Relevance of these Results to the Research Question

Bi-variate analysis in Table 11 showed a positive association between phonemic memory and reading comprehension. Importantly, visual factors of accommodation, vergence, acuity, and visual perception were also associated with phonemic memory. This suggested an indirect link between memory (as the medium of learning), to reading and reasoning (as a product of learning), shown to be associated with visual function. These associations show there is some
truth in the assertion that function is associated with memory and therefore learning, which answers the Research Question 1 in the affirmative.

Research Question 1

"Is there an association between anomalies of visual function (including acuity and function) and LD, specifically in terms of visual perception, memory, spelling, reading comprehension and reasoning skills?" As this complex question encompasses many different aspects, analysis of the data will seek to answer the following sub-questions as a way of answering the main research question.

Sub-questions for School Survey
1. What proportion of students have visual dysfunction and of what type?
2. Do students with normal versus visual dysfunction differ in reading ability?
3. Do students with normal versus visual dysfunction differ in spelling ability?
4. Do students with normal versus visual dysfunction differ in memory span?
5. Is there a link between reading comprehension, spelling, and memory deficit?

5.6.1 A review of Visual factors linked with Memory and Literacy

One key finding was that individuals would benefit from function tests to see if the eyes are working together, if there is any suggestion of LD. As expressed in Terminology (Section 1.5) in this thesis, visual terms have been separated into three categories. Firstly function relates only to eye muscle function including strength, stamina, posture, co-ordination, and focus between the two eyes. Secondly acuity is clarity of vision (related to the retina and lens) and is the basis of standard vision tests in school vision screening and upon which research into literacy is generally based. If a student passed an acuity test, it was assumed there were no visual problems. Thirdly, visual dysfunction is a general term that refers to any abnormality of either acuity or function that constitutes a "visual risk" of either clarity of vision or neural/sensory development, so these two terms have been used interchangeably. Results of this survey would suggest that such distinctions need to be made because 'vision' is generally assumed to mean 'acuity'. Consequently when functions are neglected in standard optometry tests, there is a failure to link these categories with memory deficits and literacy skills.

Sub-question 1.

What proportion of students has visual dysfunction and of what type?

In the total sample of 267 subjects, 48% were found to have some form of dysfunction, the most common problems being phoria (23%), accommodation (20%) and vergence control (13%), all of which have implications for binocularity and bi-hemispheric processing of visual
information, as well as accommodation / convergence sufficiency for near work like reading and writing. Acuity was found to be significant for auditory, phonemic, and memory deficits but not reading or spelling.

**Frequency results – Are these clinically misleading?**

Analysis of frequency results showed a relatively even distribution of visual function (Table 3), with normal vision (52%) versus visual dysfunction (48%), which would indicate that there is no link between visual problems and I.D. Given that approximately half of the sample had visual dysfunction, it would be a clinical error to assume there was no link between the two factors. The generally accepted incidence of reading problems is 10% - 30%, depending on the definition of what constitutes a learning difficulty, which leaves 20-40% with visual dysfunction but without I.D. In the case of weak binocularity and limited fusional reserves, the relative ease or difficulty with which literacy is acquired may depend on which eye is advantaged, and in which hemisphere language is located.

**Clinical interpretation of results provides greater depth of understanding**

In spite of the previous findings, further analysis of the data, and consideration of the results from a therapy practice perspective raises the prospect that dysfunction may still be a hidden, yet contributing factor in a number of key areas of learning.

Behavioural Optometrist (Howell 1990, p.12-15) considered that any one of these dysfunction variables could indicate a deeper, embedded problem within the integrated visual system, particularly where there was a cluster of imbalance or weakness. Furthermore, it can be argued that if there is an eye that is intermittently 'drifting' or out of alignment, then dominance pathways may be affected, particularly if the right eye is disadvantaged and latent dominance pathways to the language area are adversely affected.

**5.6.2 Justification for follow-up Intervention programme**

There are three difficulties in clinical interpretation. Firstly, some cells of visual variables were statistically not very robust as they have very small numbers, specifically saccades (6%), near point convergence (7%), acuity, fusion, and pursuits (8% each). However, according to the numbers and percentages in Table 1, in the above five visual anomalies, on average there are less than 4% of students with severe problems, although clinically this does indicate that one student is visually disadvantaged in fusion, acuity, and pursuits in every classroom of 30 students. However, in this study, when 'borderline' and 'severe' were collapsed into one
category, and/or allowing for the fact some students had clusters of problems, there was a potential of doubling the figure of those at risk, to two in every class.

A second point of difficulty was interpreting a test result which constituted weak binocularity, because one eye might be advantaged, or alternating dominance might occur. Consequently, it was important to take into account the issue of balanced binocularity and how efficiently the eyes function as a team, particularly in contra-motion for vergence control. These are ‘a priori’ conditions for normal function to provide binocular fusion. In the case of imbalance in phoria, for example, if one eye is weaker it can be disadvantaged if the individual is unable to aim accurately at the point of interest, thereby weakening eye ‘teaming’. Consequently, there is a theoretical probability that 50% of subjects with phoria anomalies will not be adversely affected in literacy skills due to an ‘advantaged’ dominant eye retaining the vital literacy link to the language area in the contralateral hemisphere. Conversely, with weak binocularity if the non-dominant eye is privileged, (for example, due to accommodation, vergence, phoria or untreated acuity problems), and natural dominance is upset, then any imbalance may be implicated if it co-occurs with LD.

The implication of these school survey results is that as far as diagnosis is concerned, unless it has been clearly shown that there is no deficit, it is not possible to assume anything about neurology. According to Luria’s model, higher cortical development depends on the integrity of lower cortical zones of the senses (Section 2.1). The data collected for this school survey study does not provide this specific information so any effects of a privileged eye on learning could not be established. However, there is a case for incorporating this ‘defining’ issue into the following Intervention Study by isolating the influence of dominance.

Thirdly, at best the school survey can be considered as only a rough indication of the size and depth of visual problems. This was only a 7-10 minute screening using simple tests, so that effects of fatigue, problems that require refined equipment for assessment, and other risk factors may have been overlooked. For these reasons, any pattern of association between dysfunction, memory, and literacy may have greater significance than that suggested by the reported results.

5.6.3 Links between visual function and levels of reading and spelling

Sub-question 2.
Do subjects with normal versus visual dysfunction differ in reading ability?
A significant difference of 7-8 months in reading age was found between subjects within the normal vision and visual dysfunction groups. Specifically, the mean reading age difference for the groups with normal compared with dysfunctional accommodation was 1.0 and 0.1, respectively, that is a difference of 0.9 years or 10-11 months between groups.

**Reading Comprehension**

The t-Test results presented in Table 6 showed there was only a 7 month (but significant) difference between the visual risk groups (normal and composite visual dysfunction) in terms of reading comprehension levels. In effect students with normal results in all visual variables were on average reading 1.2 years above their chronological age, whereas those with visual dysfunction were reading only 0.6 months above their age.

Of the individual visual variables, only accommodation showed a significant difference between groups in reading ability. Subjects with normal accommodation were reading on average 1 year above their chronological age, whereas those with deficient accommodation were only 0.1 year above their age, representing a 10-11 month difference between the visual function groups.

This statistic showed that not all subjects with visual dysfunction had reading problems, yet it appeared that the majority of those with LD (based on reading and memory ability) were potentially visually at risk. This is because, although central auditory processing could be a contributory factor in LD, these students would also need careful assessment of function, as this might likewise be a predisposing factor in their LD.

**Sub-question 3.**

*Do students with normal versus visual dysfunction differ in spelling ability?*

Although a small difference in spelling ability was found between the normal and visual dysfunction groups (i.e., -0.4 years versus -0.7 years, respectively), this did not reach statistical significance at the 0.05 level.

Dysfunction was not been shown to be linked with spelling. There was not a significant difference between the visual risk groups as identified in t-Test results reported in Table 7. There was a small difference in spelling age between the normal vision and visual dysfunction groups (-0.4 years and -0.7 years respectively), but this did not reach statistical significance. Although good readers tended to be better spellers and vice versa, comparison between reading and spelling numbers in Tables 6 and 7 showed a cross-over discrepancy. Table 6 showed 74
competent and 123 deficient spellers, a difference of 49 subjects, whereas in Table 7 the numbers were reversed with 137 competent and 58 deficient readers, that is with a greater difference of 79 between the two groups. This suggested that almost half of the advanced readers were weak in spelling, bolstering the spelling deficiency numbers. This could be accounted for by the ceiling effect of the 15 year cut-off point in the spelling tests resulting in the overall spelling levels being lower than the overall reading levels. Therefore, the lack of a significant link between spelling and visual function may be due to loss of discriminatory data due to the ceiling effect in the spelling results, and not because 'no link' exists.

The answer to the research question, whether there is any association between students with visual dysfunction and those with literacy problems, was inconclusive for spelling. This question will be further evaluated in the Intervention study, where patterns and any clinical implications will be sought before further inferences can be drawn from these data. As with Grounded theory, these questions are evolving from the school survey results.

5.6.4 Links between visual function and level of memory deficit

Sub-question 4.

Do subjects with normal versus visual dysfunction differ in memory span?

The groups of students with normal vision generally performed better on memory tests than the visual dysfunction group. The visual function variables included acuity, and of particular relevance to the research question, the four major variables of accommodation of vergence for distance viewing, of near point convergence, and of saccadic movements between pauses for foveal fixation were also included. These four visual variables were linked with each of the four memory variables. Binocular depth of field perception was also incorporated into this list as binocular vision was a pre-requisite in perceiving angled lines in near work, specifically, slanted ('running') writing.

Details of associations between memory and visual variables

Tables 8, 9 and 10 showed a positive association between individual memory variables of auditory, visual, and phonemic memory, and visual function. Gamma co-efficient of association tests, based on dichotomous measures showed significant differences between the two visual risk groups (normal and visual dysfunction) in these specific memory variables. Table 11 also showed significant differences between visual risk groups in terms of the four levels of memory, namely normal, single, double and triple memory deficits (gamma = 0.303, p = 0.014).
Results of gamma tests reported in Tables 8, 9, 10 and 11 showed significant positive associations between the memory span and five specific visual factors, and visual perception variables that are summarized in Table 12 below.

To assess whether the normal and visual dysfunction groups differ significantly in terms of memory deficit, the Mann-Whitney U test (the non-parametric equivalent of the independent samples t-Test) was employed at this stage of the analysis. As expected, the normal visual group tended to have fewer memory deficits than the visual dysfunction group \( (U = 1853.500, N_1 = 78, N_2 = 61, p = 0.020) \).

**Table 12 Visual variables linked to memory span in gamma tests**

<table>
<thead>
<tr>
<th>Variables</th>
<th>MEMORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>VISUAL Risk</td>
<td>Auditory</td>
</tr>
<tr>
<td>Acuity</td>
<td>0.400</td>
</tr>
<tr>
<td>Vergence</td>
<td>0.608</td>
</tr>
<tr>
<td>Near converge</td>
<td>0.465</td>
</tr>
<tr>
<td>Saccades</td>
<td>0.540</td>
</tr>
<tr>
<td>Binocular Depth</td>
<td>0.343</td>
</tr>
</tbody>
</table>

* Gamma coefficients previously reported in Tables 7, 8, 9 & 10

**Phonemic memory links suggest diagnostic value**

Triple deficit definitely incorporated phonemic memory which the therapist constructed (Section 4.5.1.4 and 5.4.5). Results suggested an indirect link between vision and literacy through the medium of phonemic memory which was shown to be a common denominator in all cognitive skills of reading and spelling \( (t\text{-Test }4.0,\text{ and }4.1\text{ respectively, }p = <0.001) \), deductive reasoning (gamma \(0.425, p = 0.0017\) ) and abstract reasoning (gamma \(0.494, p = 0.027\) ). Phonemic memory presents therefore as a diagnostic tool from which predictions about probable visual dysfunction might be made.

5.6.5a) **Effect of memory deficit on reading comprehension**

Sub-question 5.

*Is there a link between memory deficit and reading comprehension and spelling ability?*
Results showed that there was a significant effect of memory deficit, in that the greater the memory deficit, the lower the reading and spelling age. The largest differences in reading ability were between the normal and triple deficit groups (2.7 years) and between the single deficit and triple deficit groups (2.0 years).

The main difference between reading and spelling was the actual range of mean scores which in reading was from minus 7-8 months up to 2.3 years above chronological age, and for spelling from minus 1.5 years up to 6 months above chronological age. However, there was a similar difference in reading age (2.7 years) and spelling age (2.1 years) between the groups with normal memory and triple memory deficit. Therefore literacy levels appear to be closely associated with levels of memory span, in particular with phonemic memory.

Results of one-way ANOVA

In this meta-analysis of data one-way ANOVA was employed to investigate the effect of memory deficit on reading comprehension. The mean differences (in years) between reading age and chronological age for the four memory deficit groups are shown in Figure 4a). Results of the one-way ANOVA showed there was a significant effect of memory deficit ($F_{(3,129)} = 8.464, p < 0.001$). The reading age for the triple deficit group (N = 17) was on average minus 7-8 months below chronological age (i.e. -0.65 years); for the double deficit group (N = 43) the mean reading age was +0.25 years or 3 months above chronological age, whilst for the single deficit (N = 39) and normal memory (N = 31) groups the means were +1.34 years (one year 4 months) and +2.03 years or two years, respectively. It was concluded that there was an average more than two and a half years difference in reading ability between those with normal memory and the most severe memory deficits as indicated in Figure 9a).

Further, employing the Tukey post hoc test for unplanned comparisons, significant differences in mean reading ages were found between the triple deficit and single deficit groups ($p = 0.006$), between the triple deficit and normal groups ($p < 0.001$), and between the double deficit and normal groups ($p = 0.002$).

5.6.5b) Effect of memory deficit on spelling

Results of a One-way analysis of variance in Figure 9b) showed a significant effect of the memory deficit factor ($F_{(3,129)} = 10.001, p < 0.001$) on spelling. Employing the Tukey post hoc test (SPSS), significant differences were found between the normal memory range and triple deficit groups ($p < 0.001$); between the normal and double deficit groups ($p < 0.001$); and between the normal and single deficit groups ($p = 0.029$).
As shown in Figure 9b), the mean difference between spelling age and chronological age ranged from -1.45 years for the triple deficit group through to +0.6 years for the group with normal memory range.

In both charts (Figure 9) the reading age range is 2 years eight months (-0.7 to 2 years) and spelling age range is two years (-1.5 to 0.5 years). Spelling however, is between one year lower than reading age for those students with the most severe memory deficits, and eighteen months lower for those with normal memory span. The weaker spelling results could be accounted for in part by the ceiling effect on older students of the 15 year cut-off point of the tests.

From the therapist’s perspective, it can also be argued that although reading is linguistically and cognitively complex, it requires ‘recognition’ memory, whereas spelling is physically and perceptually more complex (as it involves analysis of auditory and visual details), and is a deeper ‘reconstruction’ process from the memory until there has been sufficient practice for writing of words to become a semi-automatic process, with minimal monitoring for errors.

5.6.6 Links between dominance, reading, spelling and memory deficit

Sub-question 6.

Do subjects with established right eye dominance versus mixed or unstable dominance differ significantly in reading comprehension, spelling and memory span?
There was a remarkably even distribution of stable and unstable eye dominance across the 277 subjects, with no significant links between eye/hand dominance and any of the other variables. As discussed previously, this may be due to lack of data on the functionally privileged eye in the case of weak binocularity, and this question is addressed in the following Intervention Study.

However, arm/hand dominance (the ‘latent’ dominant arm matched with the writing hand – Luria test) showed consistently significant differences in all the literacy and memory variables. In effect, t-Test results showed differences between established and mixed arm dominance groups in reading and spelling. Furthermore, cross-tabulations and gamma test results showed there were significant positive associations between arm/hand dominance and each of the four variables used to measure memory span (i.e., phonemic memory, auditory memory, visual memory, and memory deficit). Results showed that students with established arm/hand dominance tended to have better memory spans than those for whom dominance was mixed or not established.

Details of dominance, literacy and memory results

Statistical results have shown that arm/hand dominance is strongly linked to reading, spelling and memory span, whereas, eye/hand dominance shows no such effect as it is evenly distributed between the two groups, normal and deficit, in all factors. However these results were inconclusive because phoria and fusion likewise showed the same result and as these are integral factors in binocularity. Unless data indicate which eye is disadvantaged, in the case of weakened binocularity, then no conclusion can be drawn from the school survey results.

The strongest evidence of the effects of established arm/hand dominance was in t-Test result reported in Tables 6 and 7. These showed that, on average, the group with established arm/hand dominance were ahead of the mixed/unestablished group in mean scores of reading comprehension (1.6 years) and spelling (1.1 years). There were also significant positive associations between arm/hand dominance and memory deficit status (gamma = 0.662, p < 0.001), phonemic memory (gamma = 0.346, p = 0.005), auditory memory (gamma = 0.628, p < 0.001) and visual memory (gamma = 0.367, p = 0.008). Thus, these associations showed strong links between arm/hand dominance and all the key variables associated with learning.

To assess whether the ‘established’ and ‘mixed or not established’ arm/hand dominance groups differ significantly in terms of visual factors, chi-square was employed for the two-level, ordinal scales of eye/hand dominance (unstable/mixed or normal), depth perception (deficit or competent) and visual function (dysfunction or normal), with Phi as the frequency coefficient.
Table 13

Arm / hand Dominance by visual function and perception

<table>
<thead>
<tr>
<th>Grouping Variables</th>
<th>Arm / hand Dominance</th>
<th>Frequency coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mixed / Not</td>
<td>Established</td>
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<tr>
<td></td>
<td>established</td>
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<td>DOMINANCE</td>
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<td>dominance</td>
<td>Mixed / unstable</td>
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</tr>
<tr>
<td></td>
<td>%</td>
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</tr>
<tr>
<td></td>
<td>%</td>
<td>34</td>
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<tr>
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<td>%</td>
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</tr>
<tr>
<td>PERCEPTION</td>
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<tr>
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<tr>
<td></td>
<td>P</td>
<td>0.017 *</td>
</tr>
</tbody>
</table>

1 Arm / hand dominance measured on a two level ordinal scale: Mixed or not established & Established

* Significant at or beyond the 0.05 level

Results are ranked in order of Phi values, within eye dominance, perception and visual function categories.

Table 13 showed a small but positive effect in that 66% of subjects with mixed eye/hand dominance also had mixed arm/hand dominance, whilst 60% of subjects had established dominance in both factors (Phi = 0.257, p = 0.003). Within the relatively small number (33) of subjects with competent depth perception, 73% had established arm dominance but subjects with deficient depth perception were fairly evenly distributed in terms of arm dominance. As depth perception depends on binocular vision, then poor perception may relate to one disadvantaged eye, with the probability that this is evenly distributed, just as the eye dominance statistic shows, and yet it is a significant difference (Phi = 0.238, p = 0.018). Within the visual factors only two had a small positive association with arm / hand dominance, namely near point convergence (Phi = 0.222, p = 0.009) and vergence (Phi = 0.204, p = 0.017), this ‘vergence sufficiency’ is functionally associated with ability to move the eyes inwards and outwards in contra-motion to adjust focal length to maintain clarity of vision, when the eyes and visual scene are moving.

A limitation of this study is the small number of cases within some of the remaining visual variables, so their impact on LD is unknown as numbers would need to be more substantial in order to reach statistical significance.

In Chapter 6 the Intervention study methodology and methods are discussed in more detail, followed by Chapter 7 with results that address the key question raised in this School Survey, namely: Does it make a difference to literacy which eye is dominant?
Chapter 6
INTERVENTION STUDY – Method

6.1 Implementation of the Intervention Study

6.1.1 Addressing the question: Does eye dominance make a difference?
The focus of this intervention study is based on Educational Therapy practice and aims to evaluate the results of a treatment regime given to a group of participants in terms of O-m improvement, eye dominance and literacy gains. The School Survey showed there was an association between literacy and memory deficit (Figure 4), between visual dysfunction and memory (Table 12), and arm dominance (Table 13). The key variable was phonemic memory which is considered a specialised attribute of the left hemisphere. Furthermore, approximately half the School sample (47%) had visual dysfunction (Table 3), but only 30% of those had reading difficulties (Table 6). Double that number (62%) had spelling difficulties (Table 7), however it was apparent that a ceiling effect had biased the results, consequently this might be an exaggerated statistic. The emerging question was: if 50% of the school had visual dysfunction, but 30% had LD: What made the difference? This point brings eye dominance and pathways to the language area as a focal point in the investigation, and provides the rationale of the Intervention study. The investigative research model methodology being used in this study is expressed in terms of an empirical study.

6.1.2 Purpose of the Intervention study
The first research question of the thesis asks:
Is dysfunction a predisposing contributing factor in LD?
The underlying premise that emerged from Educational Therapy when supervising children in vision training was that weak binocularity is associated with one eye that is weaker in muscle tone or co-ordination. It is conjectured that this may upset natural eye dominance, as in the case of students with poor spelling, this is usually the right eye. There is, however, a 4% possibility that an individual may be naturally left eye dominant with the primary, expressive language area in the right hemisphere (Section 3.5.1, Corballis, 1991, p. 193).

The ultimate purpose of vision training was to ensure that both eyes had equal opportunity to develop an optimum range of fusional reserves and team together with improved stamina, range of movement and co-ordination, and to establish stable eye dominance. The purpose of the Intervention Study was to investigate the effects of improved function following vision training, including the outcomes of a week-long word skills programme. There were two
implications regarding improved function, one issue related to clarity of vision from being able to converge the eyes and focus clearly, and the second issue was whether the visual pathway to the language area was compromised or not. The ultimate issue is whether pathways to specialised areas are sufficiently well-established to provide ease of access to literacy skills.

6.2 Profile of participants and therapeutic considerations

6.2.1 Sample group’s composition
The term 'participants' is chosen in preference to the term 'subjects' which implies a more strictly conventional research design than is possible in this therapy setting. Individuals were enrolled by their parents, consequently, they were not a randomly selected group from the population as the term 'participants' might suggest, but were a self-selected sample from a subgroup of LD from a number of schools. The natural selection of this sample meant the researcher had neither control over characteristics nor age of the sample.

The Intervention study included all students attending the Educational Therapy practice within a eighteen month time-frame. There was a wide age range, from 6 to 21 year olds. The number of participants was reduced to 24 so that the mean age in each group for Phase 2 analysis could be more closely matched. Three cases aged between 18 and 21 were eliminated leaving Dominance Group 1 with a mean age of 12.8 decimalised years, and Non-Dominance Group 2 with a mean of 13.3 years. The reduction also helped to minimise the ceiling effect caused by the 15 year cut-off point in spelling and word recognition tests as found in older students in the School Survey.

Time spent by each student on eye exercises ranged from between ten hours over 2 months, and up to thirty hours over a 5 month period when a student had either achieved optimum vergence range and tracking speed, or, she/he felt they had reached a point where no further progress was being made, in three consecutive sessions. The word-skills workshop was thirty hours over a week for all participants. The only change to the Educational Therapy programme for the Intervention study was to run it in two stages. The week-long workshops were run only when a suitable group of 2 or 3 students, of compatible age and level of competence, had completed vision training and were ready to move onto the word-skills workshop.

6.2.2 Sample Group’s characteristics
The visual and literacy difficulties experienced by students attending the Educational Therapy practice affirmed the findings of the School Survey, where LD were found to be associated with
dysfunction. This common pattern ultimately contributed to variable or degraded central (foveal) vision, resulting in difficulty in maintaining focus on small details of print with both eyes simultaneously. As aspects of dysfunction were not detected by standard optometry assessment, or school vision screening in the school survey, all participants were assessed by a Behavioural Optometrist prior to treatment.

Participants' common pattern of literacy, memory and physical deficits
Common basic abilities problems exhibited by students of all ages have been threefold: firstly, limited auditory and / or visual processing capacity that affects memory span; secondly, difficulty in transforming visual / auditory information automatically delaying naming speed, the acquisition of phonics, and phonemic memory span; and thirdly, difficulty processing sequentially ordered information into an integrated, relational context. Eye-hand co-ordination, motor-sensory balance and co-ordination (dyspraxia), together with disordered work approach, study habits and logical operations often co-occur with a higher than average error rate in their work, together with behavioural signs of anxiety or discouragement.

Physical anomalies characteristics of students with LD
Apart from dysfunction, the researcher's background as an occupational therapist led to the observation that the majority of students with LD have a pattern of poor balance, gait and posture within a common pattern of physical asymmetry. A disturbance in the bio-dynamics of gait can be seen from pronation (foot rolling inwards) at the subtalar joint (arch / ankle assembly of bones and joints); leg pain after sport is often reported; and curvature, torsion or bend of the spine associated with asymmetry of tight postural muscles. The latter tends to impact on proprioceptive and vestibular senses in association with function, postural reflexes, balance and co-ordination. Other signs include misaligned hips, painful sacro-iliac joint of the lower spine, and one raised shoulder (tight trapezius muscle). Facial asymmetry from lowered muscle tone on one side; imbalance in the jaw (temporo-mandibular joint) affecting the bite; and weakness of one or both eyes may also be diagnosed.

6.3 Intervention as a 'study' within an Educational Therapy practice
The two-stage Intervention study was conducted as a normal part of therapy (Section 5.3.2b) in terms of the evolving order of the research plan and collection of data. Statistical analysis followed the unfolding results and interpretations of the archived data, during the write-up. Analysis of the results was by the quantitative statistical method of t-Tests, and further post hoc analysis.
The study was essentially a review of Educational Therapy practice at the time. It was based on the ethical principle that each student should have equal opportunity to undergo the same programme, under normal working conditions, with no manipulation of treatment conditions or controls, other than that required to implement the programme. Constraints, as a sole practitioner, meant it was not possible to use formal research methods, as both ethically and practically the participants could not be manipulated to create control groups. Post-tests at each stage were not feasible either owing to availability of the independent examiner, and the differing lapses of time (generally about four months) between completion of eye exercises and the word-skills programme. It was reasoned that the four months would be mediated somewhat by averaging results, so that the significance of results was not compromised.

6.3.1 Research design

In terms of the research design, there was no selection by elimination as this study was simply a part of the normal therapy programme. Except for completing vision therapy first, the therapy programme was not manipulated by the researcher/therapist, and the division into two dominance groups was also by natural selection as this depended entirely on whether a student had achieved the rigorous criterion of stable eye dominance (in Section 6.5.1).

**Intervention Stage 1 Eye exercises**

Pre-tests of function were based on two key eye exercises. Firstly, an exercise that determined a controlled vergence range while maintaining binocularity on a tranaglyph; and secondly, a dichoptic computer-based tracking exercise in which each eye had a different task with different levels of difficulty (see a description of eye exercises Procedure 6.6.3). Eye dominance measures were not based on traditional tests of referenced / preferred eye in monocular tasks because these were found to be too variable to be reliable and were discounted. Instead, records were kept of the weaker eye that had lost foveal fixation in pre- and post tests, and it was this evidence that was recorded as either right or left eye advantage. On-going records were kept of tracking scores in order to compare each eye's results. The first and final record of vergence range and tracking scores were used as pre- and post-tests.

**Intervention Stage 2 Word-skills workshop**

Data from Stage 2 of the Intervention consisted of pre-tests of literacy and memory with post-tests at the completion of the word skills programme by an independent examiner. These pre- and post tests included spelling, word recognition, oral reading, and reading comprehension, as
well as visual, auditory, and phonemic memory span, and memory deficit status. All data consisted of raw scores as interval scales.

The following Figure 10 Research Model for Intervention Study provides a research model outline of the therapy stages, with two statistical analysis phases.

**INTERVENTION STUDY Research Model**

Sample size

24 Ss

Pre-tests

Visual Memory Literacy

INTERVENTION Stage 1. same Eye Exercises for all

BINOCULAR - Tracking Accommodation Vergence

INTERVENTION Stage 2. same Memory & Literacy for all

Two-tiered Analysis

Post-tests

Phase 1

Paired-samples t Test - T value 2.086

significant difference between pre & post tests

Dominance direction

No change left eye dominant

9 Ss

Change to right eye dominant

15 Ss

Post-tests

Phase 2

Independent-samples t Test - T value 2.086

significant difference between pre & post tests

Post-tests

Same 10 variables

Figure 10. Research Model for Intervention Study

Figure 10 illustrates the order of implementation of the study, namely visual exercises and a word skills programme, and analysis of data. Once all participants had completed both stages, pre- and post-test records were archived for later analysis. In the initial phase of data analysis, paired-samples t-Test was employed to compare pre- and post-tests on the combined outcomes of eye exercises and word skills programme for the whole sample group. For the second phase
of analysis, an independent samples t-Test was used to determine if there was a significant difference in literacy outcomes between subjects who had achieved right eye dominance and those who retained mixed or left eye dominance. The division into two dominance groups was determined by the results of the eye exercises (see 6.6.5), and therefore outside the control of the researcher.

6.3.2 Research plan and benefits
The two-stage visual and word skills intervention, with a two-tiered analysis of data achieved two results. It served to answer the question that arose from the School study, namely: Does right eye dominance make a difference? Secondly, that balanced binocularity and stable visual dominance represented a fully functioning balance, strength and co-ordination, by providing a measure by which to answer the main research question: Is dysfunction a predisposing factor in LD? The Intervention itself operated at four levels. For participants it provided an opportunity to overcome visual dysfunction. The short word-skills intervention provided an equivalent educational experience for all participants, of all ages, to improve their learning skills. Analysis of results provided z means by which to estimate how changes to function had influenced LD, whereby ‘successful’ results would be a validation of the practice. Insights were also provided into possible causes of the ‘less successful’ results for the remaining participants, so that this information was used positively to extend the scope and outcomes of present day Educational Therapy practice (see Chapter 8, Case Studies).

6.3.3 Data collection
Data were compiled from pre- and post-tests from records kept during therapy. Therapy pre-tests were simple tests of key function, memory, and standard tests of literacy conducted by the therapist/researcher (see Section 4.5.1). Literacy post-tests were conducted by an independent examiner. Records were kept of each student's eye exercise responses during visual training, together with initial assessment data and post-test of literacy results from the word-skills workshop. Records were archived until analysis for this thesis was conducted. Just as in the School Survey, statistical method has evolved around results and interpretations of the data, as an examination of common patterns in the findings.

6.3.4 Data analysis
Data analysis fell into two phases. Phase 1 of the analysis was to determine the nature and size of any changes that followed vision training, and the word skills workshop. It became apparent when studying the data spread-sheets, that apart from general improvement in control and literacy, a third factor appeared to have an influence on results, depending on which eye was
'disadvantaged' before and after vision training. This observation aligned with the question arising from the School Survey, namely: Did literacy competence depend on which eye was advantaged, in the case of imbalance? Consequently, a second tier (Phase 2) of statistical analysis was used with the before and after results of vision and literacy tests, by dividing the sample into two groups according to post-intervention dominance status criteria. These were, firstly, binocular overlap of 24 dioptres or more in convergence and divergence on tranglyph measures; and secondly, right eye tracking score 20% or more greater than the left eye on a computer tracking game. This post hoc allocation of group based on results solved the problem of how to evaluate any differences in literacy outcomes following vision training and newly established dominance. In effect, it was to determine whether differences in literacy gains between the two groups were associated with a change of eye dominance.

6.4 Assumptions implicit in the Intervention Study

The cognitive framework of the Educational Therapy programme was described (Section 2.2.3) as operating on the principles of motor-sensory-cognitive 'connectivity'. This concept has been synthesised into a Developmental Model of LD based on three assumptions. Namely, it is concerning a triple mismatch; between the two eyes; the relationship between visual and auditory input; and between the two hemispheres.

Therapeutic consideration concerning the impact of dysfunction on sensory input to the associative neural networks and higher learning, has led to a number of assumptions of developmental implications. The following six assumptions, on which Educational Therapy is based, are the product of the therapist's experience and probabilistic reasoning (Section 2.2.3). These assumptions are supported by principles discussed in the therapeutic application of Luria's model (Section 2.2.1); and with some support from trends in the Literature Review (Chapter 3). However, these assumptions are not implicit in current scientific theory of LD (see Therapeutic working model Section 4.2.2). The assumptions also act as an interpretive, 'functional' extension of the Definition of Terms (Section 1.5) in exploring the impact of o-m dysfunction.

Assumption 1

A key movement in reading is the left-to-right movement of the right eye.

It is reasoned that any imbalance that impedes eye movements must have a negative effect on the visual system as a whole (Palassis, private communication, see section 4.5.1). In particular, vision training shows the right eye's movement from left to right to be the most vulnerable to
disturbance, because it is the ‘leading’ movement when reading English. The abduction movements needed for reading are more difficult to control than adduction (as the right eye sweeps back to the beginning of the next line of print). Table 2 shows the most common presenting problem of the majority of students is convergence insufficiency, which appears to also compromise eye tracking. Likewise, the ratio between convergence and accommodation ultimately leads to unreliable foveal fixation of one or both eyes, as noted in the case of foveal suppression (Section 3.2.1d). A linkage is assumed between all elements of the interactive visual system, because improvement in one area is generally reflected in gains in other aspects of function. It can be argued, that neurologically, intermittent discontinuity of the right eye’s visual input to the left hemisphere language area, is a form of hemispheric neglect. This, in turn, may result in deficits to varying degrees of phonological awareness, slower development of phonemic memory, word recognition, and praxic skills. These functional deficits are commonly found to co-occur with dysfunction in students being assessed in the Educational Therapy practice.

**Assumption 2**

*All postural, proprioceptive and vestibular senses are associated with auditory and, visual senses as an integrated whole*

Practical remediation of common physical anomalies, of pronation of the feet and spinal muscle imbalance, has reduced the time and effort required to achieve normal visual function (EGB therapist). Orthotics and cranial osteopathy treatment appear to ‘relax’ what are possibly mal-adaptive adjustments by correcting postural anomalies, muscle imbalance such that improved proprioceptive feedback facilitates greater balance and control of the visual system. Improved results support the adoption of this holistic management approach (see Case studies RW and GK, Chapter 9). Other benefits are the students’ general level of physical comfort, improved sleeping patterns, together with ease of movement which helps sport. Taken together, improvement of these physiological problems appears to create what can be described as a ‘change of mood’ in the student.

**Assumption 3**

*Binocular balance as a precursor of bi-hemispheric integration of visual information*

In vision training, the goal is to achieve balance and co-ordination in image, speed and co-ordination to provide sufficiently similar visual input from both eyes for foveal fusion (Emsley 1977), and for bi-hemispheric integration of visual information required for literacy skills. The comparative case studies between ML and LW in the Intervention study illustrate this point. In
effect, it provides both depth of field perception as three-dimensional vision (stereopsis), as well as balanced visual input for information processing in both hemispheres.

The right hemispheric "global" processing provides spatial awareness for feedback to direct eye movements (Blanke, 2002). Whilst access to the left hemisphere's specialised areas allows for sequential processing, links with phonological awareness and language, and shapes recognition as sight word recognition (Corballis 1991, Dehaene 2003). Handwriting and eye-hand coordination also incorporates left hemisphere praxic skills for motor-planning to implement intentioned actions (Corballis 1991). Binocular teaming is also assumed to include the integration of the magno- and parvo-cellular pathways for integration of peripheral and foveal vision from each field of vision, along contra-lateral pathways to each hemisphere (see Section 4.2.2-2). The importance of the right eye pathway is underscored by the natural progress towards greater left hemisphere specialisation with experience and maturity (Luria, 1973; Purves (1994); Shaywitz 1992).

Assumption 4

**Binocular balance with foveal fusion provides bi-hemispheric discrimination of fine detail needed for reading print.**

When working to achieve balanced binocularity with eye exercises using stereoscopic glasses, it becomes apparent that eye-muscle balance and accuracy allows detail-sensitive area of the retina (fovea) to be aimed accurately on the point of interest, for print to be brought into clear focus in reading and writing. Adequate aim and focus is needed for foveal fixation and the fusion of each eye’s two fields of vision, in order to discriminate fine detail like letters for word recognition, and to combine the split foveal image of each word under the demanding conditions of reading (Shillcock 2000, 'split processing model'). This includes eyes moving in unison, in contra-motion, in saccadic jumps, and fixations, whilst scanning from left to right along a line of print, at speed.

Assumption 5

**Foveal fixation and fusion is needed for attention to detail for working memory**

Students demonstrate that unreliable memory recall and recognition, poor attention to detail and difficulty with learning phonics are three key features of LD. These features may be traced back to lack of foveal fixation and fusion. Foveal aim and focus must be adequate for detail to be registered in Sensory Information Store (SIS, see Sections 3.2.2, 3.3.3 & 3.4.1) for access by the working memory in the first instance and to match this against incoming information. In the second instance it is a point of access for long-term memory recognition. Otherwise
dysfunction and perceptual deficits may be a contributing factor, not only in having a poor attention span, but also in poor attention to detail resulting in memory deficit for the symbols of literacy.

**Assumption 6**

*Visual-auditory synchrony provides access to sensory network and phonemic memory, the basic units of literacy.*

If information about the shape and sequence of letters is not matched with phonological detail in the associative area between the visual and auditory systems, this may disrupt the acquisition of phonemic memory. It is assumed that any differential delay and inconsistency between the visual and auditory modalities may then fail to bond as two (dyadic) aspects of phonics that are the ‘building blocks of literacy’. In effect, a slowed rate of processing might impede learning and prevent the ‘automatic’ response to phonics, and ‘naming’ speed required for fluent reading.

**Assumptions implicit in a Developmental model of LD**

A synthesis of these assumptions points to an underlying developmental model of LD that is based on a triple mismatch. That is firstly, a mismatch between the two eyes; secondly, between the two hemispheres for bi-hemispheric integration of visual information; and thirdly, between visual and auditory associative networks for phonemic memory. These steps towards a Developmental Model of LD will be discussed further in Chapter 9.

### 6.5 Procedures of diagnostic and therapeutic value

**6.5.1 Visual therapy**

The following comprehensive description is given of the exercise procedures in order to clarify for the reader the basis on which the therapist’s assumptions are based. Students are prompted to report what they see is happening on the optometric equipment during ‘therapeutic challenge’ of eye exercises. This form of ongoing bio-feedback guides student’s awareness and the therapist’s conjectured interpretation and response, in a trial and error process of the increasing refinement of ocular-motor control by the student.
Key observations - Three main visual anomalies

Common anomalies became apparent in vision training, specifically in vergence, fusional reserve assessment, and tracking speed, which may reflect on the meaning of 'dominance'.

Firstly, when one eye was invariably weaker than the other, with a restricted range of movement, and lack of tracking accuracy particularly when fatigued, visual fatigue, physical discomfort, wriggling and distractibility become more evident. Then hand writing becomes noticeably untidier, drifting away from the left hand margin of the page. As the weaker eye becomes tired, red and teary eyes show signs of eye strain with the increased accommodative effort to compensate for weak convergence, with resultant blurred images.

Secondly, although some students were 'right-eyed' in convergence, with the image of letters seen by the right eye retaining fixation under fusional stress, this 'leading' right eye changed to being the left-eyed in divergence. In effect, students were right-eyed for near and left-eyed for distance.

Thirdly, once both eyes were equal in range of vergence control, stamina, and tracking speed in a computer generated exercise, then (generally) the right eye was capable of up to 20% higher scoring capacity than the left eye, even though it would be expected that the eyes would have equal scoring ability in a tracking exercise.

6.5.2 Aiming for optimal visual function

The aim of eye exercises was to strengthen binocularity with balance between the eyes in stamina, tracking, and vergence control for each eye. It was found that even small anomalies compromise binocularity, so that subtle dysfunctions were going unnoticed by the individual. But stereoscopic glasses allowed the student to monitor what each eye was seeing on the tranaglyph equipment. This consists of two moveable slides with red and green elements for training eye teaming skills in convergence and divergence. In effect, the student is learning to improve muscle control from the feedback this equipment provides.

An unexpected outcome of vergence and tracking exercises was an improved binocular overlap of visual fields, accompanied by the development of stable (usually right) eye dominance. Presumably this occurs when the visual system achieves adequate ocular-motor balance, range of movement, and binocularity.
6.5.3 Visual exercises, instruments and measures

This section provides a description of the exercises, instruments, and measures involved in vision training. This was standard practice for all students, involving the development of a full range of binocular vision in both convergence (eyes turn inwards in contra-motion for near work) and divergence. Training also involved a computer-based tracking game which is dichoptic in that each eye had a different task, in order to develop accuracy and stamina, together with bi-hemispheric integration required to play the game efficiently. Theoretically, the ultimate purpose was that, by having both eyes equal and teaming together with an optimum range of fusional reserves, the neural pathways from each eye provided optimal visual input to associative networks. However, under normal conditions, it is not possible to determine whether both eyes or one ‘efficient’ eye, is being engaged in the process of reading. The anaglyph (one slide) and tranaglyph (two moveable slides) and stereoscopic glasses are useful tools to uncover what is happening in vergence exercises, as each shows when parts of images seen by one eye ‘drop out of view’ (Section 3.2.d).

The complex of pathways between retina and visual cortex are expected to provide continuity of images, even if fusion is not always possible. But this does not seem to apply in the case of fine, foveal vision when students report what appears to be visual suppression of letter details. This tends to happen when a weaker (usually right) eye drifts outwards, fine detail then blurs and is lost when such binocularity is challenged.

6.5.4 Intervention Study - Equipment and therapy tasks

a) Phoria pre-test

Equipment – Howell near phoria test card

A pre-test of phoria was administered prior to each vision training session, using the Howell Test Card and one prism lens on each eye, to measure the tendency for the eyes to deviate from their normal position for visual alignment, from the position of functional rest (Emsley, p.40). Notably, which eye was most out of alignment, or both eyes were drifting outwards (exophoria) or crossing (esophoria).

The phoria test was a key gauge of progress. It was also an alert signal if the student had not been wearing prescription glasses for near work, or not wearing prescribed orthotics, or had a stiff neck from a poor sleeping position. Vision training generally involves a number of earlier exercises until the student’s visual system is able to manage vergence and computer tracking exercises. This is because tiring an already stressed system, risks driving the visual system into making further ‘mal-adaptive adjustments’.
b) Intervention - description of vergence exercises

Equipment - red/green Bernell Tranaglyph slides viewed through red/green stereoscopic lenses. Vergence exercises involve viewing an image though two overlapped tranaglyph slides, one with red images, the other with green images, through stereoscopic glasses. As the two colours overlap, they combine as black thus completing the composite image, which is then perceived as three dimensional. In order to exercise a weaker right eye for example, one coloured slide is moved laterally, such that the right eye must make the adjustments needed to maintain 3D vision. The following outcomes of vision training are largely interpreted from the students’ responses.

Record keeping

Five measures are routinely recorded at each stage of the exercise. Firstly, with the tranaglyph slides in neutral overlapped position, students are asked to identify the small off-centre R & L letters, and report which is the clearest (preferred) eye and if one was moving or fading. Secondly, when the student is able to report that the central circle containing a line-drawn cartoon figure is perceived as ‘floating’, then global stereopsis is deemed to be established. The 3D effect may take time to emerge, indicating that fusion is not reliable, or constant. In the centre field are five words arranged vertically, two red, two green and the middle one printed black. By covering each eye alternately, the student becomes aware that two words are seen separately by each eye, and one word seen by both eye together.

Once the student is clear about what they are seeing, and can monitor and report changes in what is being seen, the slides are moved inwards to converge the eyes. The third measure is the point, indicated by a pointer along the dioptre scale at the bottom of the slide, at which one set of the central words fade or disappear. This phenomenon is recorded as foveal ‘slip’, blur or ‘suppression’ of the eye that had previously been seeing that word. The fourth point to be measured and recorded is when the large circles split into double vision, recorded as global vision break. Lastly, the slides are returned slowly towards neutral position, and the point at which foveal and global fusion is regained, this dioptre value is recorded as the outer range of foveal fusional reserves.

The therapeutic challenge is to sustain the tension between the eyes in order to hold the image together, as balanced binocularity and fusion, as the eyes converge or diverge. As a general rule, there is a positive ratio between the increased size of the overlapping fields of vision (fusional reserves) and an improved ability of the right eye to sustain clarity and fusion. At this stage, the left eye becomes more ‘recessive’ and more likely to be the first one to break letter
fusion, thus demonstrating superiority of right eye function within balanced binocularity. This occurs particularly in divergence which is the harder visual factor to train, when both eyes move outwards in contra-motion. The ability of the right eye to consistently retain foveal fixation can therefore be considered as being ‘stable right eye dominance’.

The therapeutic advantage of the stereoscopic glasses is that once the student understands that the image should look as if it is ‘floating’, within a short period this is what is seen, as the student’s imagination facilitates the brain’s scanning processes of ‘unconscious vision’ (see Weiskrantz, 1986, Section 4.3.1a). For students unable to regain stereopsis, the slides are returned towards neutral until fusion is achieved. Emsley’s description of a stereoscope (translagram) is that “When the slides are moved laterally the student makes a corresponding movement of convergence or divergence in order to maintain the simple impression of the vertical display” and “retains binocular fixation at the highest grade of binocular vision and fusion, ... and sees with both macular and foveal vision at the same time” (Emsley, 1977, Vol 2, p. 67). Younger children unselfconsciously signal they have fusion by trying to ‘catch’ the 3D image in the air.

The therapeutic value for a student with weak binocularity is that these controlled exercises provide bio-feedback about how the eyes are functioning by studying changes in the image. This helps him/her to develop both perceptual awareness and muscle control to achieve fused binocular vision. The therapist’s role is to ‘hold the space’ while the student attempts to solve the problems implicit in vision training. The role is also about being able to coach the student over difficulties by having a thorough understanding of how the exercise feels, while following and checking each response to ensure understanding and accuracy of the student’s response and the therapist’s interpretation.

The diagnostic value of anaglyphs (a single red/green 3D slide) is that the student can discriminate the particular details seen by each eye, and learn to attend, monitor and report what is happening. If images disappear, or alternate between left and right eye, the student is able to report which eye has ‘lost’ the image, or when the image splits into two as double vision. Both therapist and student can keep track of which eye was losing foveal fixation, or which eye was ‘advantaged’ and able to sustain letter fixation. In this way stereoscopic glasses become the means of uncovering and correcting suppression of the (generally) right foveal field of vision, and loss of right eye dominance. What became apparent was the ease with which the emergent ‘pattern of dominance’ was held by the right eye once stamina improved and vergence range increased.
c) Eye tracking exercise – equipment and therapy tasks.

Old model Computer – for slower speeds to facilitate perceptual challenge.

Software - a public domain bat and ball game

Scoring calibrated to reflect speed settings, to ensure internal validity of scoring values.

The computer-based eye tracking exercise is a totally dichoptic exercise as each eye has a different task, with different levels of difficulty, but the eyes must work together with bi-hemispheric feedback, in order to track both ball and bat simultaneously and play the game efficiently. Red / blue glasses control what each eye is able to see, such that one eye is following the red ball which is the more demanding task, while the other eye monitors the blue bat. The glasses are reversed at the end of each game to ensure balanced treatment effect.

The tracking exercise is a modified public domain bat and ball computer game. The red ball movements are computer generated vertical and oblique movements, while blue target 'paddle' is controlled manually. The player uses two cursor keys to control a blue bat in the appropriate direction along the bottom of the screen to intercept the ball. Tracking the red ball is the more demanding task as the movements are computer-generated and consequently unpredictable, faster, with varying angles of descent. The use of stereoscopic glasses separates the two visual pathways which in principle requires bi-hemispheric feedback to combine aspects of the exercise, so that a student is able to anticipate the trajectory of the ball, thereby maintaining control of the game with appropriate movements of the bat, with increasing speed as skills develop.

**Tracking – the therapeutic challenge**

The therapeutic challenge was controlled, by setting the initial ball speed set at a slow enough pace for the student to maintain control while building up awareness of various elements of the game, and devise 'problem solving movements' and specific skills to play the game efficiently. These skills are directional awareness for left-right manual cursor control; increased speed and diminished effort of middle finger movements (the finger that controls the pencil when writing); the expansion of vertical and lateral fields of vision to encompass both targets simultaneously so the angle of approach can be judged to position the bat correctly; the skill to identify and focus on the ball, and maintain attention on this moving target; the ability to develop the stamina to sustain accurate tracking movements; and to attend to two separate targets through two separated visual inputs, thus integrating responses from both hemispheres in order to track the diagonal line of the target as smooth, semi-automatic movements. Most students with weak binocularity have problems with some and sometimes all of these skills that would normally be expected to be automatic. These points were gleaned from a therapeutic
'task analysis', and observation of students' frustration associated with new tasks, and their emerging skills as they learn to play the game efficiently.

The advantage of this exercise is that it provides on-going active involvement in the time on the computer. Alternating the coloured lenses ensures that each eye is treated equally, it provides the opportunity for improvement of the weaker eye by functional discrimination between the two eyes, and simultaneously promotes binocularity by alternating the pathway being exercised. In contrast, the traditional way of exercising a weaker eye is by 'occlusion', namely, by patching the stronger eye for a brief period each day.

Theoretically, the value of this dichoptic exercise can be considered to be fourfold. Firstly, it provides equal but individual opportunity for each eye to achieve optimum performance. Secondly, it challenges bi-hemispheric integration by dividing the task between the two eyes. The difference in task complexity and attention level is thought to allow the brain a comparison between the eyes, and the various pathways, ultimately leading to emergence of the naturally dominant eye within a balanced partnership of the two eyes. Thirdly, the perceptual complexity of tracking a diagonal target, like depth of field perception, does requires bi-hemispheric integration. This is the 'what is it' left hemisphere specialisation of detailed shape recognition, integrated with the 'where is it' spatial facility of the right hemisphere, that provide fine tuning feed-back for timing and co-ordination. Fourthly, and possibly the most fundamental, the simple nature of the stimulus and instant feedback allows the subject an opportunity to improve concentration and discipline in a specific task, under his/her own volition, thus improving visual attention, visual processing ability, directional sense, and eye/hand co-ordination. 'Finger tapping speed' is a standard test of physiological maturity, and this exercise encourages this skill, as reflected in the speed of finger movements on the direction keys.

Eye tracking -- change of functional dominance

For the Intervention Study, the functional division of the two pathways in vergence and tracking exercises provide an opportunity for each eye to be strengthened individually by balancing the challenge, while at the same time, integrating the input from each eye at a hemispheric level during the process of improving efficiency in 'playing the game'. Although tracking is a very simple exercise, a contest between the eyes in terms of each one's scoring capacity becomes the focus of the exercise for student. The general pattern was that initially students' scoring capacity was greater for the left eye. However, as balance and vergence improved, in particular the degree of fusional reserves, the scoring capacity of the right eye increased and overtook that of the left eye, up to and beyond 20% difference in scoring capacity between the eyes.
6.5.5 **Word skills workshop -- exercises and measures**

The following description of the word skills program provides a therapeutic 'task analysis' of key activities to demonstrate the learning 'processes' involved in each skill. Each student's performance profile was assessed with the same measures as employed in the School Survey. These were recorded in the initial assessment and used as pre-tests in later statistical analysis. Prescribed lenses by the Behavioural Optometrist, and orthotics by the podiatrist, were already in use prior to starting the programme. It has been found that a focus using a 'from-bottom-up' development, of stable gait and improving visual function, enables greater speed and ease of establishing basic abilities in Educational Therapy, when attempting higher-order cognitive skills.

**Word skills workshop**

The word skills workshop was designed to develop the basic motor-sensory-memory and cognitive abilities inherent in literacy skills. The following five exercises a) trampoline, b) phonological skill, c) auditory to visual mapping for phonics, d) reading comprehension and e) visual perception, were designed to expand visual memory and imagery, auditory and visual relationships of letter / sound and spelling rules, and reading in context. Trampoline exercises develop praxic skills and co-ordination as well as sequencing skills and 'clumping' information into patterns and sets, as a 'lead' into spelling. Visual perception helps to develop perceptual analysis for logical categorisation into spelling patterns. The week long programme consists of structured mini-lessons for a small group that allows for individual rehearsal and although it may seem intensive to the students initially, they soon settle into a routine and pick-up speed because each activity is developing the same skills from different directions, 'around the synapses', and so this tends to 'fast track' each student's word skills and reading comprehension.

a) **Trampoline exercises**

These include balance and motor-patterning for bi-hemispheric integration with cross-patterned movements of four quadrants of the body, and motor planning for following instructions. Cross-patterned marching is usually poorly established in this group of students, and is apparent from the lack of synchrony between right arm / left leg crawling pattern which is normally developed in early childhood, and may be disrupted by lack of physical symmetry. The physical medium of the trampoline allows for monitoring and guidance in concentration, mental 'task preparation' with an awareness of patterns of sequential movements. The Doman and Delacato (1960) sequencing exercises were used, with additional modifications by the therapist. These are a set pattern of questions for coaching students to develop an orderly approach to listening...
implementing instructions, to develop auditory memory span and chunking of information, in preparation for cognitive skills of phonological processing and visual perception of word patterns; and in patterns for motor planning which encourages physical praxic skills.

b) Phonological awareness and visualisation

Auditory-to-visual processing and vice versa is based on the same principle of a hierarchy of sensory, perceptual and bi-hemispheric integration with higher-order cognitive skills. This is applied to auditory awareness and analysis of sounds in words, sound blending to make words, and conversion into visual symbols of letters in sequence, increasing auditory and visual memory span and development of visual imagery to analyse and categorise common groups of letters into spelling patterns. Phonological exercises are an expanded modification of Rosner phonics (1964) which is presented in a dichotic listening condition. Kimura (1961) used stereophonic headphones to send different auditory signals to each hemisphere. This principle is adapted in that ‘masking’ music and verbal instructions are simultaneously presented to each ear, by having a different input into each ear with soft, relaxing music ‘masking’ one ear while the student listens to questions put by the therapist into the other ear. For example, the student is asked to “Repeat the word ‘blend’, now say it again without the f” (bend). The process the student is guided into using is to “sound out and count each letter onto your mental screen”. Looking up and imagining what the letters would look like if they were visible is the mental trigger for visualisation which helps to bond auditory to visual signals. The ear piece is then changed to the alternate ear after each group of four questions and answers.

The therapist’s rationale for this exercise is that two levels of input in this dichotic exercise (like the dichoptic eye exercise) provides stimulation to each auditory pathway, separately but equally, to compensate for any developmental imbalance and possible sensory neglect of an auditory pathway owing to earlier problems like middle ear infections in one ear. It was reasoned that this process might ‘uncover’ the latently dominant ear, and in the manner of the survival of the fittest pathway, allow this to become functionally dominant thereby leading to an improvement in information processing efficiency. The probabilistic reasoning behind the dichoptic and dichotic exercises is based on laterality effects, namely of superior right ear and eye to the ‘dominant’ left hemisphere (Broadbent, 1954; Corballis, 1991; & Walsh, 2000; Gazzaniga & Sperry, 1962; Kimura 1961; Shallice et al. 1989).

c) Auditory to visual mapping for phonics

A modified version of the Fidel phonics chart (from Words in Colour, Cattegno, 1962) is used to present each word by tapping out letters from columns composed of all the letter variations
of each vowel and consonant. Students take it in turns to sound out the letters, blend into a word, then write the word and correct any errors promptly. Blending nonsense words is a follow-up exercise from a ‘flip book’ which is a notebook cut into three separate columns, consisting of front consonants, vowels (number of variations with example), and ending blends, as well as “bossy E” patterns. Spelling is presented orally one letter at a time, which the student visualises, blends and holds for four seconds “to burn it into their long-term memory”, then s/he writes the word down, and the total word list of up to twenty words is tested at the end of the period. “Unpacking” words written on the blackboard is a group activity, vowels and syllables are marked, spelling exceptions are identified, and the first student to ‘crack’ it earns a point. Tackling a package of key words intensively from these four different directions has proved to be a very efficient and thorough way of covering a lot of work in a short time.

d) Reading comprehension
Initially, a Gap reading text is presented orally as a group exercise, with the therapist reading each sentence, saying “ugh” for the missing word, which the students take turns to provide verbally. Mini-lessons are used to bridge grammatical blocks. Prepositions are a particular problem as they relate to depth perception which is generally weak for these children. The Gap reading exercise is redone as homework and marked as a group next day.

For students Year 6 and upwards, topic sentences are introduced with the therapist modelling the logical processes, and students take it in turns to identify key words and phrases. This activity is extended into note taking, condensing and expanding texts, and writing a small assignment, and tested next day. For High School students it is extended further into working through an essay format, and study discipline for exams. Small ‘model’ exercises are completed for homework.

e) Visual perception, logical analysis and tables
Visual perception games involve sequential order, patterns, categorisation, matching, and creating sets. Logical analysis is provided from a Basic Thinking Skills manual (Hardenek, 1977) as a group activity. Times Tables are presented in both multiplication and division form on a four-way chart which accents the patterns of numbers and assists visual memory which is more reliable and permanent than learning orally by rote. Homework for four days of the week’s programme amounted to about an hour for prep students, 2 hours for those in middle school, and 2-3 hours for high school students and adults.
**Measures**

The following is a brief summary of measures which were the same standardised tests as were used as in the School Survey (Section 4.5.1).

Literacy tests included Schonell spelling and word recognition, Holborn oral reading and Gap/Gapadol reading comprehension tests, the raw scores of which were all interval level measurements. By definition all students in the Intervention Study were performing below average, and the purpose of the study was to compare pre- and post-test Intervention results.

Memory tests contained a different number of elements in the test. As outlines in Section 4.5.1, measures were adjusted to a possible total of 15 for the purpose of comparison in the Intervention Study.

*Visual memory* (Taylor and Bender 1952): Students were required to reproduce a sequence of five geometric shapes. Perceptual errors were taken into account by awarding a point each for order and orientation, giving a possible total of 15.

*Auditory memory* (Wechsler auditory digit test): This test also had a possible score of 15 for repeating up to 7 digits, with an extra point for each number in correct sequence, and bonus of 1 for speed and ease of response.

*Phonemic memory*: This exercise was originally devised by the teacher-trained therapist from Year-level word lists, and incorporates awareness of the individual sounds and the sequence of these sounds in words. It includes converting visual letters into sounds and blending these into a word. It also requires visualisation of the letters in a word from the sounds, in order to spell it backwards. In this way it is a test of sequencing, phonological awareness and memory span. This exercise combines elements of each memory modality and is described to the students as an exercise that "does a circuit of the brain’s connections (synapses) from both directions — auditory and visual". This has proved to be a most useful diagnostic tool, as an indicator of key literacy difficulties. The range of the exercise involved identifying and blending simple phoneme words of up to 7 phonemes tapped out on a phonics chart (Fidel chart from Gattegno, 1962), with 7 points for saying the given word correctly, 7 points for spelling it correctly, and a bonus of 1 point for case and speed of response. The visual and auditory memory span tests are standardised to Year 3 level, and the pre-test and post-test raw scores have been used as the interval level variables.
6.6 Intervention Study results - two-tiered Statistical Analysis

6.6.1 Dominance - dual criteria

It had become apparent during initial analysis of the data, that there was a far larger range of visual gains in both vergence and eye tracking than expected, creating two quite distinct groups. Thus these differences were quantified in order to divide the sample into two groups based on whether right eye dominance had been established, or not.

Dominance was attributed on the basis of dual criteria. The ‘dominant’ eye was deemed to be the eye that displayed superiority in two rigorously selected visual effects:

a) The eye that maintained foveal fixation under fusional stress (on a tranaglyph equipment viewed through stereoscopic glasses), was within a full range of binocularity. Specifically, there were fusional reserves of up to 30 dioptres in both convergence and divergence, while maintaining foveal fusion up to 20 dioptres. This represents a foveal reading span of five to six words and global vision covering two pages of an open book.

b) Superiority of one eye in a computer-based eye-tracking exercise using stereoscopic glasses occurred in a dichoptic exercise where each eye has a different task and different levels of difficulty. This exercise was designed initially to strengthen a weaker eye and develop balanced binocularity, but in the process the outcomes exemplified a ‘dominance’ characteristic, of a significantly different function between the two eyes, with 20 – 30% usually in favour of the right eye.

Division of the participants into two groups was determined by these findings, as individuals gaining ‘dominance’ status on both criteria were classified into the successful ‘stable eye dominance’ group. In this way, division into two groups was not controlled by the therapist, but depended entirely on the results of vision training.

Record keeping

In vision training records all records are kept.

Vergence: the range of binocular fields of vision, indicating fusional reserves, which are measured in units of optometric measurement called dioptries (Section 1.5 Glossary). The range of the measuring instrument (Bermell tranaglyph) is 0 to 30, representing approximately 30 cms (10 inches) binocular vision at reading distance, or two pages of a medium sized book. The reading span is 3 centimetres on the tranaglyph which translates into approximately three or four words of average print, and one word for a beginner reader’s font size.
Tracking: scores for the eye following the red ball were calibrated by a formula to account for scores in relation to speed, as slower speeds are required for the early stages of tracking exercises. To ensure a clear base-line in this study, the ratio of right to left eye tracking scores were only computed once tracking speed had reached the top speed setting. The first measure for evaluating each eye's performance was computed from a formula of the ratio of right eye tracking scores compared with the left eye. This was calculated by dividing the right eye score by right plus left score, multiplied by 100. \[ \text{RE} / (\text{RE} + \text{LE}) \times 100 \]. Any score equal to, or less than 50% represents left eye advantage, whereas greater than 50% shows right eye advantage. Before and after percentages were used as interval level pre and post-tests in the dataset.

6.6.2 Choice of Statistical analysis
The method chosen to analyse the data was from a pre-test / post-test design for treatment difference, or gain scores (i.e. post-test score minus pre-test score), in the extent to which treatment differentially affects the groups. In this study, pre-test scores are very similar in both groups (Table 15), which strengthened the initial assumption of pre-test equality between subjects. The first phase was a ‘paired sample’ t-Test with pre- and post-tests of each participant to determine the size of any gains from the two interventions, namely vision training and word skills. The second phase was instigated when frequency distributions showed there were two distinct levels of eye exercise result. An independent samples t-Test was used to determine if there is a significant difference, in literacy or memory post-test results of the word skills, between the two groups, that is Group 1 (who changed from left eye to stable right eye dominance) and Group 2 (who retained left eye, mixed or alternating dominance i.e. were not right eyed).

c) Limitations of Statistical Analysis
No control group was available within a therapy practice as ethically each student must be treated equally, at a time and pace that suited them. However, it is argued that participants who did not achieve normal visual function from the eye exercises may be considered as ‘dominance controls’ as no change in dominance had occurred for this group, in spite of having undergone eye exercises. Consequently, the significant difference between the dominance groups in literacy gains indicates that newly acquired right eye dominance is a determining factor in the positive outcomes of the Intervention study.

In Chapter 7, the findings of the Intervention study are reported, together with an advanced discussion of the procedures and a therapeutic interpretation of results.
Chapter 7

Intervention Study - RESULTS and interpretation of FINDINGS

7.1 Outline of the Study

This chapter focuses on the results of the Intervention Study which involved a two stage regime of eye exercises followed by a word skills programme, as introduced in Chapter 6. That chapter described the participants and the research procedures in the Intervention Study, which were largely the steps and procedures followed in normal Educational Therapy practice, but with the addition of the literacy and memory post-tests by an independent examiner. Literacy, memory and visual pre- and post-test data were administered, with visual data taken from the first and last records of the students’ vision training records. These eye exercises are described in further depth in this chapter, to show how anomalies of o-m function may upset the natural dynamics of visual pathways to the language area. These findings provide further evidence for the central argument of this thesis namely, that developmental consequences of o-m dysfunction may impact on language based tasks like literacy.

The data on which this Intervention study was based were from archived records of previous students. These had been analysed originally as a review of Educational Therapy practice and entered onto a spreadsheet. In this thesis this data has been examined and expanded into a Developmental Model of LD derived from therapy experience. In order to maintain a ‘narrative flow’, three aspects of these results will be reported concurrently, namely, the procedure and statistical method, the actual results, and the therapeutic interpretation. The latter commentary has been instrumental in determining further analytical processes needed for examining anomalies found in students’ performance.

Dominance terminology

For the purposes of this thesis, when reporting functional differences between the eyes, the term ‘dominance’ is used generically as ‘eye preference’, by left or right-eye, without implied genetic dominance. The term ‘advantage’ is used to express a higher performance capacity, likewise without implied dominance. Later in Phase 2 analysis and subsequent chapters, ‘dominance’ is used to express a natural superiority of specialised hemispheric function related to language based tasks like literacy. Likewise the visual superiority of right eye function reflected in the results of the ‘successful’ stable dominance group. It is conjectured that these findings may indicate improved access to more efficient (dominant) neural pathways.
7.1.1 Research Questions

The main thrust of the research question of the thesis asked:

*Is o-m dysfunction a contributing factor in LD?*

As concluded in the School Survey visual dysfunction was associated with memory deficits and mixed arm/hand dominance, which were in turn were associated with literacy. As visual dysfunction (46%) was evenly distributed across the sample, this meant that not all students with visual dysfunction had LD however 30% of this number had visual problems, raising the question as to whether the difference depended on which eye was dominant. Therefore, the first research question for the Intervention Study asks:

*What benefit was gained from vision training for the Educational Therapy sample group following the word skills workshop?*

In Stage 1 of this study, the gain scores of each participant were calculated (from post-test minus pre-test scores), with the paired-samples t-Test used to determine if there had been any significant gains from the two intervention activities. In Phase 2, the research design employed in the statistical analysis was extended owing to observations made during the word-skills workshop that some students in each work group were progressing with far greater speed and ease than other students. Furthermore, literacy post-tests showed some surprisingly large gains, greater than could be expected in a week’s work. These impressions were reinforced when the dataset was studied later. It appeared these ‘successful’ students had also changed, from having mixed or left-eye dominance, to an established ‘stable’ right eye dominance during the course of vision training.

Dominance status was determined post-hoc from eye exercise records, based on dual criterion. Namely, which eye maintained foveal fixation under vergence stress on the transaglyph and which eye produced the highest tracking scores. The co-occurrence of superior literacy gains and change to right eye dominance led to the additional research question. This was posed to test the observation that the sample had fallen into two distinct dominance groups, and to determine specifically whether this held true for memory and literacy results.

7.1.2 Research statement

The assumption being tested in this study was that if significant gains in literacy were found to be associated with recently established right eye dominance, this would indicate that a dysfunctional right eye might have previously disrupted visual information input to the language area. It was conjectured that a compensatory but less efficient pathway might have developed owing to o-m imbalance.
7.2 PART I, Case Studies ML and LW - dominance findings

7.2.1 Two participants presented as matched cases

Before reporting the results of the intervention study, case studies of two matched senior students ML and LW are presented as negative and positive examples of the development of right eye dominance. The inclusion of these case studies highlights the impact of newly established eye dominance on literacy and memory performance since this was not adequately conveyed by group mean scores. Both students achieved some improvement in o-m function with vision training, however, the 'unsuccessful' ML student failed to achieve the range of fusional reserves in divergence required to manifest right eye superiority of tracking speed. The records of tracking scores shown in Figure 11 illustrate what right eye dominance in scoring capacity looks like when graphed, as shown in LW’s chart.

In vision training, records of every student’s right and left eye scores were graphed once top tracking speed was achieved. This served to ensure that each student’s record started at the same level of proficiency, regardless of age. At the end of each therapy session the ratio score between right and left eye was computed. The raw score range was set between 0 - 150 on the computer tracking game, using stereoscopic glasses with matched moving targets on the screen.

7.2.2 The advantage of right eye dominance - eye tracking graphs ML and LW

Figure 11 graph shows differences between right and left eye function of the two males, ML and LW (aged 16.3 and 15.5 years respectively), who underwent Educational Therapy together. Both were matched in being left eye dominant and having above average reading comprehension age of 17 years, but a spelling age of 10 years.

The differences in the effects of right eye dominance status can be seen clearly in graph form. LW gradually achieved right eye dominance, whereby lines that represented right and left eye scores separate into roughly parallel lines, as tracking speed increased. By way of contrast, ML retained mixed eye dominance, with right and left eye score lines which continued to intercept, and scoring rate continued to vary without advancing, as there was little improvement in tracking speed. ML failed to establish stable right eye dominance after 39 vision training sessions. This disappointing outcome suggested that there was a chronic underlying physiological problem which in current practice would receive podiatry and cranial osteopathy treatment.
Two Case Studies - comparing right and left eye tracking capabilities

Figure 11 Superior right eye scoring capacity – charts from old records

1 Scoring range 0 – 150 recorded from a computer tracking game.
2 Record and graph of raw scores for each game.
3 Ratio of left and right eye scores less than 50% = left eye, more than 50% = right eye advantage (formula: right divided by right + left %).
4 Icons: closed triangle – right eye, open triangle = left eye score.
At the end of each game, right and left eye scores over 7 even sets (14 games) were computed as a percentage of the total game. With 50% being the midline, < 50% represented left eye advantage, and > 50% is expressed as right eye advantage. Superiority of right eye score, of either 65%, or 20% more than the left eye, was deemed to be stable right eye dominance.

7.2.3 Profile of participants ML and LW

a) Student ML, 'unsuccessful' dominance status.

ML was a right-handed, left-eyed boy in Year 11 who presented as a well-read, highly motivated but tense student with asymmetrical gait and posture, and mildly 'restricted' motor co-ordination. This is a common pattern for many students attending the Educational Therapy practice, notably pronation of one or both feet inwards, uneven balance on one foot which co-occurs with musculo-skeletal imbalance and postural, cervical, and facial asymmetry, together with o-m dysfunction. The pervasiveness of this pattern suggests that the elements might be physiologically linked through interactive sensory feedback (discussed further in Chapter 8).

ML was only mildly left-eyed with an average tracking speed, but his general 'tension' appeared to be reflected in his visual system that could be described as 'resistant to change' in spite of his dedicated efforts to the contrary. Initial records showed that in convergence, right foveal vision was suppressed at 5 dioptres, although he eventually managed a normal global range of 25 dioptres. This suggested that previously his right eye was not always performing with clear foveal fixation when working on near tasks like reading and writing. Divergence was weaker as he also suppressed foveal vision of his right eye at 7 dioptres and global fusion also broke at this point. He reported how the right eye images of letters 'slipped' upwards and outwards, and broke into double vision as he lost foveal fusion. In convergence, he had achieved right eye dominance and normal range of foveal and global by Session 4, but divergence was a struggle. He managed a global range of 25 dioptres, but in foveal vision he was still suppressing his right eye at 10 dioptres and so he remained left eye dominant in divergence because of his weaker right eye. This lack of range was reflected in his eye tracking chart as some improvement is shown, but he exhibited periods of fatigue where scores dropped and he continued to alternate tracking speed advantage between right and left eye.

ML's initial performance profile predisposed him to being a 'right hemispheric reader' (Colthcart, 1980) as far as foveal vision was concerned, and his main source of binocular information was from global vision which does not register the same degree of fine detail as foveal vision, hence the stress of extra time and effort taken to 'focus' meaningfully on print. Memory tests showed his visual memory was normal, auditory memory was slightly lower, but
the main problem was a phonemic memory deficit of 8 out of a possible 15 points, with limited
gain in post-tests. Spelling progress was also disappointing as he had only a 4 month gain in
spelling in spite of his efforts in the memory and word-skills workshop, and he continued to
struggle at school. He eventually achieved tertiary entrance, but elected to do Fine Arts instead
as his poor word skills made further academic education too daunting because of the time and
effort it took him to bring his performance up to both his interest and ability level.

b) Student LW, 'successful' dominance status
In contrast to ML, this tall, loose-jointed Year 10 student had a 'relaxed' attitude to work and
life in general, reported that he read books only under duress and did not attempt tasks that
were 'too hard'. He expressed this as laziness, but what is perceived as laziness can likewise be
a survival strategy in response to visual fatigue arising from the effort required to accommodate
and converge on near-point work, and limited attention to detail from poor foveal fixation.

LW was also right-handed and left-eyed, and he achieved stable right eye dominance (mean
score ratio of 83% right eye advantage) in his fifteenth vision training session. His successful
outcome of excellent o-m function, and advanced outcomes of the word-skills workshop,
suggested that LW had 'regained' former pathways and access to more efficient, bi-hemispheric
information processing of previously established skills.

The advantage of LW's situation was that his eyes were not chronically stressed and 'tight' as in
the case of ML. During eye exercises, as his right eye became stronger, and fusion reserves
increased to a range where he was able to sustain right eye foveal fixation under all conditions,
he changed from left to right-eye dominance. Furthermore this was achieved with relative ease
which suggests that o-m function may have been normal when he was younger, but with an
underlying problem with accommodation or convergence insufficiency, imbalance between the
eyes may have developed as he spent more time on close work at school.

For LW, initial tests showed stamina and tracking speed were weaker in the right eye, because
at optimum speed on the computer, right eye mean score was only 41%. This was an identical
pattern to that of ML, with convergence limited to a foveal range of 12 dioptres, suppression of
his right eye, and 22 dioptres fusional reserves in global vision. In divergence, foveal range
was limited to only 4 dioptres before his right eye was suppressed. In the second therapy
session, convergence range had increased to full range of 28 diopters in both foveal and global
vision, with the right eye remaining dominant in maintaining fixation once fusion broke.
Divergence took longer and reached a similar range by the 6th session. As vergence range
increased, so too did eye tracking speed and accuracy, until the score lines showed the right eye
overtaking the left eye score line. Session 7 still showed evidence of fatigue of the right eye, but this had cleared and dominance was well established by Session 11 with a scoring ratio of 80% for the right eye. This stable right eye dominance was consolidated by Session 15 when vision training was discontinued.

LW's spelling age rose 2 years and 4 months over the five day workshop, and he reported good end of term exam results in written work and particularly in previously weak maths, which he explained, with a shrug, "I just know what to do now". The gains in end of term maths exams, were outside the specific topics addressed in the therapy programme. This suggests that bi-hemispheric integration of visual information had become generalised across cognitive skills. That is by providing improved access to what he knew already in memory and logic, and in freer access to innate resources and motivation. LW's final year results and employment direction are unknown.

7.2.4 Comparison between ML and LW - post-test performance profiles

Table 14 shows the comparison between the initial profiles of the two students who were closely matched in all measures except that ML was slightly stronger in visual and auditory memory. The most defining difference between the two students was LW's superior right eye tracking scores, his full divergence range, with stable right eye dominance in both variables. These achievements together with his normal memory scores in visual and auditory memory helped to double his previous phonemic memory span. Of greatest interest was the remarkable gain in his spelling results after a week's workshop.

ML on the other hand had limited improvement in tracking skill, and was still losing fixation of this right eye in divergence even though the range had improved. His auditory memory span did not improve and a phonemic memory deficit was undoubtedly implicated in his limited progress in spelling. ML's profile suggested that a lack of integration of auditory and visual signals, possibly owing to lack of right eye dominance, had not been satisfactorily addressed. This was likewise reflected in the other 8 students who failed to achieve right eye dominance in divergence (See Table 18), and also failed to achieve literacy 'success' to varying degrees.

Evidence of differences in literacy gains in ML and NW illustrated the effects of relative success and failure of two key aspects of vision training that provide insights into the subtle attributes of balanced o-m function, eye dominance and spelling progress. Specific key elements are shown to be the range of foveal and global overlapping fields of vision (fusional reserves), and right eye tracking superiority. It was apparent from this analysis that eye dominance was a contributing factor in the relative outcomes of the word skills programme for
the two individuals. These case study findings support the impression gained in Educational Therapy that right eye dominance makes a difference to learning outcomes.

Table 14 Evidence of o-m improvements in memory and literacy

<table>
<thead>
<tr>
<th>Student</th>
<th>A (16.3 years)</th>
<th>M.L.</th>
<th>B (15.5 years)</th>
<th>L.W.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>Visual</td>
<td>Literacy</td>
<td>Memory</td>
<td>Visual</td>
</tr>
<tr>
<td>Tracking</td>
<td>Diverge</td>
<td>Spelling</td>
<td>Reading</td>
<td>Oral Read</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gains</td>
<td>10.1</td>
<td>13.3</td>
<td>14.0</td>
<td>17.0</td>
</tr>
<tr>
<td>L.W.</td>
<td>10.5</td>
<td>14.0</td>
<td>14.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Gains</td>
<td>0.4</td>
<td>0.7</td>
<td>top score</td>
<td>top score</td>
</tr>
</tbody>
</table>

1. Tracking % of mean right eye score divided by sum of left and right eye mean scores.
2. Binocular divergence, maximum range 30 dioptres = approx. 22 cm (9 ins) as overlapping fields of global vision.
3. Standardised literacy tests with the following cut off points: Spelling - 15 yrs, Reading - 15 yrs, Oral Reading - 14 yrs, Comprehension - 17 years.
4. Memory span expressed in points, where 15 points is the maximum (see 6.1.6 (iv) Memory span measures).
5. 'Top score' refers to students who achieved the optimum score in the pre-test, therefore scored zero gains.

The critical difference between the two students’ results appeared to be ML’s failure to develop an adequate divergence. This appeared to have been the key that locked him out of stable right eye dominance and better access to word skills. This finding tends to support Assumption 1, namely: The key movement in reading is the left-to-right movement of the right eye (see 6.5, p. 135).

7.3 PART 2, Intervention study, Phase 1, Analysis of participants’ results
This Phase 1 analysis of the whole group compares before and after tests following the visual and word skills programme of the Intervention Study. It was designed to provide an overview by gauging the overall results of the Intervention.
7.3.1 Analysis of results, paired-samples t-Test

In the following Table 15, the data for tracking results was based on right eye percentage scores, and vergence was based on the degree of overlapped fields of vision, up to an optimum of 30 dioptres. The critical vergence score was the range of central vision fusional reserves, as indicated by the recovery point at which words on the transglymph screen were again seen as fused images, once binocular vision had been broken. Memory data are all comparable, as is spelling and word recognition since both tests have a cut-off point of 15 years. However, the cut-off point of oral reading was 14 years, whereas reading comprehension was 17 years. At the completion of the Educational Therapy programme, the paired-samples t-Test was used to determine if there had been any significant gains from the two intervention activities. The mean gain scores (shown in Table 15) show that on average, participants benefited from all IQ aspects or tempy. The results of the paired-sample t-Tests confirm that post-test scores for the visual, literacy and memory tests were significantly higher than the pre-test scores.

Table 15: Paired-sample t-Test results of visual, literacy and memory tests

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>Range</th>
<th>Mean Scores</th>
<th>Paired Samples t-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Pre-test</td>
<td>Post-test</td>
</tr>
<tr>
<td>VISUAL (max. range)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divergence (30 Δ)</td>
<td>24</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>Convergence (30 Δ)</td>
<td>24</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>Rt Eye Tracking</td>
<td>24</td>
<td>32</td>
<td>51</td>
</tr>
<tr>
<td>LITERACY (max years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word recognition (15)</td>
<td>24</td>
<td>7.5</td>
<td>7.1</td>
</tr>
<tr>
<td>Spelling age (15)</td>
<td>24</td>
<td>6.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Oral reading age (14)</td>
<td>23</td>
<td>8.3</td>
<td>7.0</td>
</tr>
<tr>
<td>Comprehension (17)</td>
<td>23</td>
<td>11.3</td>
<td>9.7</td>
</tr>
<tr>
<td>MEMORY (max points)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phonemic (15)</td>
<td>21</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Visual (15)</td>
<td>23</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Auditory (15)</td>
<td>21</td>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

1 Range equals difference between the maximum and minimum score achieved by participants
2 Divergence and convergence are measured in dioptres. The maximum range of 30Δ (dioptres) represents the optimum for overlapping fields of vision.
3 Tracking is measured as a percentage: ≤ 49% = left eye advantage, ≥ 51% = right eye advantage
* Significant at or beyond the 0.05 level. Age range of sample group 6.1 to 18 years

7.3.2 Oculo-motor results

In general, o-m function improved significantly with vision training, particularly in divergence and tracking skills, both of which are commonly found to be deficient in students with LD (Table 15). Although 35% improvement was shown in post-tests for convergence, this was not
such a discriminatory factor in LD, with fewer students presenting with convergence deficits than was the case with divergence. On average, there was an overall gain of 43% in divergence within the optimum range of 30Δ dioptres of overlapping fields of vision, of fusional reserves. The third visual exercise of eye tracking speed and accuracy gained 18% on average. Initially tracking scores for the right eye were on average only 46% (left eye advantage). But post-tests show a reversal with a mean score of 64% for the right eye showing a change from left to right-eye dominance as a result of vision training.

(i) Vergence: Table 15 shows that, on average, the pre-test score in convergence (turning both eyes inwards to match near focus) was approximately half the optimal range of fusional reserves (mean score 13.9Δ dioptres). This was not of particular concern because, although an increase would be advantageous, this range of fusional reserves fell within normal parameters adopted in optometry. In divergence (turning both eyes outwards) the optimum range normally achieved by students after vision training is 24-30Δ, which is deemed to indicate normal o-m function. Consequently the limited mean pre-test score of 8.42Δ dioptres is of particular concern as it indicates weak binocularity, and from experience, this falls within the range at which double vision commonly occurs, with a risk of suppression of one eye (i.e. 0-10 Δ). A zero score is relatively infrequent and indicates no overlap between central fields of vision. However, this deeper problem has also been found to be amenable to vision training eventually.

Post-test results showed that significant gains were made for both convergence (mean gain = 10.7Δ; \( t = 8.9, p < 0.001 \)) and divergence (mean gain = 12.8Δ; \( t = 9.0, p < 0.001 \)) such that the mean post-test scores (21.2Δ and 24.6Δ, respectively) were both within the normal to optimum 20-30 dioptre range. Convergence had the greatest gain with a mean score of 24.63Δ \( (t = 8.9, p < 0.001, \text{gain} = 10.75\Delta) \), whereas divergence is a difficult eye movement to teach (and learn), so the latter result was particularly encouraging with an average gain of 12.79Δ points and a mean score of 21.2Δ \( (t = 9.0, p < 0.001) \). Both measures were within normal range, even though these data included some students who retained areas of o-m dysfunction.

(ii) Eye Tracking: Table 15 shows post-test results with a mean gain of 18 points, from the pre-test average 45.75% up to 63.75% \( (t = 5.6, p < 0.001) \) a general change from left to right eye advantage. The point of interest in this finding is that it would be expected that both eyes’ scoring capacity in a tracking exercise would be equal when the eyes are balanced, with normal o-m function. However, Group 1 had on average a superior tracking score 20% greater than the mean score for Group 2, but this did not represent the full picture. The actual minimum and
maximum tracking scores for individuals in Group 1 illustrated the actual size of the differences. The pre-test spread of right-eye raw scores ranged from 32 to 64, whereas post-test scores were even greater, from 37 to 88. The top scoring student was able to achieve 88% right eye scoring advantage. This 20% superiority of right eye tracking scores is deemed to indicate neurological eye dominance. It was observed during the vision training exercises that once tracking speed had reached maximum speed on the computer-generated tracking game, the left eye's scoring capacity tended to slow down and plateau, whereas the right eye continued to improve its scoring capacity to the degree quoted above.

7.3.3 Literacy outcomes

Table 15 showed that there were significant improvements in performance on each of the 4 literacy tests, following the week-long word-skills workshop. On average, students' word recognition skills improved by 18 months from a pre-test mean of 10.5 years to a post-test mean of 12.0 years (t = 8.4, p < 0.001). Spelling gained over a year from 10.0 to 11.1 years (t = 6.8, p < 0.001), while oral reading gained just over 14 months from 10.5 to 11.7 years (t = 6.6, p < 0.001) and reading comprehension gained by almost 17 months from 11.1 to 12.5 years (t = 5.8, p < 0.001). The main point of interest not shown in these averaged results was the wide range of individual gains that was masked by the range of ages (6 – 18 years) and averaged scores.

The following Table 16 gives a break-down of the distribution of gains in the literacy variables. A separate category ‘Top pre-test’ is reserved for 7 cases where pre-test results already equalled the optimum score possible and consequently had zero scores.

Table 16 Incidence of literacy gains

<table>
<thead>
<tr>
<th>Literacy</th>
<th>0 gain</th>
<th>≤1 yr</th>
<th>1–2 years</th>
<th>2–3</th>
<th>≥3 years</th>
<th>Top pre-test</th>
<th>Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spelling</td>
<td>1</td>
<td>9</td>
<td>10</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word recognition</td>
<td>4</td>
<td>12</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oral reading</td>
<td>5</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Comprehension</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Appraisal of the range of scores in each variable showed the greatest gain for spelling was 2.7 years by a student aged 15.4 years; the greatest word recognition gain of 3.9 years and reading comprehension of 3.8 years were by the same 13.8 year-old; and oral reading gain of 3 years was by a 13.0 year-old. A week is not long enough to cover the range of vocabulary required to achieve these results, and in a way, the more impressive gains confirm the Developmental
Model. It is thought that by improving connectivity, individuals are provided with more effective access to an existing pool of experience, which previously may not have been clear or organised sufficiently to provide adequate 'knowledge' for the working memory (EGB).

The word-skills workshop employed the therapist's 'Patterns of Learning' programme, which incorporates a teaching style that facilitated auditory and visual perceptual awareness. For example, spelling mini-lessons include tuning up the skill of identifying individual sounds (particularly short vowels) in words, visualising these sounds as letters, and perceptually segmenting words into parts. It also promoted learning skills in creating a mental 'data bank' of all the spelling options of each sound by working from a phonics chart, and developing fluency by highlighting the spelling patterns in texts, so that unfamiliar words could be recognised by these patterns. Each activity was integrated with preceding exercises so that the brain was receiving a constant stream of 'structuring' information - a little bit, often. Reinforcement exercises were provided as homework in preparation for working at a new level each day. Theoretically, all of these activities together aimed to provide the participants with logical and creative problem solving tools by which spelling patterns could be superimposed on an existing 'shadowy' vocabulary. The positive gains expressed in their results suggested more efficient information processing and access to intellectual resources as a result of the Intervention programme.

7.3.4 Memory outcomes

At a functional level, memory span dictates the number of elements that can be registered in the initial Sensory Information Store and ultimately accessed by the working (short term) memory. In effect, the faster and more efficient the information processing, the more data can be processed simultaneously, which provides more complete array of the detail and a clearer overview (EGB). This is reflected in a wider memory span, thus allowing more resources for analysis, and creative, adaptive problem solving, including spelling and writing, with a minimum of errors. From observing students' working habits, the therapist concluded that even small memory deficits diminish working efficiency. For example, when copying words, students picked up only small parcels of information at each glance and needed training to expand their perceptual span in order to work more efficiently. Generally, "the greater the memory deficit, the more time and effort is required to process and learn literacy skills", which the therapist regarded as a practical definition of LD.

Referring back to Table 15, this showed average pre-tests scores for visual memory and auditory memory were similar (10.78 and 10.0 memory points respectively). The nature of the sample's LD is most clearly evident from phonemic memory scores which were far weaker than
the average pre-test score which was 7.0 on the 15 point scale. However, the post-test scores showed phonemic memory gained almost 5 points on average to achieve a mean score of 11.8 points ($t = 11.2, p < 0.001$) whereas average gains of only 2.6 and 2.3 points were achieved for visual and auditory memory.

Table 17 Memory deficits

<table>
<thead>
<tr>
<th>Memory scores ranges:</th>
<th>Pre-test range</th>
<th>Post-test range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory memory</td>
<td>6 - 15</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Visual memory</td>
<td>9 - 15</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Phonemic memory</td>
<td>4 - 10</td>
<td>6 - 15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of memory deficits:</th>
<th>as another way of considering the pre-test data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single deficit:</td>
<td>Phonemic deficit only</td>
</tr>
<tr>
<td></td>
<td>2 students</td>
</tr>
<tr>
<td>Double deficit:</td>
<td>Phonemic and visual</td>
</tr>
<tr>
<td></td>
<td>7 students</td>
</tr>
<tr>
<td></td>
<td>Phonemic and auditory</td>
</tr>
<tr>
<td></td>
<td>7 students</td>
</tr>
<tr>
<td>Triple deficit:</td>
<td>Phonemic, visual and auditory</td>
</tr>
<tr>
<td></td>
<td>7 students</td>
</tr>
<tr>
<td>Missing data</td>
<td>1 student</td>
</tr>
</tbody>
</table>

The Memory Deficits Table 17 summary shows that phonemic memory is the weakest element in these students' cognitive resources. Memory score ranges and number of memory deficits showed that all 24 participants had some phonemic deficits initially, whereas the possible maximum score of 15 points (see Section 6.5.5 Measures) had been found in pre-tests of three students in auditory memory, and another group of three in visual memory span.

In summary, overall vision training and word-skills programme has proved to be a successful combination in the Intervention study. What isn't known is whether both contributed to this success, and, if so, which of the two interventions contributed the most. However, the corresponding research question related to whether right eye dominance makes a difference to literacy outcomes. Consequently, Stage 2 statistical analysis has addressed this question by dividing the sample into two groups, according to whether post-test results in divergence and eye tracking reached the rigorous criteria of dominance status.

7.4 PART 3, Phase 2, two Dominance groups

7.4.1 Rationale

In the School Survey it was found that although 47% of the school had visual dysfunction (Section 5.2.1, Table 3), only 30% had reading difficulties (Section 5.3.1, Table 6). This led to the question: In the case of o-m dysfunction and weak binocularity, are LD dependent on which
eye is dominant? As the research question related to the impact of eye dominance, the emergence of two distinct dominance groups as part of the first statistical analysis provided an additional, discriminatory variable - 'recently established right eye dominance' - which could be now be used for dividing the participants into two groups to answer the following research question.

The second research question asked:

What effect would recently developed right eye dominance have on literacy and memory levels following a week-long word skills programme?

7.4.2 Measures of eye dominance

In Phase 2, the participants were divided into two groups, with Group 1 having successfully achieved right eye dominance for both tracking and divergence, and Group 2 retaining mixed or left eye dominance. The independent samples t-Test was used to determine if there were significant differences between the two groups in terms of gain scores for literacy and memory skills (based on the same data as Phase 1).

Critical factors in determining eye dominance

As discussed previously (Section 6.6.5), the ratio of eye tracking scores between right and left eyes was computed such that less than 50% was denoted as 'left-eyed' and greater than 50% indicated right-eyed advantage. The 15 out of the 24 of students who eventually achieved stable dominance had either a right eye tracking score of 20% or more than the left eye, or an average score of 65% or more for the right eye in 14 tracking games, in his/her last session of vision training. Superiority (20%) of right eye tracking speed was then adopted as the first criteria by which students were deemed to have achieved right eye dominance in eye tracking.

The second criteria of right eye dominance related to having an optimum fusional reserves range of 24 - 30 dioptres, i.e. 9 - 10 centimetres at reading distance, in convergence and divergence, with right eye maintaining foveal fixation within this range. This was measured on a tranaglyph (see Section 8.1.3) with the use of stereoscopic glasses, and provided an optometric measure of o-m control and strength of the external eye muscles that adduct and abduct the eyes inwards and outwards in contra-motion.

Measures were taken and progress records were kept during each vergence exercise. As the two tranaglyph slides were moved laterally, the first measure was taken of which eye had lost foveal fixation and at which point on the dioptre scale that occurred, from the student's report.
A second record was made of the point at which the global image broke into double vision, and then, as the slides were moved back towards neutral, the third record was taken where double vision was again fused into stereoscopic vision with all parts of the combined images in place. This recovery point was the key measure indicating the range of both global and foveal fusional reserves which generally correlated with the first measure at which foveal fixation was lost.

Fifteen of the 24 students (63%) achieved the optimum range of 30 dioptres for global vision and greater than 24 dioptres in foveal vision before foveal fusion was broken. Furthermore, when the right eye retained foveal fixation, this was evidence that the inherent weakness of that eye had been overcome. The optimum range of between 24 - 30 dioptres fusional reserves and the right eye maintaining foveal fixation was adopted as the second criteria by which students were gauged as having achieved right eye dominance in vergence.

7.4.3 ‘Dominance’ criteria by which the sample is split into two independent groups

For the purposes of this study, students were deemed to have established a stable right eye dominance if they had achieved both vergence and tracking speed criteria for dominance status cited above. These criteria were rigorous. They were not based on optometric ‘norms’ but rather on the functional levels generally achieved by the students themselves with eye exercises, and thereby regarded as representing ‘natural potential’. In order to determine whether eye dominance impacted on the outcomes of the word-skills workshop, the sample was divided into two groups, ‘stable right eye dominance’ or ‘dominance not established’ on the basis of o-m gains in the two variables described above.

7.5 PART 3 Phase 2, Dominance findings

In the following Table 18, visual data is shown because, although it is the literacy and memory scores that are the focus of the following discussion, these illustrate clear differences between the two groups in terms of divergence and tracking. These represent the criteria by which the sample has been divided into the two groups.

7.5.1 Analysis using independent-samples t-Test

(i) Literacy results

The results shown in Table 18 suggested that right eye dominance did make a difference to literacy outcomes.
The students with stable right eye dominance (Group 1) made significantly greater gains than those for whom dominance was not established (Group 2) on two of the literacy tests.

As shown in Table 18, the average gains for oral reading (1.5 years for Group 1 versus 0.7 years for Group 2; $t = 2.3282, p = 0.033$) and spelling (1.4 years versus 0.7 years, respectively; $t = 2.3, p = 0.034$) were significantly higher for students with stable right eye dominance than those students for whom dominance was not established.

The results for reading comprehension (i.e. mean gains of 1.8 and 0.5 years, respectively) approached but did not reach statistical significance ($t = 2.0, p = 0.057$). Although both groups made good progress in word recognition, the mean gains of 1.7 and 1.2 years were not significantly different.

**Table 18**: Independent samples $t$-Test of visual, literacy and memory tests for students with established right-eyed dominance and left-eyed / mixed dominance.

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>MEAN SCORES</th>
<th>Independent Samples $t$-Test$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 (stable right eye dominance)</td>
<td>Group 2 (dominance not established)</td>
</tr>
<tr>
<td>Pre-test</td>
<td>Post-test</td>
<td>Gain</td>
</tr>
<tr>
<td>VISUAL (max range)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divergence (30 Δ)$^2$</td>
<td>8.3</td>
<td>23.7</td>
</tr>
<tr>
<td>Convergence (30Δ)$^2$</td>
<td>13.0</td>
<td>24.2</td>
</tr>
<tr>
<td>Rl eye tracking $^3$</td>
<td>45.3</td>
<td>70.9</td>
</tr>
<tr>
<td>LITERACY (max. years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oral reading (14)</td>
<td>10.4</td>
<td>11.9</td>
</tr>
<tr>
<td>Spelling (15)</td>
<td>10.0</td>
<td>11.3</td>
</tr>
<tr>
<td>Comprehension (17)</td>
<td>11.2</td>
<td>13.0</td>
</tr>
<tr>
<td>Word recognition (15)</td>
<td>10.4</td>
<td>12.1</td>
</tr>
<tr>
<td>MEMORY (max. points)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phonemic (15)</td>
<td>7.2</td>
<td>12.5</td>
</tr>
<tr>
<td>Auditory (15)</td>
<td>10.1</td>
<td>12.7</td>
</tr>
<tr>
<td>Visual (15)</td>
<td>10.7</td>
<td>13.3</td>
</tr>
</tbody>
</table>

$^1$ Independent Samples $t$-test based on gain scores.

$^2$ Divergence and convergence are measured in dioptres. The maximum range of 30Δ (dioptres) represents the optimum for overlapping fields of vision.

$^3$ Tracking is measured as a percentage: ≤ 45% = left eye advantage, ≥ 51% = right eye advantage.

* Significant at or beyond the 0.05 level.

From the therapist's experience, the fact that Group 2 made similarly high gains in word recognition to Group 1 can be explained because word recognition is the simplest level of 'whole word' reading and the first of the reading skills to develop. Recognition of the overall word shape and three main features of a word are basic perceptual requirements before a sight
word vocabulary can start to develop. At this level, there is little demand for the left hemisphere refinements of fine foveal detail, sequence of letters, and knowledge of phonics, consequently word recognition can be achieved without right eye dominance being established. Indeed, this is evident in Educational Therapy practice when noting youngsters’ stages of literacy progress.

(ii) Memory Results

In Table 18 phonemic memory results show that Group 1 had an average gain of 5.3 points (on a 15 point scale) compared with 3.6 points for Group 2. The mean gains for auditory memory (2.6 and 1.5 points, respectively) and visual memory (2.5 and 2.9 points, respectively) were fairly similar. Each set of results represented useful gains in memory skills, but since no statistically significant differences between the two groups were observed, it might be assumed that dominance was not a discriminatory factor. In therapy practice, exercises involving phonemic memory are generally found to be most demanding for students with LD. The results of the study show substantial improvements were made by both groups, but more so for the students in Group 1, who made a 74% improvement on their pre-test score and Group 2 made a 54% phonemic memory improvement.

(iii) Visual results

Table 18 shows that the mean pre-test scores for tracking and divergence were very similar for the two groups, suggesting that overall standards for each group were alike prior to commencing the intervention programme. As described previously, post-test tracking scores were used to determine ‘tracking dominance’, thus, as would be expected, the post-test mean for Group 1 (70.9%) was substantially higher than for Group 2 (51.9%). An independent samples t-test based on the mean gain scores (25.6 and 5.5 percentage points, respectively) showed that Group 1 made significantly greater improvements than Group 2 ($t = 3.8$, $p < 0.001$).

It can be deduced from Table 18 above that six (67%) of the 9 students in Group 2 achieved right eye dominance in tracking compared to 100% of Group 1 students. It was apparent from the records of eye exercises that each individual’s tracking speed increased in concert with his/her widening range of divergence, which co-occurred with the right eye’s improved capability to maintain foveal fixation.

Convergence gains for the two groups were not significantly different. This is not surprising, however, since convergence is an easier attribute to train than divergence. Furthermore, 15 students already had right eye dominance in the pre-tests and all but one of the 24 students were
able to achieve a full range of fusional reserves with post-test scores within the optimal 24-30 dioptre range. On the other hand, there was a substantial difference between groups in divergence: the post-test mean for Group 1 was 23.7Δ compared to 17.0Δ for Group 2. An independent samples t-test based on the mean gain scores (15.4 and 8.3 dioptre points, respectively) showed that Group 1 made significantly greater improvements than Group 2 (t = 2.7, p = 0.012).

7.5.2 Break-down of dominance distribution in pre- and post-tests
Table 18 below shows the distribution of the students according to the pattern of eye dominance in vergence and tracking, and the changes from left to right dominance following vision training.

Table 19 Incidence of Dominance before and after Intervention

<table>
<thead>
<tr>
<th>Dominance</th>
<th>PRE-TESTS</th>
<th>POST-TESTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Right</td>
</tr>
<tr>
<td>Divergence</td>
<td>24</td>
<td>3 (13%)</td>
</tr>
<tr>
<td>Convergence</td>
<td>24</td>
<td>15 (63%)</td>
</tr>
<tr>
<td>Tracking</td>
<td>24</td>
<td>4 (17%)</td>
</tr>
</tbody>
</table>

Vergence
In the sample, 19 out of the 24 students were left-eyed in divergence pre-tests, as, only 5 were mixed, or right-eyed. However, this changed to 15 right-eyed for the post-tests, with only 7 remaining left-eyed and 2 students retaining mixed 'dominance'. The 3 students who were right-eyed at the pre-test stage, which was 'against the trend' of visual problems, may have had LD due to auditory processing deficits which would have been corrected to some extent in the word-skills programme. Convergence gains were likewise positive for all students. However, pre-tests show there were already 15 students who were right-eyed in convergence, and that only one student failed to change to right eye dominance in the post-tests. This is a further indication that convergence measures are not as clear as divergence in discriminating o-m dysfunction.

Tracking
Table 19 shows that in eye tracking, initially 16 of the participants were left-eyed (see Table 14: pre-test mean = 45.75%), while 4 were right-eyed and 4 had mixed eye preference. Following the program of vision exercises, a total of 21 students had established right eye
dominance as reflected in the post-test mean of 63.8% shown in Table 14. Three students remained left-eyed, despite having made some improvement in their tracking ability. Overall, these results showed a general trend towards natural right eye dominance exemplified by Group 1, with their superiority of tracking speed for the right eye, as the o-m balance and full global and foveal binocularity were achieved with vision training.

7.6 Limitations of the Study

Reliability

In terms of reliability of results, age may have been a confounding factor in evaluating the individual differences between participants. For example, with a range of 12 years across the sample, a one year gain has a different significance at different ages. Age also produced a ceiling effect in post-tests for the older students in oral reading, word recognition, and particularly in spelling, such that effect size of differences between groups may have been diminished somewhat.

Sample numbers were relatively small owing firstly, to the intensive nature of providing individual treatment within a group setting, by the sole therapist. Secondly, in a clinical practice, there are inevitably a number of students whose records cannot be used owing to incomplete data.

Validity

Dominance status based on these criteria may have been too rigorous to represent normal variability fairly, particularly given the differences between norms of children and adult ocular measures. Variability is shown in that there is a pattern of literacy and memory gains in the two groups. This pattern was not as clear in the total sample as that seen in the results of the case study participants ML and LW. The remainder of the sample group fell within these two extremes, depending partly on attitude and application. Some students did well in word skills because auditory processing had improved, although visual function was not fully restored. Other students still had some way to go before normal school parity could be achieved, and continued with the programme after the completion of the study.

The nature of Educational Therapy practice has undoubtedly placed limitations on following a conventional research plan, and findings need to be substantiated before the principles of the underlying Developmental Model can be validated. Therapeutically, however, the integration and overlap of activities is of great advantage because it is a most efficient teaching regime.
For the purposes of empirical research, it does, however, makes analysis and reliable conclusions more difficult to determine. None-the-less, positive results of this empirical study have validated the benefits of the combined Intervention programme and Assumptions expressed in Section 6.5.

Setting standards of therapy

The study has uncovered a number of advantages that had not been expected or planned. Specifically, that the difference in performance between the eyes and the unexpected change from left to right-eye dominance once full fusional reserves had been achieved. Furthermore, the unexpected size of the range of scores in vergence and tracking that was manifest with vision training demonstrated superiority of right eye function. In effect, these findings have opened a broader perspective of higher standards, with results that are consistent outcomes of effective practice, as opposed to more limited expectations set by concepts of 'normal parameters'. This observation follows in the same vein as concepts around 'normal' reading range, as raw scores showed some 9 year-old students were reading at a 12 year-old level, and some 10–12 year-olds were already reading at a 17 year-old-level (see Section 5.2.4). These observations have led to the consideration that o-m function is a significant variable to be evaluated before rating a student's natural ability. The link between newly established right eye dominance (as representing normal o-m function) and gains in literacy seem to support this assumption.

7.7 Answers to the Research Questions

The main research question of the thesis, at this stage, asked:

Is o-m dysfunction a contributing factor in memory and learning difficulties?

The results of the School Survey showed a link between o-m dysfunction and memory, and between memory, arm dominance, and literacy, which in terms of Luria's Model of Neural Function established an indirect link, giving an affirmative answer. This interpretation was not necessarily in a statistical sense, but certainly gained from a clinical point of view and supports Assumption 5, Section 6.5, p.137.

The first research question for the Intervention Study asked:

What benefit was gained for the sample group from the Educational Therapy programme consisting of vision training followed by a word skills workshop?
were significant gains for the group as a whole, on average, although not all individuals made significant gains in all variables.

The second Intervention Study research question asked:

*What effect would recently developed right eye dominance have on literacy and memory levels following a week-long word skills programme?* For Group 1 students, all of whom had successfully established stable right eye dominance, the gains in spelling and oral reading were significantly greater than the Group 2 students who had not established dominance. The Group 1 gains for reading comprehension were also higher than for Group 2, but did not reach statistical significance. Word recognition was more evenly distributed, possibly because this is the simplest level of reading, by three perceptual features in total word shape and is more easily adopted by left-eyed, right hemisphere readers. Group 1 had a positive trend in memory gains, in particularly phonemic memory, but small numbers have been a limiting factor in memory variables. These findings support Assumption 5, (Section 6.5, p. 137).

The exceptional right eye tracking performance and matching spelling gains by ‘successful’ LW (Section 7.3) illustrated the impact of newly established right eye dominance. This result stands in stark contrast to ‘unsuccessful’ performance patterns of ML whose remaining visual deficits were a mild limitation in divergence, with no dominance effect in tracking speed, and negligible gains in phonemic memory and spelling. These visual differences would not have been detected in standard optometry assessment, and yet the consequences are quite compelling. Fusional reserves in divergence and superior right eye tracking speed appeared to have been the key discriminatory visual variables, whereas phonemic memory and the discrepancy between reading comprehension and spelling were the key memory and literacy variables, respectively.

The evidence suggests that *tracking* speed is dependent on fusional reserves, particularly in *divergence*. Consequently, these two factors have a diagnostic value as indicators of o-m status. Divergence has been shown to be a particularly useful diagnostic test of o-m dysfunction associated with LD. Supporting evidence is that:

a) Anatomically, the abduction movement of the right eye, as in divergence, appeared to be critical for eye tracking from left to right when reading and writing English.

b) Statistically, right eye ‘dominance’ is associated with at least two, possibly three literacy variables.

c) Clinically, a range of fusional reserves of 24 – 30 dioptres was an achievable range for 15 students following vision training.
This fusional range has now provided a natural benchmark against which therapeutic potential might be judged. Indications of the range of deficits that are of 'clinical significance' are indicated to some degree in this study, in terms of evaluating where vision training might be used as a prophylactic strategy. However, further research would be required to set age-related, paediatric criteria based on before and after vision training o-m assessment of students who are under-achieving or have LD.

Neurological conclusions drawn from results
Recalibrating eye teaming with vision training may have re-established natural balance of neural pathways, with improved connections that allow greater efficiency of function and learning. It was reasoned that this possibility might open other avenues for research, to investigate further the relevance of o-m dysfunction as a contributing factor in LD, with implications for paediatric vision testing. Positive results affirmed the assumption that o-m imbalance and unreliable right eye dominance are an integral aspect of developmental LD, which provides additional management and remedial strategies.

Limitations of Educational Therapy practice exposed in this study
This Intervention Programme had disappointing outcomes for nine of the participants as there was an unacceptable level of unsuccessful eye exercises, and disappointing literacy results. However, as a review of Educational Therapy, Group 2 outcomes have provided a helpful guide to identifying critical factors for the implementation of more effective therapeutic practice. These outcomes have resulted in greater awareness and improved diligence in attending to 'hidden' handicaps that were not properly understood or taken into account at the time of the Intervention study.

Chapter 8 provides a forum for illustrating present Educational Therapy management principles, with a therapeutic rationale for a wider, more integrative therapy, as described in the on-going case studies of RW and GK. These reports illustrate in greater detail the personal impact of visual dysfunction and associated difficulties and deficits. The case studies are supported with findings from anatomical and functional neuro-anatomy literature and current research, which will contribute to furthering the Developmental Model of LD that has been progressively pursued throughout this thesis.
Chapter 8

CASE STUDIES:

Current Therapy and Functional Neurological factors

8.1 Current Therapy Management and Rationale

8.1.1 Integrative Therapy based on Luria’s Model

Results of the Intervention programme had shown mean pre-tests scores to be very similar for both dominance groups, consequently it would have been expected that outcomes would likewise be equivalent. As discussed in Section 7.8, disappointing outcomes of the Intervention Programme for nine of the participants exposed some limitations of the Educational Therapy programme. Not in the programme itself, as on average the sample achieved significant gains in all variables, but for those students who did not have stable eye dominance, it was apparent there were problems that had not been addressed, which may have blocked progress in these ‘unsuccessful’ students.

As a therapist, addressing the cause of the different outcomes for the two groups evolved into seeking ‘connectivity and coherence’, within the adapted (1973) Luria Model of Neural Function, by placing sensory integration at the base of the developmental hierarchy (Section 2.2.1). This model has proved to be an insightful guide when assessing each student, as the therapist is in effect referring to this model and asking the question:

*Where in the associative network of this individual are connections failing or mal-adaptive adjustments being made?*

From this starting point, a therapy programme has been designed from the feet up on the assumption that in order to correct higher order deficits, a clear, strong baseline of lower order mechanics is needed for optimal proprioceptive feedback and sensory network associations, and efficient motor functionality, including o-m co-ordination.

8.1.2 Additional input from Podiatry, Physiotherapy and Osteopathy

Records were analysed of sixty students attending Educational Therapy over the two year period following the Intervention Study. Advice was sort from a podiatrist and physiotherapist arising from three observations made by the therapist, which have not changed over the intervening years. Namely, students at risk have an unsteady gait; they are unstable when standing on one foot; and their eye tracking is just as unstable.
1) Unstable feet and unsteady gait
The podiatrist found from a matched sample of 20 patients in his own practice, that the majority of students with LD referred to him for assessment were ‘atypical’ in that they commonly had pronation, from one or both weak sub-talar joints. Presumably, at each step they were functionally losing up to 1 – 3 centimetres in leg length with associated knee and hip joint imbalance. It appears that flat feet may ache, but do not produce the spinal muscle anomalies evident in these students.

2) Posture and spinal alignment
The students’ spines may look straight but one hip is often tilted, one shoulder raised and head position misaligned either sideways or twisted so that the distance between ear lobe and shoulder is shorter than the other side, or the shoulders ‘see-saw’ in a manner suggestive of discomfort. Students were assessed by a physiotherapist who found instability of sacro-iliac, hip and vertebrae alignment and particularly at lumbar spine 4 – 5, and cervical 2 – 3. The latter may have implications for reflex re-actions from the cervical nerve plexus, to the vestibular and o-m system.

3) Eyes - one eye drifts, or looks larger owing to weak muscle tone
The earlier physical anomaly observed by the therapist was that one eye (usually the right) appears ‘larger’ or tends to drift sideways. In effect, one eye loses fixation and drifts outwards, often associated with a loss of attention to the speaker. The larger eye and facial asymmetry suggests uni-lateral, weak muscle tone and consequently weak binocularity which on subsequent assessment was generally found to be the case. This does not mean that every student with one larger eye has LD, as evidence from the Intervention Study. This showed that it depends on which eye is disadvantaged and whether this interferes with the visual pathway to the dominant hemisphere for literacy, or motor planning for intentioned actions (praxis).

The purpose of therapy is therefore to correct presenting ‘functional deficits’. From a neuropsychology perspective these might be considered as sensory misinformation and compensatory, mal-adaptations the brain might have been making in response to abnormal sensory input. The explorative nature of this therapeutic direction and management decisions are shared by the students’ parents, with positive outcomes of therapy leading to adoption of complementary therapies into the Educational Therapy plan. At the initial consultation, students usually present with a common pattern of deficits. They are then referred to a Behavioural Optometrist, a Cranial Osteopath and Dental Specialist if a bite-corrective-splint is needed to correct temporo-mandibular joint mal-function, and a Podiatrist for gait correcting orthotics, before commencing the educational therapy programme. Support for this holistic view is that the rate and quality of progress in vision training has shown an improved outcome,
for a higher proportion of students. The therapist's sense is that together, these treatments have the effect of 'loosening up' the visual system, with orthotics supporting the cranial adjustment so that old patterns of posture and movement do not become re-established. Support also comes from the parents' willingness to follow these recommendations, as this developmental approach aligns with the way they perceive the children's problems, in terms of levels of immaturity.

8.2 Two Case Studies

The following case studies are current students, so the study is an ongoing process. Both boys presented with deficits commonly found in students with LD, therefore the diagnoses, management and emergent results exemplify current Educational Therapy practice.

8.2.1 Case study 1: RW - male aged 7.4

An apparently atypical student responds well to the Educational Therapy programme.

This account of a current student is written as an ongoing report, integrating as it does various inputs and insights from a number of professionals who have contributed to a complementary therapy regime. Summaries of the boy's early medical reports and parents' concerns (in italics) provide a history of developmental problems of possibly neurological origin diagnosed as 'hemiplegic migraine'. He was included in the therapy programme to address: a) quite severe o-m dysfunction; b) gross and fine motor co-ordination, and c) to further explore what improvements could be achieved in an on-going assessment process. This case study makes the point that whatever the symptoms, it is not possible to make any assumptions until it has been clearly established that there are no sensory deficits impeding developmental progress, particularly in visual, auditory or vestibular / cerebellar domains.

RW was assessed by the Therapist eleven months ago and referred to the Behavioural Optometrist, Podiatrist, and Cranial Osteopath (see Appendix for description). He commenced therapy two months later, once prescription lenses and orthotics were in use and a course of osteopathic treatment completed. The delay was to ensure that any motor-sensory imbalances were minimised as far as possible before presenting him with 'therapeutic' challenges, which carry a risk of further embedding visual problems and causing discouragement if the 'motivation equation' was not in his favour. That is, if the outgoing effort is greater than the incoming satisfaction, then motivation will drop. However, as efficiency improves, the effort load is lifted, and therefore satisfaction and motivation rise. RW has now had 15, two-hour-long sessions and is on a four month break to consolidate progress, participate in winter sports, and to allow the family (in his mother's words) "for the first time, enjoy normal family life".
Earlier medical, neurological and occupational therapy reports and parents’ observations

Paediatric assessment:

RW was diagnosed by a paediatrician as having hemiplegic migraine in 2002, when he was 4 years old. Initial onset followed a bump on the head, with ongoing episodes including behavioural changes which are described by his mother as “becoming increasingly upset, right sided weakness and inability to keep his balance, uncontrollable limb movements, vomiting, and loss of speech expression and no recall after the event”.

Neurology:

RW was hospitalised three times in an eighteen month period. The neurologist explained that children who present with these symptoms need CT, MRI scans and TOE (Trans-oesophageal eco cardiogram) to rule out tumour, epilepsy, and heart conditions. RW’s tests in 2002 showed no abnormalities.

Neuro-psychological assessment: April 2004

RW was found to have LD, with intellectual ability within the ‘low average’ range. His basic expressive skills were intact with clear, well articulated verbal responses and word knowledge, verbal reasoning, and abstract reasoning above average, yet he struggled with large amounts of information or multi-step instructions. His non-verbal skills were less well developed with a rating at the lower end of the average range, with the strongest being visual perception and analysis, if there were no motor component involved. His fine movements and visio-motor efficiency and non-verbal processing were depressed as shown in poor writing, drawing, and construction. Generally he struggled to formulate strategies to solve problems, with hesitancy and lack of confidence possibly contributing to this pattern of performance. RW’s span of attention was normal, but he had a reduced capacity to register new information from the environment, so was regarded as being at risk of missing or misinterpreting information in the classroom (Summary of the original report).

Occupational Therapy report: October 2004

RW was enrolled in a mainstream Occupational Therapy program for treatment of poor visual motor integration and visual perception (both rated as very low: 1st percentile) although his motor co-ordination was average (25th percentile). This report states he had difficulty with writing, finding the correct starting position, forming letters with their constituent parts, staying on the line, and pencil control. Dressing was difficult with buttons, zips, and shoe laces, while learning to control a knife and fork took considerable time (Summary of a copy of the original). His mother reported that therapy included formation, sizing and placement of
letters in writing, motor planning, visual motor integration, stability at the shoulder girdle and fine motor skills, all based chiefly on repetitive gross and fine motor skill exercises. However, there was little improvement in his ability to write and the standard of his work was still well below that of his peer group.

Parents’ concerns: August 2005 (prior to commencing Educational Therapy programme).

RW’s mother writes: We were aware from discussions with the neuro-psychologist that up until the age of 10 years he could experience a developmental “catch up” period [in response to the challenges implicit in early schooling – author’s addition], but it was as yet unclear to what degree he might improve, whether he would be able to progress academically at peer level, given the nature of his LD, or what the long term issues might be after the age of 10. RW’s mother reports they accepted the fact they had a child with LD and writes “I felt there was a ceiling on his ability, because we had not seen any real improvements and he still experienced difficulties in other areas as well. I didn’t think he would be able to ‘break through’ this ceiling to go on to achieve a level of cognitive and academic success that would equal his peers”. Earlier developmental milestones of walking and speech were within normal limits and he had good social skills, but pre-literacy skills, word identification and numeracy skills were slow to develop.

Sample of RW’s written work, Feb 2005. Beginning of RW’s second school year, aged 7 years

Interpretation: I can surf on my Dad’s board

RW’s parents’ major concerns were firstly, his inability to write legibly, with uniform letters/words and to write on a line, rather than having letters below, through and floating above the lines (see writing Sample 1). Secondly, speech pathology assessment found his narrative skills were poor and this was reflected in his inability to construct sentences and transfer his thoughts onto paper. Thirdly, he was unable to ‘self regulate’; to start and work to completion of a task. This limitation also applied to his inability to undertake and complete daily living tasks. Fourthly, he has visual perception problems of spatial awareness and difficulty in retaining and replicating patterns. This appeared to be implicated in his inability to take in, retain and recall information sufficiently to understand and build onto mathematical principles, so he failed to grasp basic concepts and patterns. Fifthly, is unable to stay still long
enough to maintain concentration on the task. And lastly, school entry was delayed for one year, but pre-literacy development was still very weak midway through his second year.

His parents expressed the hope to at least support him at a sufficient level to enable him to move up each school year. He was placed on an Individual Learning Plan to enable him to remain in his peer level in prep (Victoria) and in Grade 1 (WA). He has had excellent support from his Grade 1 teacher and was placed in a school-based Speech Pathology programme in Term 3 which involved language development and phonological awareness of pre-literacy skills for segmenting individual sounds and manipulating these in words, including rhyming sounds. At the start of 4th term, 2005, a teaching aid supported his learning for 1 hour, 4 days a week.

Educational Therapy Assessment  August 2005

RW presented as a cheerful, willing child whose responses were stereotypical and not always relevant to the topic. Answers to questions frequently missed the point. He was easily fatigued and inclined to become emotionally fragile, particularly during simple visual tests. His eyes became sore and teary with simple tests like visually following the therapist’s moving finger in a minor tracking test, so assessment time was kept to a minimum.

Physical assessment – posture and feet

Posture was hard to evaluate because there was constant movement, particularly with ‘see-saw’ movements of the shoulders, as though he was trying to find a comfortable balance. There was also tension in his ‘raised’ right shoulder (trapezius muscle). His last ‘hemiplegic migraine’ was approximately six months before osteopathic treatments and except for one minor event, again following a bump to his head. There have been no further episodes.

RW’s feet were both severely pronated (collapsed arch / ankle assembly), the right worse than the left, which together with weak muscles, poor balance and ungainly gait means he looked as though he was walking on ‘wobble shoes’. Motor co-ordination and timing on the trampoline was extremely poor as RW had difficulty maintaining balance, finding a rhythm and jumping with alternating feet in a marching pattern. He was not able to match feet with arm movements either as he appeared to have little awareness or control of (particularly) his right arm. He displayed some degree of dyspraxia as he had difficulty fulfilling intentioned actions, because even though he was usually able to repeat simple sequential instructions, he would perform the wrong action.
Therapy - considerations and rationale

From a therapeutic point of view it was considered that owing to lack of muscular balance in posture and gait, these poorly defined movements may result in confused motor-sensory feedback and interference with proprioceptive senses, body image and ultimately motor planning. In terms of cause and effect it was not possible to say which comes first; neurological dysfunction or quality of sensory input. However, the therapeutic question was: How to best resolve the problem by finding a 'circuit breaker'? That is, how could the therapist improve proprioception, thereby supporting the vestibular (balancing) system and thus provide better integration with his visual system. This line of reasoning was based on the observation that his limited visual tracking skills and weak binocularity appeared to mirror the lack of awareness, strength, and co-ordination of his gait.

Poor eye teaming was similar in nature to his lack of hemispheric integration for cross-patterned movements between upper and lower limbs, which normally develop as part of an integrated crawling pattern. It was considered that therapeutic correction of pronation, by stabilizing the subtalar joints with orthotics, would contribute towards improving his balance, gait, and motor-sensory integration. As visual and vestibular systems are so closely related, it was reasoned that an improvement in balance and co-ordination would be reflected through the whole associative sensory network (Luria, Section 2.1), which could in time help overcome his dyspraxia and visual dyslexia. He was referred to a podiatrist for assessment.

Podiatrist’s report (Sept. 2005)

RW had “internal hip position from femur with bowing of bilateral tibia, but knee position is straight. Feet are fully compensating a forefoot varus with an 8 degree valgus in static stance. Gait is therefore bowed and heavy. Casts were taken for orthotics to stabilize balance and correct gait, dispensed 21.9.2005”. Mother has since reported postural improvement.

RW’s Visual screening - Educational Therapy

This screening uses simple optometry measures, which includes red/green lenses to view red and green words and images, on test slides, for stereoscopic vision to test binocularity. This test also differentiates each eye’s muscle performance (o-m function). RW showed very poor eye teaming and tracking skills, a mild esophoria of the right eye (turned slightly inwards) and a tendency for his left eye to drift outwards (diverge) when attempting to converge the eyes at reading distance, causing ‘eye strain’ tears. Convergence insufficiency strain resulted in intermittent and alternating suppression of central (foveal) vision as he was no longer able to discern letter details with both eyes together, that is, his eyes alternated, one eye or the other.
In a fixation disparity exercise (TED card) he tended to suppress his right eye and so had difficulty fusing two images into stereoscopic vision. Binocularity in convergence (looking in and down to see print in a book) was limited to 10 dioptres (normal range 24 - 30) before his vision blurred and suppression of one eye occurred. He was unable to relax accommodation (focus) of the right eye for clear near vision, and the left eye was blurred for distance vision.

**RW's Behavioural Optometry assessment**

Results of this assessment indicated his need for low plus lenses (slight magnification to take stress off the accommodation system) which were prescribed to provide support for his weak binocularity and to assist vision training in convergence and eye tracking.

**Therapy - considerations and rationale**

The implications for stability of eye dominance, bi-hemispheric integration and literacy is that these anomalies suggest he is right eyed for distance and left eyed for near work, although he is right handed. He could not cross his arms, but his hand position indicated he is naturally right dominant (Luria's crossed arms latent laterality test, Section 1.5) and he writes, eats and plays sport with his right hand. His mixed eye/hand dominance suggested disruption of the natural pathways that link vision to the language area for efficiency in acquiring literacy, as it is the left hemisphere that is specialised for language, word recognition and praxis (executive organisation of intentioned actions).

**RW's Memory and Literacy levels**

RW's auditory, visual and phonemic memory span are all limited to three items, consequently his working memory limitation is reflected not only in word skills, but also in sequencing exercises on the trampoline and following instructions. Likewise, he has managed to spell words of three phonemes quite easily but missed the r in 'from'. He would not attempt words of the test with four or more letters. He was unable to manage the oral reading and comprehension tests.

Test results (August 2005, at age 7.6 years, second year of schooling):

- (Rosner) Test of Auditory analysis: Grade 1 level
- (Schonell) Spelling: 6 yrs 5 mths
- (Schonell) Word recognition: 6 yrs 9 mths

**Educational Therapy Intervention programme and progress: Dec 2005**

RW has been taking nutritional supplements of Essential Fatty Acids (Efalex) as a complementary precaution against a deficiency in Omega 3, as this has been shown to support retina, myelination and cerebellum, all of which may be implicated, based on his case records.
Auditory processing exercises and rationale

RW's auditory memory span for phonics was limited to three phoneme words. However, auditory processing had made good progress so this was not as much a problem as his visual system. Phonemic awareness and memory, with visualisation exercises, are controlled as they are conducted in a dichotic mode. In this way, each ear is "masked" alternatively with relaxing music, so he listened to speech and discriminated speech sounds to each ear in turn. Each ear is stimulated individually in order to ensure that neither pathway is being neglected. Progress has been made in his reading and spelling with the addition to normal schooling of the therapist’s 'Patterns of learning' literacy programme based on perceptual and phonemic analysis. The end of year Speech Pathology report (Dec. 2005) affirmed that RW’s phonological awareness was within his education level, so “no further intervention is indicated”.

Vision training and rationale

Eye exercises using stereoscopic glasses include computer eye tracking. This exercise is dichoptic in that each eye has a different task at a different level of difficulty, but there is a need to have integrated feedback between the hemispheres in order to track the moving red ball and intercept the blue bat. Vergence and accommodation exercises develop smooth eye movements and balanced binocularity.

Interim report sent by the therapist to the Behavioural Optometrist: December 2005

RW’s prescription glasses have provided an immediate improvement in his visual perception, namely writing on the line and better letter shapes, although these are still large and untidy. After eight, two-hour therapy sessions on vision training, sensory-motor, auditory processing and word skills have improved, however only limited visual progress has been made to date. Eye tracking is very undeveloped as initially he had no idea of how to follow the movement of a finger, making Union Jack ‘tracks’ in the air for him to follow. He still tends to lose fixation on the moving object unless he is concentrating very hard. Midline flicker and tracking ‘wobbles’ are still apparent sometimes, but generally there is improvement - possibly not enough to explain the improvements reported in school (see writing Sample 2) and there is still a long way to go to achieve binocularity and right eye dominance.

Eye exercises have been focused on developing co-ordination and stamina of global vision and he is now just able to reach 8 (the goal is 24 - 30 diopters) on the tranaglyph in convergence, and divergence is also beginning to come together, so the global visual system is coping with the challenge with no further sign of suppression.
However, he still ‘loses it’ if asked to report on foveal detail (what the letters and words are doing), so he still can not manage fine detail like print with both eyes simultaneously. Phoria is still not steady as the left eye drifts and right eye tends to compensate by ‘locking’ into mild esophoria. Initially he suppressed his right eye at 4 dioptres on the TED card (fixation disparity exercise). Accommodation still varies from day to day, possibly depending on level of fatigue which may be the main factor interfering with his ability to hold binocularity. A review by the Behavioural Optometrist is requested in case there are other binocularity issues interfering with progress.

Neuro-psychology REVIEW: Dec 2005

In spite of the concerns about limited progress in vision training, the neuro-psychologist’s review is positive (the following summary is taken from the original report):

As at initial evaluation, RW still experiences ongoing mild weaknesses in acquisition of new information from his environment, fine- and visio-motor co-ordination, and non-verbal processing. During assessment he had intact concentration and task persistence and provided his best responses at all times. He still struggles with novel or complex non-verbal activities, so makes impulsive judgements but when prompted he is prepared to rework responses. His visual perception and analysis are stronger and fall within his age level.

His ability to store information for later recall has developed at an accelerated rate since previous assessment as he is now within the average to above average range for both auditory/verbal and spatial material. He has shown pleasing development in the literacy area and now scores at age level on the word reading test. At the completion of Year 1 (W.A.), migraines have ceased and disturbed sleep has diminished. Behavioural optometry assessment and Educational Therapy have both been beneficial. Mother reports RW “has been more settled, made friends at his new school and has no social difficulties”.

Results of standardized tests of intellectual ability showed that he has made solid progress and now performs within the ‘average’ range. Otherwise language skills are towards the upper end of age expectations. Progress in non-verbal skills has been greater than would be expected based on normal maturation processes although these still fall within the lower end of the average range.

RW’s Mother’s observations - interim review (January 2006)

RW has indeed ‘broken through’ many long-standing barriers which include an ability to describe thoughts accurately and write these down on paper (see Creative writing, sample 2); Speech therapy is no longer considered necessary (see Speech Pathology report). He has
shown some improvement in counting and his ability to retain and replicate patterns, however he still requires a deal of help in the area of mathematic principles so at this stage he still benefits from assistance in class with his teaching aide. Emotionally, RW is more relaxed / placid / settled within himself and is better able to 'cope with' and handle situations on his own. Physically, he doesn't have to move his body around constantly, which improves his ability to sit, focus and concentrate. He is able to use a trampoline to cross pattern his body movements across the mid-line. Writing is more mature with uniform, legible letters/words, consistently on the lines.

Sample of RW's written work, unassisted December 2005, aged 7.9

who sun-dial
I was making
a sun-dial
I was happy
because it was fun
I put sultanas
it was tasty

I now, still cautiously, feel that there is the real possibility / hope that RW will be able to learn and progress academically at peer level. I believe key management factors have contributed to these exceptional improvements in my son's dyslexia and dyspraxia.
1. Prescription glasses [to increase magnification and take the stress of his accommodation system so he is better able to converge his eyes and focus on his work – author's addition]. As soon as he put on his glasses he wrote clear uniform letters/words/sentences on the line.

2. Eye exercises to develop eye muscles for tracking, focus, vergence, and binocularity.

3. Orthotics in his shoes to correct his gait.

4. Two Cranial Osteopathy treatments.

5. Fish Oil (lime flavoured liquid is well tolerated) included in his diet 10ml, am and pm.

6. Extensive auditory processing, memory span and visualisation of letter/sounds, [from auditory to visual and vice versa until it is an automatic process – author's addition].

7. Cross-patterned exercise, balance and co-ordination together with sequencing and memory extension exercises on the trampoline.

Therapist’s summary as RW takes four month’s leave from therapy: May 2006.

Interim assessment

After 18 therapy sessions over nine months supported with a homework programme, RW’s spelling age is 7.4 showing a gain of 11 months; word recognition at 8.1 is a gain of 16 months; and an oral reading age of 7.9 which he was not able to manage initially, all are consistent with Grade 2 work.

If RW were referred for therapy at this stage he would be considered as falling into the category of visual dyslexia, with convergence inadequacy, suppression of foveal vision of his right eye, and weak spelling. Although sight word recognition has improved and he is reading independently for pleasure, oral reading and comprehension are uncertain as he tends to judge words by three features of the overall shape, as in ‘right hemisphere reading’. He will use visualisation when prompted, but it is not easy enough for him to use spontaneously. Multi-element concepts are difficult and this limits his access to number concepts. Limited memory span for detail is holding back his ability to ‘build a model’ from verbal detail and follow complex instructions, however, his activities of daily living and taking personal responsibility have improved considerably.

Mother’s report during a break in therapy: June 2006

After working in the Educational Therapy programme for nine months we have taken a six month break to consolidate and enjoy the progress and achievements [he] has made over this period of time. He is currently more happy and settled within himself than we have ever known him, he is writing legibly and is managing the academic content of Year 2 at a peer level.
standard (maths however is still a weakness). His reading has improved significantly and he reads now of his own choice.

RW is continuing to progress well. We are continuing with the Efalex and Swisse Childvite 1 vitamins. We are continuing with trampoline exercise, and red pen tracing with the green lens on his right eye. In eye exercises, he still does not seem to be able to get the merging red and green pictures together at the moment [global fusion]. A significant social improvement is that he is now more interested in playing with boys his own age and is able to 'hold his own' on computer games that boys his own age are interested in. Until 3 months ago he did not play the computer at all and would spend a lot of time playing with his younger sister (she is 2½ years younger) and her friends. From my perspective as a parent, I have realised that for the first time (since he started 3 year-old kinder) I have not felt constantly concerned about RW, about his ability to progress socially and academically [fit] has not played constantly on my mind. His progress in all areas has allowed me the luxury of being able to relax and not be constantly worried about him and this for me is a gift. A huge weight has been lifted off my shoulders. This programme has helped RW show recordable progress and I feel indebted to it for assisting [him] in achieving his best and we intend to return to the programme later this year to further explore his potential.

8.2.2 Case study 2: GK – male 10.5 years

This newest student's assessment profile is included as typical of most LD students

An assessment profile of OK aged 10.5 is included because his physical anomalies follow the typical pattern of students with specific LD attending this Educational Therapy practice. This student's experience also demonstrates that o-m and physical links with LD is a poorly understood problem in schools at this time.

GK was assessed yesterday (11.6.2006) and he exemplified some physiological issues under discussion in this thesis; namely, unstable arches, spinal muscle imbalance, a right eye that loses fixation and which can be observed to drift outwards when in eye contact with him, as when conversing. Visual assessment shows limited binocular fusion, which is assumed to contribute to 'left hemisphere neglect' in literacy, including phonics and phonological awareness which are poorly developed. Although motor co-ordination is good and he is a keen sportsman, his LD are manifest in poor performance following sequential instructions on the trampoline, and lack of clarity of speech, with poorly enunciated vowels. His behaviour
suggested discouragement and some anxiety which became more apparent as visual fatigue set in during assessment activities.

Although he is healthy and his mother reports he has plenty of energy, his work tolerance was less than 60 minutes even though activities were at an easy pace, in a supportive environment, with his mother present. In spite of breaks to jump on the trampoline, he fidgeted, slumped on the desk, wriggled and appeared to be acutely uncomfortable. He was willing to continue (as he obviously accepts his discomfort as habitual for him); however, his visual system appeared extremely ‘fragile’ as his eyes became strained and teary when trying to maintain binocular fusion in convergence, after which he reported that he could no longer see clearly with both eyes when using the flipper (accommodation glasses with one eye occluded). Completion of assessment was postponed until next appointment.

GK has recently moved from the local primary school to a private school to improve his learning skills. Following an Educational Psychologist’s report, he has been referred to this Educational Therapy practice because of “impulsive, anti-social, unacceptable” behaviour, which the school considers to be ADD, or ADHD and possibly dyslexia because of “LD, distractibility and fidgeting”. Medication was suggested instead of expulsion from the school.

Educational Therapy assessment

GK presented as friendly and co-operative. He had no difficulty in understanding and complying with quite complex instructions during simple binocular eye tests, he gave full attention and intelligent, observant responses and he is obviously keen to do well and succeed. He is certainly not ADHD and any medication for this might increase the risk of depression that students are reporting as teenagers, if they are mis-diagnosed. His attention span is excellent, but his work tolerance is undermined by what appears to be quite severe o-m dysfunction and postural muscle imbalances that impede smooth eye movements and also make him physically uncomfortable.

Physical assessment

His health and physical development is good, but small zinc deficiency spots on his finger nails suggest either nutritional mal-absorption or running high on adrenalin, as with stress. Small dietary changes have been suggested to increase zinc and eliminate artificial products in factory foods. He is already taking omega 3 fish oils which support cerebellum, retina and myelin sheaths for nerve impulse conduction. He reports his “head is feeling clearer already”.

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Both feet pronate, the right worse than the left, which undoubtedly contributes to post-exercise pain that he reports in muscle attachments around his knees (Osgood-Schlatter's syndrome). His back is straight but his hips are misaligned to the left (possibly gluteal tightness), the right shoulder is very tight. His head is held habitually to the right, such that he 'leads' with his left eye, possibly in the absence of normal binocularity because his right eye drifts outwards. It is advised that he have a podiatry assessment to check if his gait can be corrected with orthotics. It is expected that by maintaining normal balance in this way, osteopathy treatment can 'hold', rather than slip back owing to on-going pre-disposing factors associated with pronation with every step. It is possible this has contributed to muscle imbalance and mal-adaptation of proprioceptive senses as postural forces push up unevenly against gravity. Uneven spinal muscle balance might likewise create a discrepancy between the vestibular and visual system contributing to o-m imbalance.

NOTE: See Appendix C for a description of Cranial Osteopathy

Dominance
He demonstrated left dominance, with preference for left eye, crossed arm (latent dominance test) and also when he mimed eating. However, he eats right handed. He writes and bats right handed which can be culturally influenced in the case of mixed dominance (ambidexterity). He qualifies as having mixed dominance, but until o-m imbalance is corrected and balanced binocularity is established, with improved right eye movements and stamina, then the 'left dominant' eye can be regarded as dominant by default, with left handedness following the stronger left eye to facilitate eye-hand co-ordination.

Therapist's observation and rationale - Visual Assessment
GK reported that letters on the acuity chart were fuzzy when attempting to focus (accommodate) at reading distance. In order to understand what happens when GK is working, the three key elements of tracking, binocular and foveal fusional reserves were mapped, to establish initial measures, but also to uncover if further range was available, or how the visual system responded to what should be normal demands being made of it. The Behavioural Optometrist was concerned to implement vision training to resolve the problem of GK's slow visual processing.

(i) Phoria
Eye posture at rest is normally 0 dioptres (Howell Phoria Card), but GK's left eye turned outwards (7 diopters exophoria) and was steady, with the right eye drifting outwards (between 4 to 7 diopters exophoria). He is left eye dominant possibly because this eye is steady, but it
prevents convergence of both eyes at near range range, so no measurement could be taken of central vision (foveal) fusion.

(ii) Convergence inadequacy
Initially he was able to converge his eyes for stereoscopic global and central (foveal) vision on the tranaglyph (when superimposed images of both slides are fully overlapped and matched) viewed through red/green 3D lenses. He was able to maintain global binocularity for a third of the optimum range (10 out of 30 diopters), but complained of pain with this simple inwards movement of the eyes. After the first trial he was no longer able to achieve this binocular fusion of global vision beyond 2 diopters in both convergence and divergence, after which it broke into double vision. He was not able to report what was happening with the words on the screen, either because of visual and mental fatigue, or because he no longer had conscious awareness of central vision (foveal) images. In effect, his eyes were not able to turn inwards sufficiently, without pain, for binocular vision at near range range, so his left eye appeared to maintain monocular vision which predisposed him to ‘right hemisphere reading’. That is, the right eye with its most direct link to the language area can not operate as a full binocular partner. Foveal fusion might therefore not be possible for him under normal working conditions when his eyes are moving.

(iii) Accommodation
‘Flipper glasses’ are used to test the balance of the focussing mechanism (accommodation muscles) of each eye separately and together. Flippers consist of a pair of double lenses set at distance and near viewing. When viewed through one pair the visual imperative is to clear the focus which triggers muscle contraction to change focus for distance viewing and when the lenses are flipped over, the accommodation muscles must relax to focus clearly at the near range. With one eye covered, GK reported the right eye was clear at near range but rather slow to clear in the distance. The left eye could not relax at near range so the image remained unclear and even in the distance it was “fuzzy”, so in spite of the right eye being the clearest for near work, weak eye posture and lack of steadiness is determining left eye dominance, as binocular vision was blurred for both distance and near.

Reading
GK’s report of blurred images would certainly account for his difficulties in reading and he also displayed errors common to right hemisphere readers. His visual memory was limited to three items which was reflected in his reading. His errors indicated that he was attending to only three visual features of a word within letter groups or overall shapes. For example, ‘postage’
can be misread as ‘package’ because of the same shape of each word and common meaning. 

GK read ‘sugar’ as both ‘sausage’ and ‘sauce’ (limited awareness of sequences). He also had poor attention to detail with small words missed, or reading only two syllables out of multi-syllable words. In spelling he wrote ‘your’ as ‘our’. When encouraged to study each sentence before reading and attend to details, he managed reasonably well, but it took an unsustainable amount of effort and did not last.

**Literacy levels**

GK reports that he is ‘good at maths’ which is a bonus and something that can be advanced further with tutoring if needed, in order to provide him with a grade that reflects his intelligence in at least one area. It appears he does not visualise, and this is possibly linked to poor visual perception. However that can be developed in the word skills programme, so when he learns times tables visually he should be ready to manage proportional reasoning in Year 6. His literacy levels are handicapped by a poor awareness of individual sounds in words, which is reflected in his blurred speech, although he can manage to repeat words clearly when pushed. Impulsive responses account for much of the behaviour for which he is criticised and also for the error rate in writing, as he does not refer to his memory and ‘hopes for the best’ from rote memory of letter names for spelling, rather than extracting visual spelling patterns guided by phonological analysis. However, he quickly adopted the concept of having an ‘executive manager’ that checks things out first and proceeds carefully; for a short time his error rate dropped accordingly. Short vowels were poor, (‘a’ was uncertain, ‘e’ frequently called ‘i’, ‘i’ needed a reference picture, ‘o’ and ‘short oo’ were established, but ‘u’ was unknown). As mentioned this is an auditory as well as a visual problem. The spelling ‘options’ for the long vowels were not established for spelling, although present in his simpler, total word recognition vocabulary.

<table>
<thead>
<tr>
<th>Test</th>
<th>Score</th>
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<tbody>
<tr>
<td>Schonell spelling test</td>
<td>7.10</td>
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<tr>
<td>Schonell word recognition</td>
<td>8.1</td>
</tr>
<tr>
<td>Holborn oral reading</td>
<td>7.9</td>
</tr>
<tr>
<td>GAP reading comprehension</td>
<td>8.2</td>
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</tbody>
</table>

These low literacy results are of concern for a 10 year old in Year 5, however in effect he has only had eighteen months in a school where literacy has been taught, so he has missed all the early phonics work. His first school did not provide structured reading and writing lessons. He offered the comment “I asked my teacher in Year 3 when I was going to learn to read and he told me to ask my parents to do that”. This comment suggests that, with this Steiner school’s philosophy, it was not observed that he has dyslexic visual and auditory information processing problems.
Memory span

Phonemic memory span: Limit of 3 in a word, (any more caused errors or omissions).
Auditory digit span: 10.7 yrs. (6/7 correct forwards but only 3/7 in reverse (WISC-R).
Visual memory span: 3/5 but re trial 5/5 with only one small error.

Initially there were perceptual errors of lines and orientation, related to lack of stereoscopic vision. However, after providing GK with an analysis of errors and trials in visual problem solving, he managed the full memory span in a re-trial with an equivalent test and self-corrected one small error. Initially, poor attention to visual detail and a mentally uncoordinated approach to addressing tasks meant that he made careless errors from impulsive responses. Performance improved after careful coaching - he is a sunny-natured ch. d with a wry sense of humour, so all this was managed without stress.

Conclusions about GK

The lack of visual clarity for close work might account for his lack of perceptual clarity in awareness of small detail and poor eye-hand co-ordination, which results in untidy writing. Left hemisphere neglect and lack of visual clarity is a double deficit for GK that may well account for his LD and his discouragement.

Planned Therapy for GK

Specialist assessment by a Behavioural Optometrist is generally followed by eye exercises, to correct visual dysfunction and develop right eye dominance. A bridging programme involves bi-hemispheric integration exercises in physical co-ordination, auditory / visual analysis and memory to help develop word-skills connections. Educational Therapy results reported in this thesis show that establishment of right eye dominance significantly increases the speed and ease of learning, once auditory and visual aspects of phonics are established sufficiently to facilitate language-based tasks like literacy. Basic skills training for GK was provided in therapy sessions and was consolidated by parents, in a litle bit of home programme, which was expected to complement the remedial help GK was receiving already.

Report of First therapy session 22.7.2006

GK's visual profile had not altered in the last five weeks since the assessment. He remained left eyed, with exophoria at 7 dioptres in the left eye and 4 exophoria in the right. He was still not ade to 'centre' either eye after convergence exercises on the Brock string as initially he suppressed the right eye at 30 cms. However with hard work and some eye strain he managed to maintain the fused image up to 3 cms: from his nose (normal range). Tracking (by following
Union Jack movements drawn in the air by the therapist) was an effort, with some 'flicker' across the midline, loss of focus and ‘losing his place’. The stereoscopic glasses and tranaglyph with lateral movement of the two slides was still beyond his capability. In convergence, foveal vision was lost and binocular fusion broke at 4 dioptres, and recovered at 1 dioptre (expected range is 24 for foveal fusion and 30 for global vision). He did however have a ‘breakthrough’ on the fixation disparity TED card, as he discovered that the images were ‘floating in 3D’ and he managed to extend foveal fusion from 3 to 7 dioptres in convergence, so he had made real progress. He was also able to maintain concentration and energy for two and a half hours which was another great gain. He had obviously worked hard at ‘crossed pattern marching’ on the trampoline and he managed well, although ease and timing of movements were not yet automatic enough to be relaxed. Motor planning, memory span and sequencing exercises are ‘hard to keep together’ as he kept losing his place in his head, but he was most responsive to coaching.

Homework for the next fortnight consisted of simple convergence exercises (Brock string) with anti-suppression awareness; tracking exercises (Union Jack) for smooth following movements in all directions and particularly across the midline for seamless integration of the two fields of vision; and binocular fusion and foveal attention (TED card); right eye / handwriting exercises, (tracing with a red pen wearing the green lens on right eye in order to ensure the right eye is co-ordinating with the right hand, while retaining foveal fixation with no suppression). He also had a text where vowels were randomly printed in red or green, for him to be read with stereo glasses to engage binocular foveal fusion. Word skills lessons incorporate transformation from visual - auditory and vice versa presented by his mother from exercise sheets, consolidating short vowels, and multi-syllables.

**Report of Second Therapy session 6.8.06**

Dichotic phonological exercises commenced, wearing a head phone in alternate cars with ‘white noise’ music in one ear and therapist’s questions in the other ear. Short vowels were not clear and he managed only three phoneme words, did not visualise and became lost if required to change the last sound to make a new word, so there was much to be done before he can decipher words by sounds and spelling patterns. The word skills lessons for homework are designed to reinforce therapy exercises, patterns of spelling and variations of sounds.

**Visual progress**

Eye tracking movements were greatly improved with very few ‘flickers’. Right eye phoria was the same but left eye was responding (3 dioptres exophoria compared with 7 dioptres the
previous week, 0 is the goal). Convergence had improved, with fusional reserves (TED card) with stereoscopic lenses now achieving full foveal fusion to 9 dioptres in convergence. On the tranaglyph he maintained foveal fusion to 18 dioptres, double vision at 22 dioptres but recovery was still weak at 8 dioptres. He had very little sign of fatigue and he was ‘getting the knack’ of controlling his eyes. Accommodation flexibility was normal for right, left and both eyes together. There was no sign of suppression of right eye, so he was making excellent progress.

**GK’s visual progress suggests postural correction has helped**

The surprisingly quick response to vision training suggests that GK was either simply regaining normal o-m balance that he has had previously, or, there was some variable maladaptive response to abnormal sensory information from postural feedback from his proprioceptive senses via the vestibular system that was upsetting his o-m balance. A difference between the Behavioural Optometrist’s and the Therapist’s assessment, both using objective optometric measures, suggests that the latter explanation may be the immediate but intermittent reason for his schooling problems and disruptive behavioural responses.

**GK’s mother’s report**

The following communications are from GK’s mother in reply to the therapist’s report, and this is included as it makes the point that ‘disturbed’ behaviour can be due to physical discomfort and discouragement, which can be overlooked when neurological, or emotional / behavioural causes are being considered. His mother was asked to keep a record of GK’s problems and progress and these are included below.

**Mother’s response to Educational Therapy report 19 June 2006**

Thank you for forwarding your thesis report on GK. The information contained in this report is a handy reference point for us and will be forwarded on to his teachers at school.

As per your recommendation, we took GK to the podiatrist and during the wait for the orthotics he wore mass produced orthotics. Whilst these are not designed to remedy all of his problems, he has reported that he is more comfortable and is sitting better at school. He had a “really bad” time and was on a ‘Behaviour Report’ in the previous week, but is more comfortable and relaxed, his behaviour at school has settled down and he is enjoying school now. Indeed, I have not had a negative comment from the school about his classroom posture or behaviour since he has started to wear them.

It is also of great comfort to know that you believe that my son’s school difficulties can be remedied. Whilst he has been identified as possibly ADD, and ADHD we are very reluctant
to offer him any form of medication. We therefore are very hopeful that your program will assist him.

First Appointment — assessment: Mother's report: 11.6.2006
GK was keen to attend. He has experienced years of frustration and failure at school. In short, he knew something was not quite right with the way he conducted himself at school. At the appointment he squirmed, slouched on the table, he was restless and concentrated poorly - I gained a real appreciation why his teachers complain, it was most annoying! As GK does not finish all the class work this is added to his homework which should take a competent child 30 minutes maximum, but it takes him an hour to complete. GK's general behaviour progressively improved over the following weeks of the term and he received a Merit Certificate for this.

First Therapy Session: 22.7.06
GK was positive about the appointment, he sat still, concentrated and worked well - it was like watching another child! The orthotics have removed the persistent sore back, which incidentally we had no idea about prior to you identifying it. Since the first therapy session he has done his eye exercises daily, initially with me, but toward the end of the second week he was doing them independently. It is a struggle to finish school homework and the therapy work but to his credit he applies himself and usually completes all work although he leaves for school at 6:50 am and returns at 5pm, as well as sport twice a week. He is concentrating better at school, has not brought additional work from school this term, and I am impressed that he is quicker and more accurate in his work.

Second Therapy session: 6.8.06
GK did not want to go, saw no reason for it, couldn't see any improvement in himself as a result of doing the eye exercises and extra work. At the appointment his apathy was apparent, the therapist had to prompt him to stay focused, he squirmed and slouched a little. The therapist worked him hard, and after about an hour GK started to improve his attitude and concentrate. Further, tests of work that he had done after that hour allowed him to become aware of the advances that he has made.

8.3 Summary - ‘Common Pattern of Deficits’ from Case Studies
These case studies, although the boys are still in the early stages of therapy, have shaped the focus of the thesis in a number of ways. They reinforce the observation of a common pattern of deficits experienced by students with LD, with diagnostic support for the underlying integrative
providing a refined and positive direction in answer to the research question, by showing o-m dysfunction as one aspect of a systemic sensory-motor problem that is an integral, if not predisposing factor, in their LD.

The question at the beginning of this chapter was: Where in the associative network of this individual are connections failing or mal-adaptive adjustments being made? The answers are intimated in the narrative of these two students' ongoing therapy. The pattern of deficits is apparent in the following summary of the main deficits of each boy at the time of their initial assessment.

8.3.1a) Assessment findings: comparison of the Junior school students RW and GK

In brief, RW's speech and vocabulary was good but when expressing his ideas it was hard to follow in sequence and logic, and answers failed to connect with the point of a question. GK's speech was poor, as unclear vowels affected his pronunciation. Both boys were dyspraxic, RW severely so, lacking the ability to integrate right arm movements and perform cross-patterned marching on the trampoline. Both boys pronated, the right foot more so, with unsteady gait (corrected with orthotics). Their general posture looked straight, but GK had misalignment of the spine with subsequent back and neck discomfort, a tight right shoulder. He also held his head to the right side, so led with the left eye. RW was hard to assess because of his constant movement and apparent discomfort. Both boys responded well to Cranial Osteopathy, as they became more relaxed and settled.

The boys' visual profiles were likewise similar. Both boys' eyes tired quickly, more so with eye exercises. Both had severe eye strain in convergence. GK showed a full range of convergence initially, but then his visual system 'collapsed' as he lost the ability to relax focus at near, with images becoming blurred. RW had little convergence and no divergence, with eyes moving in parallel. Eye tracking was particularly poor; he had alternating foveal suppression, no stereoscopic vision and generally he could not use both eyes together. GK had asymmetric accommodation, poor focus of the right eye in the distance and of the left eye at near. In binocular vision both of his eyes blurred in distance and near, so he was largely monocular and left-eyed, possibly because his right eye drifted outwards, so generally he could not use both eyes together. This poor eye teaming limited global fusional reserves 10 dioptres briefly, then 'lost it'; consequently both boys had no foveal fusion. Both boys suppressed their right eye in convergence and divergence at 5-7 dioptres.

b) Assessment findings: Comparison of the Senior school students ML and LW
Details from the Intervention study show the initial assessment of two older students *ML* and *LW* (Section 7.2) were similar in o-m problems. *LW* had a weaker right eye, limited foveal fusional reserves of 12 dioptres; *ML* had a wider convergence range. In divergence, both boys had a foveal range limited to only 4 and 5 dioptres respectively, the point at which the right eye was suppressed for both students. Both boys were left-eyed; *ML* reported that “letters seen by the right eye slipped up and upwards”. His asymmetrical gait and posture and mildly ‘restricted’ motor co-ordination would have been referred to a podiatrist and cranial osteopathy under present Educational Therapy management. It is expected that this treatment would have offered *ML* a greater chance of success in establishing normal o-m function with full foveal reserves and right eye dominance. These changes may have eased his access to literacy and spelling gains, as was achieved by *LW*.

8.4 Adequacy of Optometric tests and School Vision screening

These results raise some serious questions about whether students’ interests are being best served under present optometric assessment. The questions are serious enough to justify further research and evaluation of current practices. As severe as many of these students’ o-m dysfunction were, optometry tests did not uncover any ‘significant’ problems. *RW* missed school vision screening, but a standard optometry assessment showed “clear, no optical issues”. However, low +0.50 lenses from the Behavioural Optometrist provided immediate improvement in writing. For *GK*, school vision screening found ‘normal vision’. Three subsequent, separate optometry tests also reported “no action to be taken”, although one optometrist noted “some trouble looking from the blackboard to desk” (relaxing accommodation for near work), but added, “glasses would be an over-reaction”. The fact that *GK* has difficulty relaxing his focus at near suggests a little magnification with low+ glasses might assist in improving vergence range and therefore fusional reserves. Obviously, both boys’ acuity was fine, the problem was that their eyes were not working together adequately for them to achieve foveal fusion, or their natural potential in schooling.

Three issues arise from this summary. Firstly, the fragile nature of these boys’ visual system predisposed them to fatigue and distractibility, both visually and mentally. This common problem made assessment difficult owing to variability of function, particularly related to close work, and even to the time of day. Normal risk assessment for an individual with LD should therefore provide a number of separate tests at different times of the day, particularly if a child is tired. It is important to retest suspect areas, in order to have an accurate profile of the student’s true situation under working conditions. Anything less than this must be misleading,
by providing false assurances about ‘no visual problems’, which can only lead to other, less helpful conclusions about the cause of the LD. In a topic so close to an individual’s welfare, such an assessment protocol should not be considered too difficult logistically. In RW’s case, although rigorous neurological assessment showed ‘no cerebral lesion’, his symptoms inevitably led to assumptions about his learning potential. The fact that his general coordination, including control of the right arm have improved to within normal range, suggests the problem was one of sensory misinformation and motor mal-adaptation, which have now been largely overcome.

The second issue is that of an adequate definition of what constitutes ‘normal vision’ and ‘no visual issues’ for children. The results of these case studies suggest that paediatric vision tests should take account of the developmental aspects of vision. Tests need to include information about literacy competence, as evidence of visual stress, under-achievement, or LD. This would determine the extent of the protocol required for accurate assessment. At the very least, a sample of hand-writing indicates any eye / hand co-ordination or perceptual problems arising from o-m dysfunction. School vision screening should incorporate simple tests of phoria, vergence, and fusional reserves, with referral to a Behavioural Optometrist for additional assessment. That is, assessment of foveal fusion, or any problem that may inhibit ease and clarity of focus on near work, including long-sightedness which many optometrists do not consider a problem for near work.

The third issue is that if vision specialists were more aware of the developmental consequences of having: a) weak binocular vision and limited fusional reserves; b) poor ability to focus clearly at near; or c) foveal fusion, then attitudes might shift from a fear of ‘over-prescribing’, to a concern about the risk of overlooking hidden visual handicaps, which may be small, but may still have serious secondary effects.

8.5 Functional Neurological factors pre-dispose to o-m dysfunction?

8.5.1 ‘Mal-adaptive’ adjustment to abnormal sensory feedback

A Developmental Model of LD needs to take account of what sensory input contributes to the early stages of learning. In terms of setting up networks and pathways to the neurological ‘end address’ such that incoming visual information is directed to the appropriate specialised area (Shatz, 1992, see p. 2).
The key deficit suffered by all the students with LD was that phonics were hard to learn and retain, so students failed to reach a level of automatic response that provides fluency. This is reflected in slow 'naming speed' – a key diagnostic measure of dyslexia. It is reasoned that o-m dysfunction causes variability of visual signals and consequently sensory dissonance. Thus a lack of reliable visual signals prevents the same neurones being fired repeatedly and consistently, in response to the same stimuli over time. O-m dysfunction might disrupt the input into the Sensory Information Store of the memory system. This in turn may prevent visual signals from being mapped onto auditory signals in the angular gyri to produce the dyadic attributes of phonics. Consequently, any significant delay between an auditory signal and its corresponding visual letter shape might then fail to register and fail to bond the two signals as a grapho-phonemic unit.

Likewise, during the formation of ocular dominance columns, if corresponding cells are not active at the same time as an incoming signal this "dissonance would lead to weakening and ultimate removal of that connection" (Shatz 1992, p. 41). Evidence supporting these assumptions was found in the lack of phonological awareness that co-occurred with a weak 'drifting’ right eye in the cases of RW and GK, and of ML and LW, which is characteristic of students with LD. Furthermore, on a student's 'bad days', working memory is variable and appears to lose access to what had been previously learned, as memory is dependent on the "precision and overall stability of the neural wiring, cells that fire together, to wire together" (Fischbach 1992, p. 30).

The causal explanation for anomalies associated with LD is generally considered to be that of 'brain damage during foetal development” (Corballis 1991, p. 195). The Developmental Model provides another scenario, that of maladaptive reaction to post-natal 'environmental’ causal factors, including the birth itself.

Change of eye dominance following vision training

Right eye foveal suppression might be an event that disrupts a natural pathway. Evidence to support this assertion was that generally students were found to be left-eyed initially, but left eye preference changed to right eye dominance once o-m balance was established between two equal eyes and foveal binocularity became possible. This finding suggests the left-eyed 'alternative' route had been mal-adaptive, in that it was less efficient, as it did not match predetermined dominance pathways. Inevitably this mal-adaption is intrinsically more stressful if progress requires more time and energy than normal, as was the case for the students in this study. From a therapist's perspective, o-m responses during vision training appear to be mal-
adaptive, in the sense of Piaget's concept (Piaget 1963, p. 42) of an organism's “assimilation and accommodation” to environmental influences and stresses.

The main conclusion to be drawn from the pattern of anomalies described in the Case Studies and results from the Intervention Study is that o-m dysfunction and hemispheric sensory neglect might be linked to the observation that these students are generally left-eyed, and right or left-handed. However, during therapy this changed naturally to stable right eye dominance once o-m function was restored, with balanced foveal fusion providing bi-hemispheric integration. Such integration has been shown in the Intervention Study to be significantly associated with improved memory and literacy skills. Interpretation of these results in this way might not have been possible, if a causal factor were identified as ‘brain damage’ or ‘lesions’, constitutional, or genetic, as is maintained by the medical model of LD.

The following section seeks answers from functional neurology and neuro-anatomy. In regard to possible correlates of foveal suppression of the right eye, which has been a consistent finding from the Intervention Study and Case Studies, and has become the central issue of interest in this thesis.

8.5.2 Factors preventing smooth, co-ordinated eye movements

Another way of asking the research question is: What naturally occurring phenomena can predispose an individual to having visual dysfunction in the absence of any neurological signs?

This question can be put into perspective by Emsley’s observation “We can never be sure of the extent to which other influences, such as impulses from the neck muscles and labyrinthine ... may be tending to urge the eyes somewhat away from the rest position” (Emsley, 1977 p. 39). That is a description of a ‘drifting’ eye. Eye movements are controlled by the external muscles which are attached to the eyeball and the orbit of the skull. Conjugate gaze with proper alignment and focus provide an integrated image on the two retinas and a neural circuitry that allows smooth binocular movements in all directions.

Anatomical considerations

Students' vision training has been benefited by Cranial Osteopathy treatment, that is, from gentle non-intrusive cranial manipulation. This contributes to correction of mis-alignment of cranio-facial bones, temporo-mandibular dysfunction and external muscles of the eyes. Krebs (1998) states that o-m factors can be caused from imbalance of the sphenoid bone position, as indicated by a deformed palate which “affects the whole cranial and dural membrane system”
Krebs points out that five of the six external eye muscles are attached to the sphenoid bone which is the ‘centre piece’ of the cranium, forming the posterior of each orbit and locking all the cranial bones together with the facial skeleton. Misalignment of the sphenoid bone then results in unequal tension of the eye muscles. Instead of smooth, co-ordinated movements, the eye’s movements tend to ‘stick’ and ‘jump’ and fatigue easily, with redness, teariness and rubbing of the eyes (Krebs 1998, p. 307).

Orthodontists note that narrowness of the hard palate (maxilla bones), has been found to coincide with torqueing (twisting) of the sphenoid bone and eye muscle co-ordination problems (Walker, R. 1997 cited in Krebs, 1998, p. 309). Oleski, Smith and Crow (2002) and colleagues have established radiographic documentation that validates the effects of cranial manipulation with Dental Orthogonal Radiographic Analysis (DORA, AAFO Journal 1997), with significant degrees of change (by 2.42 degrees) including that of the sphenoid bone. Smith also reported that changes were achieved with cranial manipulation which can affect the alignment of the 22 cranial bones. Smith states that according to Gray’s Anatomy “The sphenoid articulates with all the bones of the cranium, and five of the face” (p.36). Smith explains that the movement of cranial and facial bones is possible, as “bones derived from membrane, function like membrane throughout life… with sutural areas [connections –author’s addition] enabling hinge-like, sliding and pivotal actions …which the researchers describe as having the potential for micro-motion as a means of responding to bio-mechanical forces and stresses” (Smith 2002, p. 1).

**Functional neuro-anatomy**

In this thesis it is being argued that foveal suppression is due to intermittent ‘drift’ of the right eye, (Figure 12, Chapter 9) that reduces the area of binocular overlap and bi-hemispheric integration of visual information. Inadequate muscle control of the (potentially dominant) right eye’s abduction movements can interrupt the smooth movements when the eyes are tracking from left-to-right along a line of print.

Functional neuroanatomy provides some support for this assertion when the signs of abducens cranial nerve anomalies are considered. The abducens nerve is the only uncrossed cranial nerve. It supplies external rectus and oblique optic muscles, providing divergent movements of the eyes and is a branch of the sphenopalatine ganglion. This point provides support for **Assumption 1**, that divergent movements are controlled by the same muscles that provide the key movement in reading, that is, the left-to-right movement of the right eye (Ch. 6, p. 131). The nerve supplying these muscles is the abducens nerve, which passes through the superior orbital fissure in the sphenoid bone (Gray’s Anatomy, 1938 p. 290; 1992 p. 33), which may be
a source of problems if this bone is displaced sideways, as cranial nerves are unmyelinated and might be sensitive to abnormal pressure or tension.

From the perspective of functional neuro-anatomy (Chusid & MacDonald 1956, 1983) the abducens nerve supplies all important abductor muscles that provide divergent movements. Signs of abducens cranial nerve VI damage are: "mild, compensated forms of squint (strabismus), diplopia (double vision), compensatory tilting of the head and conjugate deviation in the form of foveal suppression" (Chusid & MacDonald, 1956, p. 78; 1983 p. 158). The list of abducens signs is a precise description of o-m dysfunction in participants of the Intervention Study and Case Studies, in particular, the limited range of divergence associated with foveal suppression in students with LD. This neuro-anatomical model likewise provides insights into how Cranial Osteopathy benefits the students by correcting alignment of the sphenoid bone and orbit, thereby allowing smooth o-m function.

Observations of physical anomalies in early childhood

A final observation about possible origins of facio-cranial anomalies is made by the therapist who has observed a similar pattern in younger children. That is, there is a sequence of developmental events from infancy to school entry for children who are eventually found to have LD. Problems such as limited cross-patterned crawling; anomalies of the bio-dynamics of gait which become apparent with later weight-bearing, or pronation causing poor balance, or ‘pigeon-toes’ with tripping. These may co-occur with earlier signs of one eye that is larger, or ‘drifts’, with concerns related to an infant’s visual milestones of visual attention, tracking, searching, gaze shift, and reactivity. On the issue of infant assessment, present practice does not reach the standards suggested by the Centre for Promotion of Child Development through Primary Care (Anderson, 2005). Post-natal assessment and gentle Cranial Osteopathy provides a promising preventative practice.

The multi-sensory approach to vision training is supported by Bach-y-Rita (1972) who states, “The extra-ocular muscles are under fine neural control ... for highly co-ordinated movements ... The eye motor control system includes an integrating system ... where multiple inputs (e.g., vestibular and visual systems, neck and eye muscle proprioception) interacts with neural inputs” (Bach-y-Rita, 1972, p. 126). Attention paid to motor-sensory integration and development ‘connectivity’ between vision, balance, and the postural muscles, together with vision training has increasingly contributed to improved literacy and learning skills outcomes in the Educational Therapy practice.
8.6 ANSWER to RESEARCH QUESTION 3

Where in the associative sensory network, of individuals with LD, are connections failing or mal-adaptive adjustments being made?

Answers to this question are to be found in the presenting pattern of physiological anomalies found in these two case studies and the majority of students with LD being assessed for Educational Therapy. This pattern includes unstable arches, spinal muscle imbalance, neck tension and o-m dysfunction, which might impact on physical comfort, sensory integration, and learning skills. Optimal development requires proprioceptive senses of movement and posture for co-ordination; the integration of auditory and visual information for phonics; and the integration of the two hemispheres so the frontal lobes of the brain are fully informed with two points of reference, in terms of stereopsis as well as the cognitive equivalent. This allows the student to integrate detail into the context of overall concepts as three dimensional thinking.

This summary supports Assumptions 2 and 3, that all senses, including auditory, visual, and vestibular, contribute to an integrated whole; and that binocular balance is a precursor of bi-hemispheric integration of visual information (Chapter 6, p. 132). As Luria stated, "A disturbance of lower zones of the corresponding types of cortex ... must therefore lead inevitably to incomplete development of higher cortical zones" (Luria 1973, p. 74).

In the final Chapter, findings will be discussed further in reference to a) the substantive research questions asked; b) the adequacy of the Luria model; and c) the conduct of the research.
Chapter 9

DISCUSSION

There are four strands of information integrated into this chapter. Foremost is Luria's Model of Levels of Neural Function which has been a most effective framework for Educational Therapy practice, and has also served to explain and support the findings of the present study. Secondly, there is a focus on the way therapy insights, explanations and principles have been guided by experience from the fields of Occupational Therapy, Education, Psychology and vision training. Thirdly, there is a consolidation of the results from the School Survey and the therapeutic outcomes that the Intervention and Case Studies have addressed regarding areas of visual, memory and literacy deficits. Fourthly, further information from the literature of theories and research are reviewed to determine how much they support the concept of an integrated, Developmental Model of LD. In effect, this chapter sets out to determine the adequacy of the Developmental Model as a heuristic device to inform both theory and therapy practice.

The content of the chapter is presented in six sections:

- Section 9.1 covers the purpose of the thesis.
- Section 9.2 synthesises the findings.
- Section 9.3 draws out key issues from the findings from a therapeutic perspective, and provides conjectured explanations.
- Section 9.4 discusses the dynamics of o-m dysfunction in terms of the neural framework of visual pathways, foveal suppression and left hemisphere neglect.
- Section 9.5 is a description of the seven levels of the Developmental Model in a probabilistic reasoning mode, incorporates the therapy principles, findings, support from literature and key issues.

Key issues and recommendations are given in Chapter 10.

9.1 Purpose of the Thesis

The stated aims of this thesis were threefold. The first aim was to find evidence from the School Survey, Intervention study and case studies to answer the research questions in terms of the developmental importance of balanced o-m function, in particular, for children learning the developmentally advanced skills inherent in literacy. The second aim was to challenge the adequacy of standard vision testing in paediatric optometry, in terms of developmental aspects of vision. The third aim was to advance a Developmental Model of LD based on Luria's
Model of Levels of Neural Function. This has provided a theoretical framework out of which therapeutic principles have evolved and informed the therapist's working theory.

- The Developmental Model projects visual dysfunction as mal-adaptive adjustment to physical and sensory anomalies.

Consequently, successful results from the Intervention Study were considered as validation of the Developmental approach, providing another avenue for further research and potential additions to present LD programmes.

9.1.1 From experience to theory: 'left hemisphere neglect' and LD

The main focus of therapy has been to address negative effects of o-m dysfunction, which have been shown to weaken binocularity, diminish the degree of overlapping visual fields and limit foveal fusion of the two retinal images.

- A key observation has been that students presenting with LD tend to be left-eyed because the right eye has weak muscle tone and co-ordination.

Theoretically, this is of concern if it disrupts the ontological move towards greater left-sided specialisation with experience and maturity (Luria, 1973; Shatz, 1992; and Purves 1994), which is of particular relevance to the acquisition of literacy. Hence 'Educational Therapy' aims to activate neglected pathways and create bi-hemispheric balance in auditory as well as visual modalities, using dichotic phonological exercises and dichoptic eye exercises.

Findings from the three studies provide snapshot of a consistent range of visual, academic, and memory factors presenting as a profile of 'LD'. The girls' school results represent normal parameters and so may be applied to a general school population as Shaywitz (1999) found the incidence of reading difficulties was evenly distributed between the genders (p. 999). (See Appendix C for the full list of the Inventory of Findings).

9.2 Synthesis of Findings into Key Concepts

In the following section findings from the School Survey are synthesised into key concepts which are supported from the research literature.

9.2.1 The lack of a statistical link between vision and literacy is clinically misleading

In the School Survey, the distribution of visual dysfunction and incidence of below average academic standards was evenly distributed. This data replicates a large body of research on which the Paediatric and Ophthalmology association's policy statement is based (1998, 2005).
However it would be wrong to generalise by concluding there was no correlation between the two factors of visual dysfunction and LD. Results showed that o-m dysfunction was linked with memory deficits. Likewise memory deficits were significantly linked with literacy. Memory was the prime variable as it is the medium through which both vision and literacy operate. Therefore, there is a functional, not a statistical link, between vision and reading. This study has created a clearer definition of ‘vision’ that incorporates o-m function; and ‘learning’ includes not only reading but also spelling and memory span. Consequently:

- A deeper analysis has dispelled the commonly held view that no link exists between visual dysfunction and LD.

(i) Acuity is well-managed, but o-m dysfunction was the problem

Acuity, the main factor assessed in standard optometry tests and school vision screening, was shown to have a negligible impact (8%), and was corrected with prescription glasses. However, o-m dysfunction was of concern. The optometrist’s analysis of their findings stated 52% girls had o-m dysfunction, 23% of which was heterophoria. If the eyes are not in parallel, binocularity is compromised and limits the range of fusional reserves. Ultimately this disrupts the ability to maintain binocular foveal fixation for small detail like print. The other predominant dysfunctions were unreliable or imbalanced accommodation (20%) and vergence (13%), particularly of near point convergence, which has the effect of limiting the ability to sustain clarity of focus for near work. Given the importance of literacy in our culture, an inability to perceive clearly and ‘effort fatigue’ not only impacts negatively on learning abilities, but the whole personal developmental process. The child may be unaware of the problem and others may not understand it, so self-perception is frequently undermined.

(ii) O-m dysfunction was linked with specific elements of learning

Specific factors of memory and literacy provided a clear link with o-m dysfunction, specifically perception, memory, literacy, and logic. Reading comprehension was associated specifically with binocularity, depth perception, and accommodation, as well as three memory factors, and deductive and abstract reasoning. Results showed a consistent and progressive increase in o-m dysfunction with age, rising to 38% from Year 8 upwards. From these findings it can be concluded that:

- Paediatric assessment protocol that includes o-m factors of foveal binocularity and vergence control would provide a clearer view of the students’ ‘internal’ working conditions.
- School vision screening should be more than a one-off school entry exercise.
Reading was found to be an imprecise measure of 'LD' as it lacked the discriminatory ability to indicate whether the student had underlying difficulties that needed attention. Literacy measures that included spelling with word recognition, oral reading, and reading comprehension, provided a more comprehensive profile. These observations were supported by results that showed an incidence of below average reading (32%) and spelling (62%). In terms of LD, in the reading deficit group 61% achieved spelling scores below average, but in the Spelling deficit group only 30% had reading difficulties. From this it was concluded that:

- 30% had both reading and spelling deficits and were classified as having LD.
- 20-30% proficient readers were poor spellers. This 'under-achievement' may indicate an intelligent and conscientious student struggling with visual dysfunction.
- 20-30% of students with visual dysfunction did not have LD.

For this last group, weak binocularity due to an imbalance between the eyes indicates that the difference between literacy levels might depend on which eye was disadvantaged. This question was addressed in the intervention study.

- Any literacy problems justify further investigation, including phonemic memory and visual function. A discrepancy between spelling and reading is an 'alert' signal that a more thorough o-m examination is justified.

(iii) O-m function and memory deficits linked to literacy

Phonemic memory and arm dominance were two key variables, with phonemic memory more discriminatory (than reading) as it showed a clear link with visual dysfunction. This included accommodation, divergence, near point convergence and saccades, which were linked with each of the four memory variables. In this way, visual dysfunction was indirectly found to be a contributing factor in LD. Phonemic memory showed the greatest difference between groups represents a useful diagnostic tool for both o-m dysfunction and LD.

- an indirect link was found between visual dysfunction and literacy, through the medium of memory through which both operate.

Results showed that the greater the memory deficit, the lower the reading and spelling age. There was on average more than two and a half years difference in reading ability between those with normal memory and the most severe memory group including all three categories of phonemic, auditory and visual memory. In spelling there was a difference of two years (between 1.5 years below and 0.5 above, average) between normal memory span and triple memory deficit.
(iv) Aspects of dominance and LD

a) Eye dominance results from the School Survey were inconclusive because these data did not indicate which eye was dysfunctional, so no conclusions can be drawn. Whereas the Intervention study showed that students who changed from left to right dominance achieved the most significant gains in literacy and phonemic memory.

- Results indicate that in the case of weak binocularity, the effect on literacy appears to depend on which eye is functionally advantaged.

b) Arm Dominance was employed as an indicator of neural dominance and was found to be a key factor. Arm dominance was significantly linked to all variables, eye/hand dominance, depth perception and vergence control; phonemic, auditory and visual memory deficits. Arm dominance also showed a difference between groups of 1.1 years for spelling and 1.6 years for reading comprehension. Although this dominance indicator may not appear to be related to visual or cognitive function:

- Arm dominance was a key factor. A ‘hidden’ indicator that dominance is an intrinsic part of the genetic neural architecture through which growth and learning evolves.

In the case of weak binocularity, it was concluded that literacy skills probably depended on which eye was dominant and whether a clear link was maintained to the left hemisphere language area. This supposition was substantiated in the follow-up Intervention study.

9.2.2 Benefits of right eye dominance after vision training and word skills

(i) Intervention Study – matched case studies of senior students ML and LW

LW became ‘successful’ in that he achieved right eye dominance in fusional reserves and exceptional right eye tracking following 15 vision training sessions. This was an increase in right eye vergence control and superior right eye tracking capacity of 20% greater than his left eye. This was matched with spelling gains of 2 years and 4 months and phonemic memory improved from 7 to 15 (optimum score), following the five day word-skills programme. These results can best be explained by the assumption that he had gained access to full bi-hemispheric resources of improved information processing and extra resources providing more efficient access to his established memory bank.

ML’s results stand in stark contrast, although he was the more conscientious and determined of the two boys, his performance patterns were ‘unsuccessful’. ML achieved some o-m improvement over 34 vision training sessions, but retained visual deficits of limited divergence range and no dominance effect in tracking speed. He had negligible gains in spelling and
phonemic memory. The differences between the boys’ visual function would not have been detected in standard optometry assessment, yet the consequences were quite compelling. This further confirmed that:

- **Key discriminatory variables** were phonemic memory span and a discrepancy between reading comprehension and spelling,
- **Discriminatory visual variables** were fusional reserves; right eye vergence range; and right eye tracking speed.

(ii) **Intervention Study results for the whole sample**
This study examined the literacy and memory span results for the sample group as a whole. On average significant gains were achieved in all ten variables. Significant gains in all ten variables were achieved by the majority of students following vision training and a week-long word-skills programme. Fifteen out of 24 students who had previously been left-eye dominant achieved normal o-m function with vision training and also changed from left to stable right eye dominance.

Word recognition skills improved by an average of 18 months; spelling gained thirteen months; oral reading gained just over 14 months; and reading comprehension gained almost 17 months. The main point of interest, not shown in these results, was the wide range of individual gains that was masked by the range of ages (6 – 18 years) and averaged scores.

(iii) **Intervention Study comparing the two ‘dominance’ groups**
Pre-test results indicated that initially both dominance groups were roughly equivalent in all variables. Group allocation was determined post hoc, in which the comparison between pre- and post test records indicated whether or not right eye dominance was established following vision training. Students who established right eye dominance had achieved full o-m function in tracking speed, in vergence range and had changed from left to right eye dominance. This ‘dominant’ group also achieved the greatest gains in literacy and phonemic memory after the week-long word-skills programme. By comparison with the group of nine students who failed to achieve normal visual function and/or remained left-eyed, had insignificant gains in spelling.

- These results suggest that literacy gains depended on which eye was dominant.

A therapeutically positive outcome has arisen from the negative results of nine “unsuccessful” students. Their limited results provided greater awareness of ‘hidden’ handicaps, which were not properly understood at the time of the Intervention study. These insights have resulted in more integrated therapy being implemented in current Educational Therapy practice.

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9.2.3 Specific details of newly established right eye dominance

a) Divergence range:

Participants in the ‘established right eye dominant’ Group 1 achieved on average a 20% greater increase in fusional reserves in divergence, compared with Group 2 with eye tracking speed that increased concurrently with an increase in divergence.

- Students retained right foveal image once fusion was broken, indicating right eye dominance where previously the ‘prevailing’ eye had been the left eye.

Divergence represents the most important movement for the right eye for reading, when scanning with saccades along a line of print from left to right.

- Divergence is particularly vulnerable in the case of weak binocularity. It is also crucial factor for o-m function in reading and writing.

b) Superiority of right eye tracking speed:

When o-m function is in binocular balance with optimum fusional reserves, it would be expected that both eyes would have an equal scoring capacity. For the left-eyed students, the left eye initially gained the better scores in a dichoptic, computer-based tracking exercise. It became evident from studying the student’s eye chart records that once fusional reserves had reached greater than 20Δ for students in Group 1, the tracking speed of the originally weaker right eye continued to increase whereas the left eye reached a plateau. On average there was a 20% superiority of tracking speed and accuracy demonstrated by each student’s right eye, compared with the left eye. That is, the right eye was superior in speed and accuracy.

- When both eyes are equal, right eye tracking has been shown to be faster and more accurate. Presumably this is an attribute of the left hemisphere’s processing style that makes it suited to the demands of fast processing of a mass of sequential data. Likewise better suited to processing language and ‘foveal’ detail, such as is involved in learning to read and write.

9.2.4 Case studies RW and GK, importance of motor – sensory integration

These boys exemplify the pattern of physiological anomalies commonly found in students with LD being assessed for Educational Therapy. This pattern included unstable arches, spinal muscle imbalance, neck tension, and o-m dysfunction resulting in a drifting right eye. Students with a weaker left eye displayed a different range of LD. The physical anomalies were responsible for physical discomfort, and results of these studies suggest they also impacted on sensory integration, and learning skills. This was evident because all three aspects improved once the physical problems were corrected with podiatry, cranial osteopathy and vision...
training. Improved physical function has been shown to address ‘developmental deficits’ of balance, co-ordination and eye tracking.

- Physical anomalies can be indicators not only of physical discomfort and discouragement but also of mobility problems.
- They may also be implicated in proprioceptive, vestibular and o-m desynchronisation, possibly leading to o-m dysfunction, weakened binocularity, and foveal suppression.

9.3 Key Issue - Central (foveal) Vision
9.3.1 Implications of clinical findings on visual function and learning skills

Foveal vision is a key issue arising from the case studies. Associated problems were poor eye tracking, convergence inadequacy and limited fusional reserves which were also key issues for current students attending the Educational Therapy practice.

Recent students show a similar pattern of ‘before’ and ‘after’ results

The Intervention Study findings were checked against that of the latest 18 students (5 females) aged 6 to 12 years attending Educational Therapy. A summary of individual records showed that in convergence exercises, once binocularity was broken, 11 of the students were unable to regain both global and foveal fusion. The remaining 7 students’ fusional reserve measures ranged from 2 up to 14 dioptres out of the optimal 24 dioptres. Divergence was even weaker for all students, with the right eye most commonly affected. Their limited abduction eye movements also adversely affected reading movements from left to right, with poor co-ordination and eye teaming.

Those results matched signs of abducens nerve involvement, which Cranial Osteopathy manipulation appears to release. Generally, a student’s visual system tended to become more responsive to eye exercises following treatment, provided orthotics continued to be worn to maintain balance in the bio-dynamics of gait and posture.

All 18 students achieved a full global range of 30 dioptres, and foveal ‘letter fusion’ up to 24 dioptres in both convergence and divergence. This range greater than the current clinical norm, but as these findings indicate, this is the ‘natural’ range generally achievable with vision training.

- Experience shows that these frequently undiagnosed problems result in limited fusional reserves, in which a weaker eye can intermittently lose foveal fixation.
9.3.2 Evidence of foveal suppression

The evidence from these studies showed that when o-m dysfunction co-occurs with LD, foveal fixation appeared to be a critical factor. In the case of weak binocularity, insufficient overlapping ‘fields of vision' preclude the ability to maintain clear focus on the point of interest and fuse images, under working conditions. As foveal fusion breaks, double vision is avoided by suppression of the weaker image leading to one half of the image failing to reach the contra-lateral visual cortex. In effect literacy depends on the o-m system's ability to maintain both fields of vision, of both eyes, for sufficient foveal focus on the print for “retinal fusion to be maintained” (Emsley 1977, p. 47). Speed and timing of input needs to be accurate enough for the foveal impressions to be received as separate... and provide time for the fovea to recover sufficiently to cover forty or more letters in a second and allow time for interpretation (Emsley 1952, p. 31). All of which occurs within an extremely narrow visual field essentially restricted to the fovea, which is “drastically reduced in dyslexics” (Juttner & Rentschler 1997, p. 55). Dyslexic and normal readers differ in duration thresholds of left and right fields of vision (Gross et al. 1978); the left occipito-temporal region (angular gyrus) is the area critical for skilled reading (Horowitz et al. 1998; Shaywitz et al. 2002); left superior temporal gyrus is normally involved in phonological processing (Aminoff, Greenberg & Simon 2002, p. 127); and ‘word form recognition’ is located in the left hemisphere (Bakker, 1980; Cohen, 2000; Dehaene 2003; Samuelson et al 2000).

Following this line of argument, the optimal connection is for fused images from both foveal fields of vision to the left hemisphere that remains reliable and intact. This criterion is exemplified by the examples of ML and LW in the Intervention Study, RW and GK Case Studies and the most recent group of 18 students. These findings suggest that factors contributing to inconsistency of sensory input become destabilising elements that ultimately compromise connections to the language area in the left hemisphere and may therefore become a predisposing factor in LD.

- it is not the severity of the problem that is the critical factor, but rather the unreliability of eye balance and movement (Howell & Peachey 1990, p. 16).

9.3.3 Foveal suppression as a ‘hidden handicap’

Unreliable o-m function presumably increases the margin of error in an individual’s ontological development. Literacy is a pinnacle of human evolution, consequently extraordinarily refined resources need to be developed during the process of learning to read and write. The degree to which an individual can perceive detail will influence the level of awareness. Although generally students had been assessed as having ‘normal’ vision, yet during Educational Therapy
assessment it was evident that much detail went unnoticed without him/her having a sense of
deficit. Lack of awareness of fine detail was a common problem and it appeared that the o-m
system was not adequate to support foveal binocularity.

Analysis of errors indicated deficits in perceiving finer foveal images of internal or sequential
details when reading, although perplexed by poor comprehension, students were unaware of the
detail they were missing, presumably because their global vision for the overall shape of words
was adequate for total word recognition. This was also apparent in spelling, where detailed and
accurate memory traces are required in order to reconstruct words from memory. Presumably
they failed to notice the lost detail if foveal vision had become monocular because clarity of
global vision was maintained. It was only when wearing stereoscopic glasses that students
became aware when details seen by (usually) the right eye ‘drops out of the picture they are
seeing’ owing to foveal suppression.

Bi-hemispheric visual processing and auditory / visual integration
These findings indicate that literacy difficulties are associated with a lack of both efficient o-m
function and matched binocularity for by-hemispheric processing, as well as visual input
matched to auditory signals in the associative areas of the left hemisphere for phonics. This
observation was supported by an unexpected finding from the School study, which showed
visual function was more closely associated with auditory than visual memory.

- Auditory and visual senses are of equal importance in the literacy networks,
- The ‘hidden’ nature of foveal suppression indicates that foveal binocularity is an
  important aspect of paediatric vision assessment.

Paediatric vision screening limitations
At the most fundamental level functional description of o-m proficiency is that if an individual:

- is not able to aim the eyes accurately;
- maintain fixation for as long as needed; and
- is unable to track along a line of print smoothly while fixating on foveal detail between
  saccadic jumps,

such o-m inefficiency should be regarded seriously as visual insufficiency, even if acuity is
normal. If both eyes are not fixated on the point of interest, the individual will lack the fovea’s
specialised resources of sensitivity to light and acute reception for colour, including ‘detail’
acuity for edge discrimination required for specialised shape-form recognition that has evolved
into letter recognition (Dehaene, 2003). In short this is the ability to register detail for accurate
memory traces from which to reconstruct letters in writing, or letter strings in spelling. Consequently,

"in the absence of reliable foveal vision a student would be restricted to intermittent macula vision at best, or, increasingly peripheral-like vision under conditions of eso- or exophoria that increases with fatigue, or in difficult fighting conditions."

O-m dysfunction might underpin the finding by Stein, Talcott and Witton (2001a) that "unstable binocular control and difficulty keeping the two eyes focused steadily on the print" may be due to poor motion sensitivity. If the magnocellular system fails to detect anomalous movements and fails to send correcting signals, consequently reading, spelling and orthographic skills are adversely affected (Stein 2001, cited in Robinson, 2002, p. 2; Cornelissen, & Stein et al. (1998).

Foveal suppression as a consequence of convergence inadequacy can be considered as a 'hidden handicap'. This has largely gone undetected, by the individual, by traditional optometrists, and by researchers, principally because it is not an aspect of standard paediatric vision tests, or school vision screening. These are simple acuity tests which are conducted under static conditions, with target, eyes and head immobile, consequently they do not take account of what is happening when the eyes are moving, or when abnormal fatigue occurs.

As shown in this present study, under the 'novel' viewing condition of viewing a transalp document through stereoscopic lenses, the individual has the means to become aware of what each eye is seeing. Under these conditions it is possible for the student to monitor foveal fixation on specific letter shapes, as bio-feedback, and to learning to overcome visual suppression of one eye. In the process, students learn the knack of consciously controlling eye muscle imbalance.

"O-m dysfunction omitted from current causal theories of dyslexia?"

Convergence insufficiency and instability of eye dominance are key concerns as these are commonly found in students attending the Educational Therapy practice. Stein, Riddell and Fowler (1986) likewise found "weak vergence and binocular control for small targets [print] in children with poor reading performance" (Stein et al. 1986, p. 319). Marks (1938) found unstable eye dominance, associated with control of fixation was significantly correlated with reading age. Eye movement deficits were in turn associated with short-term memory deficits (Stanley, Howell & Marks, 1988). Under present day standard optometric assessment, these subtle problems would have gone undetected in participants in this study, if tests of o-m function had not been part of this researcher's assessment protocol. The Developmental Model
view is that intermittent bi-hemispheric integration of visual information, into the left visual cortex and interrupted input into the associated language area, results in phonemic deficits. In the Intervention Study, post-test gains in literacy and phonemic memory showed gains associated with the establishment of balanced binocular o-m function in accommodation, vergence control, and right eye dominance following vision training. Particularly, sufficient fusional reserves were achieved to maintain foveal binocularity of up to 20 dioptres, and to maintain the right eye’s foveal fixation under vergence stress, as evidence of stable dominance of the right eye.

- foveal suppression compromises literacy competence

9.3.4 The importance of binocular foveal fusion

a) O-m dysfunction and foveal suppression uncovered in vision training

The importance of foveal binocularity has been demonstrated during vision training, because if the visual system cannot adapt under increasing vergence stress, as the tranaglyph slides are moved apart laterally, either fusion breaks into double vision, and then one image is suppressed to maintain a single clear image. In this thesis the argument is being developed to reveal that the visual system may respond with a response similar to the saccadic suppression effect. Under working conditions, a weaker eye may drift outwards to a degree where foveal fixation becomes unsustainable and breaks, as seen in the Case studies. The results of this study have shown that:

- if the right eye is weaker or drifts so that foveal suppression occurs, then the adverse effect on literacy is reversed once right eye dominance is re-established

b) Three levels of suppression, in global or foveal vision

Suppression is assumed to be a visual strategy to retain clarity of vision and avoid double vision while retaining clear, binocular global vision. However, it appears to be at the expense of foveal binocularity and so becomes a ‘mal-adaptive adjustment’ in terms of the demands of memory and literacy skills. Three levels of visual suppression have been uncovered in vision training. These effects were apparent on a) the Brock bead-on-string exercises; and b) failing to sustain foveal stereopsis in vergence exercises on the tranaglyph.

These suppression effects led to the notion of a third and deeper level of suppression. It was conjectured that the dominant pathway to the language area is lost if the right eye ‘drifts’ (as illustrated in Figure 12). Convergence insufficiency from long-sightedness, accommodation imbalance or fatigue of one eye can result in exophoria, such that the weaker eye fails to maintain foveal fixation. Consequently it is assumed there would be intermittent visual input,
which is depicted as dotted lines in the diagram. In any of these cases, letter acuity level is ‘lost’, and the left eye retains the image. It is reasoned that in time this may become perceptually dominant, by default. The degree of left eye dominance is therefore in proportion to the lack of constancy of right eye foveal fixation. This variability might explain:

- the difficulty in obtaining a reliable eye dominance reading for students with LD.

The present study supports a view that can be deduced from research literature that suggests optimal binocular vision incorporates a number of levels of parallel pathways. As noted by Emsley (op cit.) accurate accommodation and fixation between the two eyes enables binocular fusion of matched images of the fovea and surrounding macula. In order to register form and spatial movement respectively, co-ordination as functional integration is required of central (parvocellular) and peripheral (magnocellular) fibres. Lovegrove (1985) found that in reading, the high spatial frequency (parvocellular) foveal channels are involved with detailed central viewing and the low spatial frequency (magnocellular) peripheral channels collect general spatial information from peripheral vision (p. 4). Synchrony is also required between the two eyes, to match the two fields of vision of each eye and ‘split fields’ of the two foveae. Shillcock et al. (2001) found “part of the word to the left of the fixation point is initially projected to the right hemisphere and the right half of the word to the left hemisphere” (Shillcock 2001, p. 6).

The therapist had observed that students with LD tend to guess a word from the first three letters and the overall shape. This suggested predominantly left foveal hemi-field vision combined with right hemisphere reading (Saffran cited in Coltheart 1980). This observation is supported by Kelly et al. (2004) who found “dyslexics tended to fixate closer to the word beginning than normal readers” (p. 2630). This anomaly suggests insufficient fusion of the two foveal hemi-fields. This is possibly due to foveal suppression of the critical right hemi-field pathway that crosses over to the left hemisphere angular gyrus, resulting in a switch to left eye dominance for as long as the suppression lasts. Shatz (1992) states that binocular stimulation is imperative for neural development as it ensures that separate fibres of each eye run from the retinal ganglion cells, to the pre-determined ‘end address’ in the visual cortex in each hemisphere (Shatz, 1992, p. 34).

9.3.5 Preconditions of weak fusion and foveal fixation leads to suppression

The use of a visual pathways framework to explain findings of foveal suppression observed in vision training, require even deeper consideration. The effect of vergence stress has become central to the discussion, particularly convergence insufficiency and lack of balance in relaxing
accommodation to fixate at near range. It is being argued that if the eyes are not teamed, then
to avoid double vision, one eye is suppressed in a similar dynamic as saccadic suppression to
avoid blurring. The finding of foveal suppression has both diagnostic and prescriptive value.
For example, in the case of heterophoria, where the tendency is for the eyes to “deviate from
their primary position of central alignment when images are fused” (Emsley, 1977, p. 40), as
mentioned previously, it is conjectured that:
- if the fovea of one eye is not aimed accurately, then its point of fixation might be on the
surrounding macula, or drift onto the peripheral area of the retina, with loss of detail.
Foveal suppression can then occur, which includes loss of letter images seen
previously by the affected eye.

Suppression of the right hemi-field of foveal vision due to a ‘drifting’ right eye can be inferred
by findings of Lorusso et al. (2004) who employed measures of recognition of letters presented
in the centre and in the periphery of the visual field simultaneously, where “dyslexic and poor
readers” had significantly higher recognition rate of letters in the periphery to the right of
fixation, than that of ordinary readers” (p. 2420)... and yet they were the same as normal
Lorusso et al. suggested that the normal reader’s perceptual span narrows toward the right with
practice, in the direction of reading left-to-right.

The interpretation offered by Lorusso is of interest to this discussion. Namely that the
dependence on peripheral vision for letter recognition in dyslexic children might depend on
their difficulty in focussing attention in the centre field, thereby inhibiting the information
coming from the periphery i.e. in a more diffused attentional state (Facetti et al., 2000 cited in
Lorusso 2004, p. 2420). A similar lack of synchronicity between peripheral and foveal vision
was the explanation given for the difficulties poor readers had in reading words embedded in
text than single words (Hill & Lovegrove 1993; Lovegrove & MacFarlane (1990) cited

In response to Lorusso and Lovegrove, when a student’s right eye drifts outwards during vision
training due to heterophoria or convergence insufficiency, it is reasoned that the right hemi-
field of vision is out of range, with loss of foveal detail leading to ‘suppression’. This might
lead to a compensatory stimulation and increase of receptivity of the outer cone cells in macular
and peripheral vision. In other words, loss of foveal fixation might lead to a greater
dependency on, and development of, peripheral resources.
Bakker (1984) stated, physical activity can have a durable impact on the brain, for example, words flashed in a visual hemi-field have been found to modify electrophysiological activity [or conversely inactivity, which might suppress existing function – author's addition] of the contra-lateral hemisphere in dyslexic children and affect their subsequent reading performance (Bakker, 1984, p. 2). In other words:

- **Compensatory attention towards the periphery of the macula might be due to the absence of a reliable foveal image in the right hemi-field of vision, involving the right eye's major contra-lateral pathway to the left hemisphere.**

- **Suppression would in this manner serve to preserve clarity of vision, but at the expense of the most efficient pathways to the left hemisphere for acquiring literacy.**

Sireteanu et al. (2006) found dyslexic children presented with selective deficits in visual attention, as they were slower and had a greater error rate than the control group in feature detection. Interestingly, they did not show the "pseudo-neglect of the left visual field characteristic of normal adult readers". In effect, the dyslexic group differed from proficient readers in attending more to the left visual field with its major pathway accessing the right hemisphere. This can be interpreted as neglect of the right field of vision, and supports the notion that a 'drifting' right eye that loses foveal focus creates a mini-neglect of the dominant contra-lateral pathway to the left hemisphere, which might disrupt specialised processing related to literacy.

A statement related to the possible impact of oculo-motor dysfunction on selective attention is made by Serences (2006). "Conditions such as visual neglect might arise from damage in the post parietal cortex because it disrupts processing [italics added] at a point along the continuum that is strongly influenced by the behavioral relevance or the value of a stimulus ... not because the damage has destroyed the sole source of attentional control" (p.8). It can be reasoned that:

- in the case of disruption, from either 'stimulus source' or 'target driven attention', both might become a 'cause' or an 'effect' at any given moment.

There is further evidence from functional brain imaging studies of an abnormal increase in activity in the right hemisphere of dyslexics. This provides support for the assumption of right hemisphere dominance, by default, in the case of left hemisphere neglect. It shows that for dyslexics, left hemisphere posterior brain systems, of visual cortex and angular gyrus, fail to function properly during reading, when compared with the cascade of areas activated in normal readers (Brunswick et al 1999; Helenius et al 1999; Howitz et al 1998, op cit., Paulesu et al 2001; Pugh et al 2000; Rumsey et al 1992, 1997; Salmelin et al 1996; Shaywitz et al 1998;
Simos et al 2000 cited in Shaywitz, 2002). Similar areas of activation occurred during non-reading visual processing tasks, (Domb et al 1998; Eden et al 1996 cited in Shaywitz 2002) “a finding that cannot be ascribed simply to a lifetime of poor reading” (Shaywitz, Shaywitz & Pugh et al 2002, p. 108). In brief, it is assumed that:

- if foveal suppression interrupts the stream of visual information to the left hemisphere language area, this constitutes a form of ‘sensory neglect’.

These references support the inference from the present study findings of foveal suppression. Specifically, that left of centre field of vision may become the dominant pathway by default, owing to the intermittent loss of the right of centre field. This concern justifies the use of an illustrative diagram to describe possible functional dynamics of how and why foveal suppression occurs. This is represented in the following Figure 12, by the fibres from location 5 (green path) in the binocular field of vision.

9.4 Neuro-anatomical framework

9.4.1 Schema of right eye foveal suppression and left hemisphere neglect

The following Figure 12, described as ‘a schema of right eye foveal suppression’, is a heuristic device to illustrate the effects of o-m dysfunction and a weaker right eye, labelled ‘Right eye drift’. It shows the dominant pathway for literacy as being from the right of centre hemi-field of vision (red pathway from location 6 of the binocular f.o.v), because this contra-lateral pathway travels to the associative area of the left hemisphere, in the angular gyrus where visual signals are combined with auditory signals as dyadic grapho-phonemes. It is also the pathway most likely to be compromised as a ’weak’ eye drifts out of foveal range. This diagram also provides a framework to illustrate pathways from the “split fovea” (Shillcock, Ellison & Monaghan 2000).

The schema of right eye foveal suppression has been adapted by the author from Lindsay and Norman (1977 p. 74) and provides the means by which to trace and interpret effects of foveal suppression. It is conjectured that suppression effects, uncovered in vision training with anaglyph and stereoscopic glasses, might indicate a hitherto hidden deficit which is likely to happen under normal working conditions, in the case of a ‘weaker’ right eye that drifts outwards.
Tracing optic fibre pathways from the retina to the visual cortex, and beyond

Figure 12 Schema of right eye foveal suppression  
Adapted from Lindsay & Norman, 1977 p. 74

Fields of vision, location scale 0 - 10: right hemi-field crosses to the left hemisphere.
1 & 2 left eye monocular field;
3 - 8 binocular overlap;
9 & 10 right eye outer monocular field.

5 & 6 central vision, macula 1.5 mm. and fovea 0.5 mm. wide fovea cone receptor cells only.

Split fovea: 5 fibre pathway's destination is to right hemisphere, for spatial o-m feedback
6 fibres are the dominant 'literacy' pathway to the left hemisphere language area.

Lateral geniculate nucleus of six separate layers, alternate layers receiving signals from each eye.

Red/green stereoscopic lenses: Red letters look black when seen through a green filter, but green letters are 'neutralised' and can not be seen. The dotted lines represent the 'disrupted' pathways.

Consequently, the left eye would see a green-coloured 5 in the right visual cortex, and the right eye would see a red-coloured 6 in the left visual cortex.

Binocular fusion is required to combine the split foveal images as one, for word recognition.
The red/green glasses allow the individual to differentiate between what each eye is seeing, and which eye is affected if blurring or loss of foveal fixation occurs.
9.4.2 Description of Figure 12

Central vision includes the 1.5mm wide macula surrounding the 0.5mm foveal pit which contains a dense concentration of the smallest cone-cells (Emsley, 1977, p.19). The split foveal f.o.v consists of a colour and detail-sensitive reading span of approximately 3 centimetres, between two to three words, or one word in a beginner reader’s font size. The neurological importance of the fovea is reflected in the fact that it is “much more directly connected and... more strongly represented in the cortex than other areas of the retina” (Emsley 1977, p. 19).

When both eyes converge to focus on print at a reading distance, it is the nasal field of vision that is most directly aimed at the print and registered in the temporal area of the retina, with the fibres crossing over to the contra-lateral occipital lobes where conscious vision is aroused (Emsley, 1977; Frisby, 1979 cited in Palmer, 2002).

(i) Explanation of Figure 12

Figure 12 shows right and left fields of vision shaded to illustrate the pathways of each eye, with the binocular fields of vision optimum overlap of 2/3rd providing an area of approximately 10 centimetres of binocular span. The two fields of vision (f.o.v) are numbered on a scale 0 - 10, representing the location of a range of function-specific fibres. Left monocular vision is location 1 - 2, and 9 - 10 is right eye monocular vision.

Normal binocular range is an overlap between location 2.5 and 8.5, measuring an optimum range of between 24 - 30 dioptres on the tranaglyph, or 10 centimetres as the width of two pages of an average sized book, at reading distance.

When the uniocular images of each eye are sufficiently alike, “under the compelling desire for fusion” (Emsley 1977, p. 29), they become one perceptual image. In terms of optic pathways, according to Emsley, as both eyes are directed at a word, the foveal image in the right visual field is formed on the left halves of both retinae. This allows “corresponding areas of the retinae to be associated with a common region in the same lobe of the visual cortex” (p. 21). This arrangement not only allows for perceptual comparison of the images from both eyes to produce “stereoscopic relief in the external world”, it also “provides a common path from the two eyes to the o-m nerves, an essential basis for the co-ordinated movement of the eyes” (Emsley 1977, p. 21). As Emsley comments, vision has become the dominant sense in which “the wonderful mechanism of co-ordination in the visual apparatus” has evolved, however such a “complicated mechanism is more easily deranged than a simple one ...and in general, those faculties most recently learned, are the more easily upset and more susceptible to modification of development by training (p.30). This comment can be interpreted as meaning that:

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youngsters are more responsive to remedial action, but conversely more vulnerable to developmental deviation from the natural pathways, as a result of o-m dysfunction.

Relating this functional information to Figure 12, the retinal ganglion cells have long fibres reaching back to the visual cortex. The central field location 5 and 6 on the diagram are nominated as the foveal cone cells and fibres, represented in both eyes and in both hemispheres. Specifically, fibres from right of centre retinal location 6 of both eyes are represented in the left hemisphere, providing the closest link for the signals of letter images to be mapped onto its auditory equivalent in the angular gyrus for bonding as phonics. Under normal viewing conditions, the image falls evenly between location 5 and 6 of the fovea on the temporal half of each retina, in each eye. In Figure 12, fibres from location 5 (left foveal hemi-field and green pathway) from the left eye cross at the optic chiasma, combine with right eye Fibre 5 and continue in parallel to the right Lateral Geniculate nucleus. Here each eye is represented in a separate layer in which the fibres' positions are transposed, to arrive at the final destination on the right side of the right visual cortex. Likewise, Fibres 6 of both eyes is right of centre foveal hemi-field and is represented in the left visual cortex, such that fibres 6 are the most directly associated to the angular gyrus, language, and word shape recognition areas. Under normal viewing conditions, binocular fusion provides a completed foveal reading span comprised of the perceptually combined two hemi-fields of the split fovea.

9.4.3 Stereoscopic glasses uncover foveal suppression

In Figure 12, the red/green stereoscopic lenses show that a red-coloured 6 would be perceived as black through the green lens and conveyed to right eye’s temporal foveal hemi-field optic fibre pathway, from the retina to the visual cortex and language area. Whereas, the corresponding image would be ‘neutralised’ by the red lens on the left eye and therefore remain unseen, as depicted in a dotted-line.

Foveal suppression may occur when an individual is unable to maintain foveal fusion for near work, within the o-m demands of reading and writing. The ultimate visual requirement is that both eyes should be aimed accurately and consistently on the print in order to achieve binocular fusion, with the point of fixation falling evenly on the each fovea. Evidence reported in Chapters 7 and 8 suggests that students with LD lack this ultimate visual requirement. Stereoscopic lenses have uncovered foveal suppression during vision training. This manifests when students reported that (foveal) letters seen by the right eye had disappeared (i.e. from location foveal 5 and 6 in Fig. 12), although large (global) shapes were still visible to both eyes, so global vision had remained intact. It is assumed that suppression of both foveal fields of
vision from the weaker eye was due to loss of foveal fixation. If the eyes were not able to converge or accommodate adequately for clear focus for near work, this might cause the right eye to be displaced sideways (drawn as dotted line labelled ‘Right eye drift’). When the student’s left eye was covered, the missing letters reappeared, only to disappear again with the return to binocular viewing. Theoretically, the visual system had solved a problem of foveal double vision within global binocular vision, by suppressing the weaker foveal image. This is in spite of dual foveal pathways from each eye, to both hemispheres. As far as the individual was concerned there had been no awareness of the loss until prompted with questions about which words were seen. Presumably this lack of awareness was because there was no loss of clarity of vision, since the left eye’s global vision remained continuous. It is considered that:

- **stereoscopic glasses uncovered the hidden handicap of foveal suppression of one eye while global vision remained intact. Functional vision had not been disrupted, but fused foveal images and bi-hemispheric integration might have been compromised.**

It is reasoned that both fibres 5 and 6 from the right eye had drifted out of foveal range, or the incomplete or blurred image had resulted in an inadequate perceptual match, triggering both right foveal pathways suppressed by central visual processing. Either effect would leave the left eye dominant with monocular vision, with the dominant contra-lateral pathway to the right hemisphere where conscious vision is accessed. The recessive ipsi-lateral pathways provide the oculo-motor feedback. However, the right hemisphere lacks the primary language area and phonological facility of the left hemisphere, thereby creating a mal-adaptive situation that would adversely affect literacy acquisition. This might be through loss of detail, limited memory span for fine detail, or slower reaction times when adapting to new but less proficient areas in the right hemisphere.

This argument does not apply to an individual suffering chronic monocularity as the brain can adapt to constant conditions. Rather, it is the confusion of intermittent o-m dysfunction that is thought to create the phenomenon of foveal suppression (EGB). Visual word recognition requires matched and synchronised images from the two foveal hemi-fields. This is because a single word is split between the two hemi-fields (vertically split fovea), processed in each hemisphere and synchronised to produce the fused image for word recognition (Shillcock, Ellison & Monaghan 2000 p. 825). However, if there is a “failure to integrate the initially split input” (Shillcock & Monaghan 2001 p. 6) it might be assumed this would be owing to o-m dysfunction; an inadequate match or lack of synchronisation with loss of foveal fixation; or a weaker eye that is slower to respond, these disparate o-m dysfunction may create disassociation and as a consequence, disrupt visual processing, as has commonly been found in students during vision training.
As the stereoscopic glasses show, both hemi-fields are suppressed and in the case of a weak drifting right eye, words are registered predominantly in the right hemisphere. This suggestion is supported by fMRI studies which showed increased right hemisphere activation in dyslexic subjects (Shaywitz, et al. 2002; Simos et al. 2000; Howitz et al. 1998; Shaywitz & Fletcher, 2000). If suppression is a habitual response, this could account for poor phonological processing, slowed reaction times, poor word recognition, and ‘lack of attention’ to internal details of words, typically ascribed to dyslexics (Chapter 3). This finding may also account for the finding from Kelly & Shillcock et al. (2004) that dyslexics tend to fixate to “the left of centre”, closer to the word beginning, with longer fixation duration, further into the word which they interpret as “hemisphere desynchronisation”, presumably as a compensatory adjustment. Theoretically, if a child is reading with the left eye, this would account for right hemisphere reading.

It is theorised, from the findings of the present study that an intermittently ‘drifting’ right eye and subsequently loss of foveal detail might result in interruption of input into the right field of vision pathway, contributing to left hemisphere neglect, thereby disrupting and slowing the acquisition of phonemic memory and word recognition, as in LD.

- The key concept of this thesis encompasses the effect of loss of foveal fixation on neural pathways, based on the evidence of foveal suppression, uncovered in vision training with the use of stereoscopic glasses.

These points are discussed in further detail in the following Section 9.6 which constructs a Developmental Model of LD from the findings of these studies and the research literature.

9.5 Developmental Model of LD

The Developmental Model has evolved from therapy practice and the findings of these studies. This forward progress has enabled the therapist to ‘model’ the processes a student is going through when working to overcome LD. These findings have substantiated Luria’s model of neural function. The following discourse is a formulation of a Developmental Model of LD, which also serves as an overview of the thesis and effectiveness of the Luria Model in therapy application. Four aspects are woven into each level of the Developmental Model. These include clinical experience that incorporates aspects of occupational therapy, education, psychology and vision training; findings from the three studies; and therapeutic interpretation and concerns supported by theoretical and research literature.
9.5.1 The role of Luria's model of Levels of Neural Function in this study

The Luria 1973 model formulates three levels of function (summary from Ch. 2) including:

1) The primary function is in non-specific networks related to arousal, which are continuous and work on the principle of gradual change;

2) The secondary level includes memory traces arising from sensory stimulation. This relates to reception and relay of discrete impulses which differ from the primary level as they operate on an "all-or-nothing" principle, matching impulses with associative networks, and lateralization of pathways. These networks are sensitive to disruption from competing or masking stimuli, and if there is too much discrepancy in shape or timing, then associative networks do not fire, viz. auditory / visual signals in phonics.

3) The tertiary cortical level, where conscious activity assumes the character of a complex, self-regulating system which takes place through two-way, combined interactions working of all three functional brain units, with wave-like connections throughout the brain. It has "diminishing modality specificity and increasing functional laterality" than the secondary level functions.

Luria's model has provided diagnostic insights into functional pathways to be pursued through practical application in Educational Therapy. It has provided theoretical background and support as the framework out of which the Developmental Model has evolved. The Developmental Model is the theoretical basis for the three studies into LD is validated by the results which were in brief:

a) The School Survey found an indirect link between visual dysfunction and LD, through associations between o-m dysfunction, arm dominance and memory, which in turn were linked with literacy.

b) The Intervention Study showed that for 62.5% of the sample, vision training provided balanced foveal binocularity and ultimately stable right eye dominance, which manifest as superiority of right eye tracking speed, and foveal binocularity that ensured foveal fusion and bi-hemispheric processing. The improved visual function and emergence of right eye dominance made a significant difference to literacy outcomes. Thus validating the premise of the Developmental Model, expressed in the Key Research Question, namely that o-m dysfunction is a contributing factor in LD, specifically memory function and ultimately in literacy.

c) Early results from the two Case Studies of children with poor bio-dynamics of gait, balance and co-ordination show that orthotics and Cranial Osteopathy treatment made a difference to their physical comfort, attention span and facilitated the rate of progress of eye exercises. It is apparent that an individual's physical anomalies and internal environment can not be
overlooked as indicators of dysfunction, contributing to the reasons and solutions of behavioural problems, o-m dysfunction and LD.

The results of the present study substantiate the adoption of The Developmental Model, as it opens research possibilities in integrative therapies that might contribute further to the present management of LD, in individuals with a wide range of diagnosed disabilities.

9.5.2 Levels of the Developmental Model of LD

Luria (1973) described development as a 'bottom-up' hierarchical process, which will be followed in describing the ordered levels of the Developmental Model that incorporates sensory-motor-cognitive integration. These levels are presented as descriptive, diagnostic and prescriptive tools in the management of LD. It is a conceptual view of developmental processes, with evidence provided from results of the present study and linkage to the extended Literature Review. The 'top-down' selective attention model is the other component of this process described by Sirenteanu et al. (2006) and Serences and Yantis (2006).

There are seven levels proposed to the Developmental Model:

- Level 1 Sensory-motor integration
- Level 2 The central role of Dominance
- Level 3 Binocularity and bi-hemispheric integration
- Level 4 Hemispheric specialisation - angular gyrus
- Level 5 Foveal suppression
- Level 6 Left hemisphere neglect from right hemi-field foveal suppression
- Level 7 Literacy competence, Logic and Life Skills

In brief, in keeping with Luria's model of levels of neural function, contemporary research findings taken as a whole can be regarded as part of a Developmental Model, with even contradictory findings fitting in as another aspect of the whole. In this thesis LD are conceived of as being intermittent sensory disruption, diminution of integration between the associative networks and compensatory adjustments that may be mal-adaptive in some respects. Findings of this study and allied research are considered in the light of asynchrony between:

a) proprioceptive, vestibular and visual senses that orchestrate balance and co-ordination.

b) o-m function affecting balance and synchrony of the two eyes.

c) integration of auditory and visual modes for phonics,

d) the two hemispheres, through hemispheric neglect resulting in diminished bi-hemispheric integration.

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Level 1: Sensory-motor integration

(i) The principle of sensory-motor integration
Integrative therapies work on the principle that sensory stimulation and movement determines the architecture of neural development. Educational Therapy is based on sensory-perceptual-motor-cognitive skills that develop interactively, consequently the firmer the foundations, the greater the speed and ease of learning is likely to be (Luria, 1973, p. 74), as demonstrated in this study.

(ii) Therapy findings - muscle imbalance, from feet to eyes
The therapist's observation was that the majority of students present with a common pattern of physical anomalies. Namely, a noticeable disturbance in the bio-dynamics of gait associated with pronation (uneven 'collapse' of arch/ankle assembly) and spinal muscle imbalance, as exemplified in the case studies of RW and GK. Also apparent was a similarly uneven eye posture, or one eye larger than the other (weaker muscle tone), which eye tests show to include deficits in eye tracking, convergence insufficiency, weak binocularity, and limited fusional reserves, reported in findings of the Intervention Study. These observations were confirmed Podiatry and Osteopathic assessment and Behavioural Optometry respectively. Furthermore, treatment provided functional improved, further substantiating the integrative nature of the links between disparate symptoms.

(iii) Mal-adaptive connections - research findings
It has been argued earlier (Chapter 8) that the sensory-motor feedback loops and connections produce perverse outcomes if subtalar joint and postural muscle imbalances produce sensory misinformation in the proprioceptive senses. It was reasoned that these in turn might adversely affect the vestibular system and thence o-m balance as a mal-adaptive adjustment to abnormal input, with less efficient outcomes, which are slower and require more energy. In this way, poor connectivity becomes a learning difficulty.

The link between muscle imbalance of feet, spine, shoulder, neck and eyes were accounted for, within vestibular and visual systems, as neck and eye muscle proprioception all interact with neural inputs. The sensory associative networks operated on "orientation constancy feedback", between the visual system's retinal image and the proprioceptive system's information about the position of the head, through the vestibular system (Bach-y-Rita, 1972, p. 126; Emsley 1977, Vol. 2, p. 39; Palmer 2002, p. 334).
The sensory-motor principle has formed the basis of physical therapies involved in helping to overcome developmental deficiencies in children, and is supported by the work of Kephart (1971), Ayers (1979), and Farnham-Diggory (1992). Likewise, Dore DDAT exercises (Dyslexia, Dyspraxia, Attention Deficit Treatment) designed by Nicolson and Fawcett (1990) to stimulate the cerebellum (centre for motor co-ordination) and vestibular (balance) system showed "improved visual tracking ... and saccadic control" (Reynolds, Nicolson & Hambly 2004, p. 14), without eye exercises [author's addition]. Their research affirms the interactive connection between vestibular and o-m co-ordination, particularly as the cerebellum receives heavy magnocellular input (Fawcett & Nicholson, 2001, cited in Robinson, 2002, p. 2). There were also gains in "working memory, speed of processing and phonological skill" (Reynolds et al. p. 16). However the DDAT programme has been criticised because results did not "generalise across to improvement in literacy skills" (Snowling & Hulme, 2003, 127-133).

(iv) Descriptive and prescriptive view of LD – associative networks
Following the adoption of orthotics, cranial osteopathy treatment and low (+0.50) magnification glasses to take stress off the accommodation system, these additions were found to assist convergence exercises. Activities that brought about the most improved performance in Educational Therapy practice included vision training, left-hemisphere-based therapy exercises involving motor planning on the trampoline; sequencing; perception of word form and spelling patterns; dichotic exercises for auditory awareness and phonological analysis with visualisation; vision training with dichotic eye exercises to increase accommodation, vergence and fusional reserves (binocular overlap); and tracking to achieve foveal fusion and (generally) right eye dominance.

• Any omission in this therapy programme tends to reduce and delay results, which further validates the hierarchical and integrative nature of learning, which therapy needs to support.

Level 2: The central role of Dominance in the Developmental model
(i) Inferences regarding dominance are supported from research literature
Each hemisphere controls the contra-lateral side of the body. Lindsay and Norman (1977) state the left hemisphere receives input "from the right half of the visual field, tactile information from the right half of the body, and the bulk of auditory information from the right ear" (p. 448). Asymmetries of function between the two cerebral hemispheres include different processing styles. Such as the left hemisphere’s capacity to manage a large amount of sequentially ordered data, thereby making it suitable for expressive language, whereas the right hemisphere is geared for spatial, overview processing. Because each hemisphere has
specialised primary processing areas, dominance depends in part of the type of task. Eye
steaming connections provide bi-hemispheric integration of visual information, for efficient
information processing and motor-sensory feedback.

(ii) Therapy findings in the present study — arm and eye dominance
Hand dominance was generally regarded as the preferred hand for fine manual dexterity. O-m
dysfunction, for example, of the right eye early childhood may disrupt eye-hand co-ordination
(as the choice of hand to guide a full spoon to the mouth) to the point that hand dominance
changes from the genetically dominant hand to the recessive hand and adversely affect
language development. Luria's 'crossed-arm' test (1966) employed in this study indicates latent
dominance. Mixed arm / hand dominance was shown to be a key indicator of LD in the School
Survey as it was most closely associated with all the memory, literacy and logic variables.

Eye dominance was found to be evenly distributed in the School Survey, whereas the
Intervention study showed that newly established right eye dominance had a significant effect
on the outcomes of a week-long word-skills workshop. The right eye was likewise shown to
be capable of greater speed and accuracy than the left eye, with this superiority of function
predisposing it to greater suitability for literacy, reading and writing. Furthermore, as the
Schema of Foveal Suppression in Figure 12 shows

• The right foveal hemi-field is the dominant pathway to the contra-lateral left
hemisphere angular gyrus for mapping sounds to letters, for dyadic phonemic memory
and naming speed, in expressve word recognition.

Consequently, in spite of the difficulty in determining true dominance and vulnerability to
disruption in the developmental process, dominance was shown in the present study to be
critical for efficient learning skills. It is reasoned that intermittent suppression of the right eye
might lead to compensatory adaptations in the right hemisphere which are less efficient and
thereby recognised as LD. That is:

• the more often the right eye's foveal fixation is lost, the greater the likelihood that the
left eye will become dominant, by default, intermittently and increasingly with fatigue.

(iii) Right hemisphere dominance - by default? Research findings
Further support for a compensatory increase in right hemisphere activation shown in dyslexic
subjects is provided by a number of researchers in functional Magnetic Resonance Imaging
(fMRI). In three studies, normal readers were found to activate the temporo-parietal language
regions, critical for skilled reading ...whereas the dyslexics in the main activated the
Corresponding regions of the right hemisphere (Shaywitz, et al. 2002, p. 102; Simos, Breier &
Dyslexic men also showed a "functional disassociation between the angular gyrus and visual areas in the left hemisphere" whereas normal readers had strong connections in the left but very little in the right hemisphere (Howitz, Rumsey & Donohue, 1998 p. 7). Shaywitz, Shaywitz and Reid-Lyon (2004) conducted an intervention study, where participants also showed improvements in brain organization that were significant and durable, and had continued to improve a year later (p. 930) ..."as right hemisphere processing would no longer be necessary and diminish once the more efficient left hemisphere networks are established sufficiently to sustain reading demand" (p. 931).

(iv) Functional indicators of laterality
The Intervention study of this thesis found a 20% gain in: a) tracking speed and b) fusional reserves, particularly in divergence, in students who achieved stable right eye dominance with vision training, which was c) followed by significant improvements in literacy. Furthermore, the 'successful' students had d) changed from left eye 'advantage' in range and scoring capacity to stable right eye dominance. It was reasoned that these four factors are functional indicators of laterality pre-disposition. As exercises progressed, in this study, generally the right eye became the dominant 'prevailing' eye without stress or fatigue. Although right eye was weaker originally, these results suggested it had been the genetically dominant one, which had become 'released', with vision training.

- **By definition, eye dominance may be described as being the neurologically determined 'leading' eye within a balanced partnership of two fully-functioning eyes.**

Pre-conditions can be further confirmed as being: a full range of binocular foveal fusional reserves, providing reliable bi-hemispheric, contra-lateral pathways to whichever areas are appropriate for the task, supported and reinforced by appropriate multi-sensory feedback.

Level 3: Binocularity and Bi-hemispheric Integration

(i) The principle of bi-hemispheric integration
It was conjectured that L.D, in language based tasks like literacy, are partly due to disrupted bi-hemispheric integration of visual information and upsets the genetic visual dominance pathways to the language area. Just as binocularity facilitates stereopsis, and allows details to be seen in special three dimensional context, bi-hemispheric processing may likewise be considered as facilitating 'depth of field reading' that includes many levels of interpretation. This metaphor also applies to logic, with awareness of what are relevant and significant issues, using left and right hemisphere logic and divergent thinking in decision making, as adaptive intelligence (Piaget, 1963, cited in Travers, 1977, p. 154).
Binocularity which produces three dimensional vision can be equated with bi-hemispheric processing which delivers three dimensional cognitive skills by integrating two points of view.

(ii) Therapy findings – effect of vision training on learning skills

The usefulness of the ‘developmental model’ and its practical application is apparent from the positive outcomes of vision training, followed by significant outcomes of the word-skills workshop in the Intervention study. In LW’s case, he changed from left to right eye dominance with normal o-m function and integrated binocular vision. His remarkable results can be seen as an expression of his innate intelligence and abilities that he had previously been unable to manifest. His self-professed ‘lazy’ attitude was interpreted by the therapist to be a combination of discouragement and stress avoidance.

Even though both LW and ML had excellent reading comprehension, with imaginative interpretation in spite of being ‘careless’ right hemisphere readers, the foveal suppression in the right eye of both students may have been complicit in “memory deficits, poor phonological awareness, slow reading performance, and a range of associated LD” (Reid-Lyon, 1995; Shaywitz, 2002; Snowling, 2001b). These factors were all part of these two students’ deficits profile, in common with the majority of students attending Educational Therapy.

(iii) Change to bi-hemispheric processing – Research findings

Bi-hemispheric processing is an integral part of cognitive activity, including literacy which accesses highly specialised skills and reading-related thinking, correlated with high level activity in the left-hemisphere cortical regions and language processing centres in the brain. But learning to read is also a dynamic aspect of neural development, which in Luria’s model is mediated by the senses and lower order systems like the cerebellum to relay feedback mechanisms between all the senses, including the vestibular and proprioceptive senses.

Further affirmations of present study findings are that Wiesel and Hubel (1965) stated: “deprivation effects ...of some sort cause disruption to innately determined connections ... and maintenance of synapses” (cited in Bach-y-Rita 1972, p. 51), which “depends not only on the amount of incoming impulse activity, but also on a normal inter-relationship between activity in the different afferents” (p. 52)...from the vestibular and visual systems, and neck and eye muscle proprioception (Wiesel and Hubel 1965, cited in Bach-y-Rita 1972, p. 126).

- In this way literacy is a long-term outcome of an integrated sensory-neural system.

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Reading is a language-based activity and phonological processing is a known key predictor of reading difficulties, none-the-less, in Educational Therapy practice, predisposing factors in LD are found to be deficiencies of either auditory or visual function, or both. They are of equal importance, as signals are needed from both sensory modalities, matched in sound / shape and timing, in order to bond both signals as a dyadic unit in phonics. Hayek (1952) in his essay on perception and memory stated that temporal coincidence of inputs from multi-modal and internal sources, by association become the “essence of sensation, perception and memory” (Hayek, 1952, cited in Fuster, 2003, p. 8).

**Binocular fields of vision and bi-hemispheric processing**

The finding from the present study that foveal fusion can be broken when students lost foveal vision in one pathway, while leaving global vision intact, may be due to both global and foveal vision being ‘split’ vertically. That is, divided into left and right fields of vision (f.o.v), with “part of the word to the left of the fixation point initially projected to the right hemisphere, and the right half of the word to the left hemisphere” (Shillcock & Monaghan 2001a, p. 6). Consequently, synchronicity and fusion of two parts of the word is required for bi-hemispheric visual and lexical processing (Shillcock, Ellison & Monaghan, 2001, pp. 824-851). Fusion brings the two word halves together for word recognition. Consequently it can be reasoned that foveal suppression may have two inhibitory effects, where it might:

a) interrupt input into left hemisphere for phonetic auditory/visual bonding;

b) suppress one hemi-field which would prevent foveal fusion for word recognition.

c) constitute left hemisphere neglect including dyspraxia

Adaptive mechanism are employed as the individual adjusts fixation to off centre (Shillcock & Monaghan, 2001 p. 6), or encompasses outer macular and peripheral retinal cells (Spafford & Grosser, 1991, p. 10), presumably in compensation for the loss of one foveal hemi-field. This research finding fitted a description of many students in the present study, who had excellent reading comprehension with silent reading, but difficulty with recall of detail. Oral reading frequently lacked fluency and was hampered by inaccuracies.

**(iv) Functional indicators of lack of bi-hemispheric processing**

Monaghan and Shillcock (2004) found poor readers had an increased awareness of exterior letters, which was consistent with the therapist’s observation that left-eye-dominant readers base word recognition on three main features in the shape of a word. They also have limited phonemic and visual short term memory which may account for phonological and visual errors in reading. A difficulty with reading non-words may be accounted for by poor phonological processing due to left hemisphere visual neglect in the angular gyrus matches the description of
to bond visual-to-auditory signals for phonics, fails to see enough detail to register internal
details of words, or to perceive spelling patterns, or build a spelling vocabulary, as in the case
of ML and LW.

• a discrepancy between spelling and reading comprehension is indicative of left
hemisphere neglect.

It may also be added as a rule of thumb that:

• if a right-handed writer insists on placing his/her work to the left of the body midline,
this tends to signal the left eye is leading, possibly due to the right eye's inability to
sustain foveal binocularity.

Level 4: Hemispheric specialisation – angular gyrus

(i) The main hemispheric specialisation in literacy

In this present study, the left angular gyrus became an area of special interest as it was the
associative area where visual and auditory signals are bonded as phonics, into dyadic memory
traces. It is conjectured as being the neural equivalent of the genesis of literacy, which makes
the right eye / left hemisphere dominant for literacy. In support of this area of interest,
Corballis (1991) states that “left-hemisphere dominance holds for reading and writing as well
as speech” (p. 174). The left occipito-temporal region (angular gyrus) is considered by others to
be the area critical for skilled reading (Shaywitz, et al 2002).

(ii) Therapy findings – phonemic memory as a key factor in literacy

In the School Survey, two items - arm dominance followed by phonemic memory - were the
strongest ‘key’ factors associated with literacy levels. This finding was validated by the
significant gains in phonemic memory for students who had achieved eye dominance in the
Intervention Study. Dejerine noted in the late nineteenth century that “damage to the
angular gyrus produced an inability to read ... and write ... in patients who had previously been
literate (Dejerine cited Corballis, 1991, p. 174). The implication then for beginner readers is
that if auditory and visual information is unreliable and fails to match in the angular gyrus in
time and consistency, then the rate and quality of learning to read and write may be adversely
affected. This however, would not be from sudden loss of an existing skill as a result of
trauma, but as:

• a developmental difficulty, from piecemeal neural disruption of sensory input and
pathways, which over time makes literacy time-consuming and hard to acquire.
Angular gyrus—visual signals mapped to auditory signals as grapho-phonemes

Snowling (2001) observed that the relationship between dyslexia and other learning disorders is not fully understood, however, language based deficits are possibly the causal link “in the output rather than input systems” (Abstract). In terms of Luria’s model of levels of neural function, it can likewise be argued from the findings in this present study, that “output” includes links with associative areas. This includes left visual cortex signals into the neighbouring angular gyrus which is “a crucial transmodal interface between auditory or visual word forms and stored lexico-semantic knowledge” (Mesulam, 1998 cited in Cohen, 2003 p. 1327). Cohen et al. also noted that the left angular gyrus was activated at similar levels during word reading as well as during simple visual fixation (p. 1328), which appears to be a ‘priming’ reaction as ‘reading preparation’. Hence the importance of foveal fusional reserves that ensures bi-hemispheric integration of visual information. Monaghan and Shillcock (2005) conclude that asynchrony between the hemispheres, of visual origin, contributes to dyslexic difficulties. In particular, the phonological difficulties dyslexics have in reading irregular or non-words results in compensatory mechanisms “owing to their inability to integrate orthographic information in the two hemispheres and map it directly onto phonological representation” (Shillcock & Monaghan, 2001b, p. 6).

Other researchers have similarly found auditory, visual and reading links. Auditory and visual variables were both robust predictors of children’s literacy skills (Talcott, et al. 2002); dyslexic subjects were found to have impaired accuracy sensitivity to both dynamic visual and auditory stimuli, (Talcott, 2001b); asynchrony of speed of processing between visual-orthographic and auditory-phonological modalities was found to be associated with word recognition deficits among dyslexic readers (Breznitz, 2002, p. 16); dysfunctions in accommodation and/or vergence were associated with deficits of coming to attention and sustaining attention (Borsting, 1991, p. 152). Under-achievers in a group of gifted children were also found to have visual problems similar to those of this present study, namely hypermetropia (long-sightedness), squints, lazy eyes and double vision (Congdon, 1989, p. 216), which are abducens nerve signs (Chusid & MacDonald, 1956, 1983).

Synchronisation of vision and hearing is crucial for phonics

Intermittent loss of quality may be auditory, visual or both. For example, maintaining auditory attention is difficult when auditory clarity or stream of input is variable as from middle ear infections. Likewise,

- intermittent or diminished quality of foveal information might cause discontinuation of matched visual to auditory signals in the associative area of the angular gyrus.
Phonological awareness can be compromised in the early stages of learning, by delaying automatic responses to either visual or auditory stimuli for phonemic memory, as well as lack of fluency in ‘naming speed’, the key definitive deficits of dyslexia. Findings of the present study (GK case study) also show: attention deficits have frequently been found to be related to physical discomfort, unreliable visual accommodation, with loss of concentration in otherwise keen students who can not ‘settle into’ tasks requiring clear vision for near work.

Level 5: Foveal suppression

(i) Making a case for foveal suppression of the right eye

This thesis proposed that LD co-occurs with ‘left hemisphere neglect’ from intermittent visual input as a result of o-m dysfunction. If foveal fusion was lost then suppression of images from the right eye was reported by the student. If it is the right eye that is being consistently suppressed, as has been shown in vision training, this was assumed to have compromised the link with the left hemisphere language area as development of literacy had also been adversely effect. The evidence in support of foveal suppression was that for 15 students in Group 1 of the Intervention Study, when o-m function was restored with vision training, dominance changed from left to right eye dominance. Literacy gains in these ‘successful’ students suggested this was because the students had ‘reconnected’ visually with the naturally dominant pathway to the language area. Figure 12, showed the neural pathways of the visual system and illustrates how a disruption to natural pathways might occur.

(ii) Key therapy findings – Suppression subverts natural pathways

Findings from vision training in the present study show that when a weaker right eye ‘drifts’, it fails to provide sufficient overlapping visual fields to allow simultaneous foveal binocularity for fusion of matched images. Loss of foveal fixation then causes either diplopia, or induces the brain to activate suppression of one image. That is, the image from the weaker eye is lost in spite of there being parallel pathways. There are not only two eyes, but each fovea is also split into nasal and temporal halves (Emsley, 1977; Palmer 1999; Shillcock & Monaghan, 2001), yet foveal vision of one eye can be lost in vision training, while concurrent global vision for larger images retains fusion as one image.

It appeared that the visual system operates at two levels, foveal and global, if it has been possible to suppress one eye’s foveal pathway, while leaving global vision fused. As global vision does not have the same acuity as the foveal vision, the consequence is that visual information being received will be of poor quality. It is reasoned that this leads to short term loss of concentration; and long term, students to learn to recognise words by their overall shape,
without internal letter or sequence details. Furthermore, if right eye foveal fixation is lost, that
leaves the left eye maintaining fixation, without subjective loss of clarity of image.
Consequently the left eye becomes the monocular ‘preferred eye’. The concept that foveal
vision can be suppressed without affecting global vision is supported by Gilbert (2001) who
states that the “ability of a given brain structure to participate in alteration of topography
depends on the pre-existing framework of connections ... and this framework changes, as in
contrast to ‘global’ vision, ‘local’ foveal processes become more lateralized with maturation”

It was found that in the case of visual dysfunction, of heterophoria (abnormal eye posture) for
example, if the left eye fixates, the right eye is displaced and fixation slips out of foveal range,
into peripheral vision. Loss of foveal detail may be due to simply being out of foveal range, or
direct suppression to avoid the confusion of blurred or double vision. Either way, the effect is
that the remaining word to left of centre is registered and directed to the right visual cortex, as
‘right hemisphere reading (Coltheart, 1980, 1987; Saffran, 1980). Shillcock and Monaghan’s
’split field model’ indicates that “part of the word to the left of the fixation point is initially
projected to the right hemisphere and the right half of the word to the left hemisphere”
(Shillcock & Monaghan, 2001, p. 6).

It can be inferred from findings that in language-based tasks, a switch away from the naturally
dominant pathway may be mal-adaptive. Although the right hemisphere language area has
speech recognition, it has no expressive speech capability. As a consequence, it is not the
primary word processing area. This re-routing of literacy input away from the natural centres
is what has been shown in fMRI studies. For dyslexics, areas of neural activation “show as a
disruption of left hemisphere posterior brain systems ... encompassing both visual and
language regions” (Shaywitz & Shaywitz, 2001, p. 5), with an increase in activation of “right
hemisphere areas homologous to the language areas on the left hemisphere... which may reflect
compensatory processes” (Temple, Deutsch, Poldrack, et al., 2002, p. 1203-1213). The use of
right hemisphere sites by the poor reader was considered as “compensatory use of other
perceptual processes to compensate for poor phonologic skills” (Shaywitz, Shaywitz and Pugh

(iii) Support for findings of foveal suppression
Support for the foveal suppression finding comes from Kelly, Jones, McDonald and Shillcock
(2004) who found that “dyslexics tended to fixate closer to the word begining (to left of
centre) than normal readers” (Shillcock et al. 2004 p. 2630), leaving only the left hemi-field
(see Figure 12, location 5) of the right eye to proceed to the right hemisphere. Restricted foveal
field was suggested by Spafford and Grosser (1991) as they found a larger area of peripheral vision represented in the visual field of inefficient readers than is the case for normal readers (Spafford & Grosser 1991, p. 10).

These findings have relevance for the ultimate impact of convergence inadequacy and foveal 'suppression'. It appears that as the right eye drifts outwards, foveal fixation from the right hemi-field is lost (see Fig. 12 central vision, Location 6) resulting in a failure to activate the left angular gyrus, amounting to intermittent, mini-neglect of the major literacy pathway. At worst,

- students may be viewing print through peripheral more than foveal vision, with the information normally addressed to the left hemisphere being rerouted to the right hemisphere, along a recessive pathway, accounting for phonological deficit and restricted memory span, speed of processing and 'patchy' performance, attributes identified as LD.

Theories – support and dissention about foveal suppression

Foveal suppression is supported by a number of other studies, which contrary to predictions made from magnocellular deficit theory, deficits were found in parvocellular (foveal) stimuli (Gross-Glen, et al., 1995, cited in Skottun, 1997). This finding was identified in later studies by the Lovegrove group (1987, 1988 &1993, cited in Skottun, 1997). Skottun (1997) concludes this is positive evidence for parvocellular deficit (p. 398), which this present thesis suggests might be due to o-m dysfunction of a drifting right eye, whereby the fovea does not maintain accurate fixation. Supporting evidence from the “Cellfield” intervention study also showed unstable foveal fixation as a contributory factor in LD (Prideaux Marsh & Caplygin, 2004). Stein and Walsh (1997) proposed that dyslexics are “unable to process fast incoming sensory information”, and that “visual deficit is only one of a group of phonological, motor and visual problems”. Their evidence supports magnocellular impairment that disrupts eye movements and “which may destabilize binocular fixation” ... and “visual attention” (Stein & Walsh, 1997 p. 147). It is well supported from the literature, that both magno- and parvocellular pathways might be compromised as the visual system becomes desynchronised by o-m dysfunction and foveal suppression.

Suppression of a weaker right eye becomes 'mal-adaptive'

The following range of scenarios describes a possible connection between foveal suppression and LD that are supported by findings in the Case studies. Foveal suppression appears to be a strategy to avoid competition from mismatched retinal images, or blurring, as suppression
occurs naturally during saccadic jumps to avoid blur. It is also known to be a compensatory strategy in heterophoria and binocular instability (Galaburda, 1999, pp. 45-50). It has been reasoned that in order to avoid the perceptual confusion of double vision, the central nervous system institutes monocularity, by suppressing the weaker eye. A principle of ‘survival of the fittest’ ensures that clarity of vision is maintained, without the individual being aware when this compensatory manoeuvre has been employed. At a neurological level, it would be ‘mal-adaptive’ if only the recessive ipsilateral pathway to the left hemisphere remains. This may contain insufficient visual information to complete the journey from retina to angular gyrus, if both foveal hemi-fields are lost in the right eye. This would leave the left eye-right hemisphere dominant, by default. A variable image might likewise interfere with feedback, and synchronisation. In this way,

- intermittent loss of one pathway must disrupt bi-hemispheric processing of visual information and be counter-productive for higher level, bi-hemispheric activities like literacy, given the loss of access to the expressive language area.

(iv) Descriptive and prescriptive overview of o-m sufficiency

The difficulty however is in determining what constitutes a ‘clinical deficit’. According to Fletcher (2002) causal attribution can be more reliably tested in before-and-after intervention studies “because of the difficulty in specifying what level of impairment would constitute disability” (Fletcher, 2002, p. 27). It has been argued that inadequate vergence resulting in foveal suppression may force changes in functional dominance. As findings from vision training show, any o-m imbalance that alters the appearance or synchrony of the paired retinal images makes the break point of letter fusion (foveal fixation) more sensitive to vergence stress. Disruption can likewise occur with acuity imbalance, of hyperopia (long-sightedness), vertical astigmatism or accommodation, in one eye. Heterophoria is a form of convergence insufficiency for near work, but is frequently overlooked by optometrists as being a problem in LD. It is apparent that a key inclusion into vision assessment is advisable, namely

- the ability to consistently retain binocular foveal fixation, representing ‘stable eye dominance’.

The optimal qualifying range for ‘natural’ (as opposed to ‘normal’ distribution) fusional reserves evident in outcomes of the Intervention study, showed that a two-thirds (20 dioptres) overlapped field of vision of both eyes is required for adequate foveal fusional reserves for bi-hemispheric integration for academic tasks. This involves visual/auditory/linguistic processing and o-m feedback for efficient information processing and response. The findings of foveal ‘suppression’ reported in this study suggested that regardless of the array of parallel pathways,
the brain can respond to each eye separately, with foveal suppression of one eye while maintaining binocular global vision. To be even more specific:

- **The visual and vestibular systems are closely associated with proprioception and posture. The Developmental Model predicts that o-m dysfunction is interactive with common anomalies in biodynamics of gait, muscle imbalance up the spine and unilateral neck tension. These are in turn associated with weakness of divergent o-m control of the muscles supplied by the abducens cranial nerve.**

**Level 6: Left hemisphere neglect from right hemi-field foveal suppression**

(i) **Lack of bi-hemispheric processing and hemispheric ‘neglect’**

In terms of hemispheric function, the left hemisphere controls the right side of the body, likewise the right hemi-field of each eye leads to the contra-lateral left hemisphere. Consequently an unstable right eye means the pathway to the left hemisphere language area may be vulnerable to intermittent or degraded sensory input.

(ii) **Therapy findings – weak right eye and phonemic memory**

Lack of right eye dominance was found to make a difference to literacy competence in the Intervention study. Phonemic memory was also a significant deficit for students with LD in the School Survey. Consequently, the angular gyrus had become the focal area of possible ‘neglect’ because this is where the visual and auditory signals connect as phonics. By tracing backwards from the left hemisphere angular gyrus, along the neural pathways to the eyes, the genetically determined pathway for literacy is location 6, in the right field of vision (see Figure 12). This then would be the first area to drop out of foveal range if the right eye drifted laterally. It was assumed that this occurs with o-m imbalance of heterophoria, or if weaker uniocular muscle tone affects accommodation or range of vergence, resulting in the individual being unable to maintain binocular fixation for working in the near range, as in reading and writing.

(iii) **Left hemisphere neglect - compensatory move to right hemisphere for literacy**

An aspect of cerebral asymmetry is that other specialised areas, apart from visual to auditory associative networks, might also be deprived of adequate stimulation. For example, expressive speech development, sequencing, shape recognition, and praxic organisation of intentioned actions, are each located in the left hemisphere (Corballis 1991; Dehaene 2003). All of which might be compromised by right eye suppression, leading to sub-symptoms of LD.

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It can be argued that foveal suppression was a survival device used by some participants, to ensure clarity of vision. But from a developmental point of view, literacy came late in human evolution and foveal suppression presents a risk to higher level skills. That is if balanced binocularity for bi-hemispheric processing is compromised if data from both fields of vision is intermittently unavailable. That is, if matched foveal fixation can not be achieved simultaneously or reliably enough for fusion of the split fields of vision into one image. Thus, lack of sensory synchronisation between the hemispheres (Monaghan and Shillcock, 2005 p. 44) might be considered as either a cause, or an effect, of the natural right eye link to the left hemisphere being dysfunctional, owing to suppression of foveal detail from a drifting right eye.

(iv) Projected consequences of weak binocularity - which eye is dominance?

In the simplest of terms,

- the Developmental Model of LD, if used as a heuristic device, suggests that balanced binocularity and bi-hemispheric processing provides for the optimal developmental opportunities.

This study has demonstrated that:

- in the case of weak binocularity, proficiency in left hemisphere-based skills depends on which eye is dominant.

Level 7: Literacy competence, Logic and Life Skills

(i) Application of the Developmental Model in Therapy

‘RW’s progress highlighted the application of the Developmental Model within the therapeutic process. The dynamic between the therapist’s perception of a problem and expectations, and student’s responses together determined the therapeutic content and presentation of remedial action. In effect, the student was coached into awareness of ‘instinctive’ processes that normally develop within family and school life experience. The case studies have shown functional problems have arisen from lack of bio-hemispheric integration, owing to a faulty flow between sensory modalities. These were conceptualised as lateralised pathways between specialised areas, with interactive flow stimuli, response and feedback within the networks, as a dynamic web that ‘holds it all together’, in on-going development.

Integrative therapy involved proprioceptive senses of movement and posture for co-ordination; vestibular and o-m integration for orientation and balance; and integration of auditory and visual information for phonics. Balanced binocularity and bi-hemispheric integration meant that theoretically, frontal lobes of the brain were fully informed with two points of reference. This enabled stereopsis in vision and its cognitive equivalent. That is, the student gradually
developed the ability to integrate detail into the context of overall concepts, as three dimensional thinking. For example, interpretation of different levels of meaning in a text; being able to prioritise and implement a plan, as the antithesis of procrastination; or likewise arrange ideas into a logical flow and maintain this overview while attending to the detail of converting the ideas into written script, in a story.

(ii) Right hemisphere processing – less efficient?
Results of this study, in addition to contemporary fMRI studies of left hemisphere neglect, have suggested that transfer and compensatory functional development, to the right hemisphere, adversely affected the higher order skills like literacy. If o-m dysfunction exists in the right eye and the right hemisphere becomes the primary literacy processor, by default, this is less efficient. This is because the right hemisphere generally lacks the primary expressive language, sequencing, and memory span facilities of the left hemisphere. Consequently, the individual is slower at processing and less attentive to detail, so that normal education may take more time and effort, as is the case for students of all ages attending Educational Therapy, exemplified by the four case studies. As suggested by Emsley 1977, vision is a major source of sensory stimulation, consequently a ‘shift’ to right hemisphere dominance may be considered as mal-adaptive. This becomes particularly evident in terms of schooling which focuses on left hemisphere based, high memory span demand, particularly in language-based, literacy skills. These are the vital skills on which a student’s intellectual competence is judged and from which their self-perception is forged.

(iii) Left hemisphere neglect - 'sub-symptoms' of LD
Lindsay and Norman (1977) state that: “The right half of the brain can not generate speech, but recognises language and written words and can obey spoken commands” (p. 448), but normally both hemispheres “build up duplicate memories for tasks” and so can co-ordinate the activities of both systems, “even when the sensory messages may be restricted to one half of the brain” (p. 449). It might be assumed therefore, that laterality of pathways is no longer relevant in the final stages of information processing, but Luria (1973, p. 74) stated that the earliest stages of neural stimulation and development are critical for higher levels of function. It is implicit then, in the Developmental Model that quality of bi-hemispheric sensory input is of primary importance for the development of neural pathways and for both stereopsis and bi-hemispheric integration of visual information, given the asymmetry of the hemispheres in terms of specialised areas. Support for the developmental view is provided by contemporary fMRI results, where a characteristic of dyslexic individuals was the lack of bi-laterality shown as left
hemisphere ‘neglect’. This was assumed to be a ‘compensatory shift’ of activation to the right hemisphere (Howitz, 1998; Simos, 2000; Shaywitz, 2002 & 2004, see p. 221).

Any unreliable o-m function has been shown to diminish the quality of sensory information, which, if it results in intermittent suppression of the right eye’s foveal vision, might interrupt bi-lateral input to the left hemisphere and bi-hemispheric processing. Suppression is assumed to be a compensatory strategy, to minimise perceptual confusion from mismatched retina images, and to maintain clarity of vision. Consequently, foveal suppression of the right eye may contribute to left hemisphere neglect in terms of visual input, and integration with auditory associated networks. Evidence for this assumption from the Intervention Study was that right eye dominance made a significant difference to literacy and memory outcomes. Initial assessment showed participants were commonly left-eyed by default, presumably owing to a weaker right eye. However, 62.5% of students switched to right eye dominance as the outcome of regaining normal balanced o-m function with vision training. In rebuttal to Lindsay and Norman’s assertion, that the brain can co-ordinate the activities of both systems, “even when the sensory messages may be restricted to one half of the brain” may hold true in the case of ‘constant / compensated’ visual anomalies, but not in the case of intermittent o-m dysfunction.

This paper outlines the dynamics of the visual system’s reaction to variability of input, in foveal suppression. This can be considered as the ‘bottom up’ aspect of selective attention. Serences and Yantis (2006) state “Conscious perception of the visual world depends on neural activity at all levels of the visual system from the retina, to regions of parietal and frontal cortices”. It involves hierarchical organization of a two way interaction of ‘bottom-up’ (sensory properties of the stimuli) and ‘top-down’ (voluntary attention of behavioural relevance ) processes (pp. 1 & 3).

It is argued that unreliable sensory connections’ from intermittent suppression of the weaker eye can prevent the development of adept, adaptive pathways, and as a consequence become part of a network of ‘misinformation’, causing left hemisphere neglect. As the fMRI studies show, mal-adaptive compensatory development is directed to the right hemisphere. As the learning difficulties described in this thesis show, the right hemisphere is less efficient for language based, sequential processing like literacy.

- in the case of unreliable sensory input, and weak binocularity due to o-m dysfunction, integrative therapy can change the direction by establishing a stable right eye dominance.
(iv) Broader implications of o-m dysfunction

The problems that the therapist addressed involved the re-direction of maladaptive stages of development that have culminated in foveal suppression of one eye. The problem faced by schools is that a major opportunity to 'head-off' LD is being lost, if o-m dysfunction has resulted in basic learning tools that are too immature for the child to keep pace with normal education challenges. The problem is that if current paediatric optometry tests and school vision screening fail to identify 'at risk' children or to provide full visual assessment and vision training. Consequently LD based in o-m dysfunction, perception and memory deficits, and lack of auditory/visual integration problems will tend to persist. Even with extra assistance, the pace of learning remains slow and discouraging. Results of these studies show that given assistance to develop an adequate range of binocularity assists bi-hemispheric processing of visual information. This together with integrated sensory networks can then provide efficient pathways of learning for these children.
Chapter 10
CONCLUSION

10.1.1 Limitations of the Study
There were limitations inherent in conducting a study within the constraints of a school and therapy practice, consequently the research design was determined by the circumstances, not controlled by the researcher. The small case numbers have created statistical difficulties with cell numbers such that data may not have been sufficiently robust, to identify all significant links. However reliability of results has been supported by the wide range of variables. Validity of findings has been shown in the consistency of results across the three studies. Action research, with further Intervention Studies, is needed to confirm or modify these findings.

10.1.2 Sensory Integration
Luria in his Model of Neural function asserted that the earliest stages of neural stimulation and development were critical for higher levels of function. In terms of the Developmental Model of LD proposed in this thesis, the key to optimal neural integrity and growth was determined by the quality of sensory signals and how well these are matched and synchronised in the individual’s sensory associative areas.

10.1.3 Summary of Discriminatory Variables
Fusional reserves in divergence and superior right eye tracking speed were the key discriminatory visual variables. Mixed or left-eye dominance and visual dysfunction were both evenly distributed across the School sample. However in the sub-group of students with o-m dysfunction, 52% did not have LD, but the remaining 48% had memory deficits and corresponding levels of LD. The Intervention study indicated that LD was generally associated with a compromised right eye, in terms of o-m function, but not visual acuity.

The three most discriminatory variables were Luria’s test of arm dominance, followed by phonemic memory and the discrepancy between reading comprehension and spelling. Consistent results in independent $t$-Tests led to the conclusion that o-m function is linked with memory span and literacy variables.
Combined results of these studies showed that students with LD would benefit from Behavioural Optometry assessments of o-m function, with subsequent vision training to increase fusional reserves and stable right eye dominance. Although the School survey was conducted in a private girls’ school, these findings have been shown to be applicable to the general school population.

10.2 Conclusions from Findings

10.2.1 Results implicit in the Developmental Model

The following conclusions are implicit in the Developmental Model based on the principle that therapeutic processes include the whole neuro-sensory system:

- the proprioceptive senses of movement and posture for co-ordination,
- the integration of vestibular and visual feedback for o-m balance,
- the synchronisation of binocular function and foveal fusion,
- the integration of auditory and visual information in the left hemisphere for phonics;
- the integration of the two hemispheres for higher order cognitive function.

Based on the Luria model of levels of neural function, the brain is conceptualised as a complex construction of cells with pre-determined pathways between specialised areas in each hemisphere. It was reasoned that the quality of sensory input and adequacy sensory networks was reflected in the integrity of function. Some responses may become mal-adaptive in the case of disruption to the sensory processes from postural anomalies that impact on proprioceptive and vestibular senses, and ultimately disrupt o-m dysfunction, dominance and learning.

Visual and auditory sensory input is bilateral, but it was the matching of signals in the associative areas that appeared to be the key to optimal neural connectivity. Based on this assertion LD were conjectured to be determined, to some degree, by the impact of o-m dysfunction resulting in right eye foveal suppression. This appeared to be a strategy employed by the student to enable the visual system to overcome blurring and diplopia (double vision) due to loss of fusion, in order to retain clarity of vision.

In brief, o-m dysfunction may be mal-adaptive if foveal suppression:

- desynchronises bi-hemispheric processing,
- disrupts the unification of foveal hemi-fields,
- changes visual information flow from latently dominant, to less efficient pathways,
- disrupts bonding of visual and auditory signals for phonics;
• produces left hemisphere neglect and inadequate access to not only language, but also affects sequencing, word recognition, praxic organisation and logic (that sets events into context, as opposed to immediacy of right hemisphere logic of 'best outcomes'),
• consequently, a potentially normal brain begins to operate on limited sensory resources
• with developmental delay identified as ‘LD’.

In general, results have supported the six Therapy Assumptions (Ch 6)
1. A key movement in reading and writing is the left-to-right movement of the right eye, because the abduction movement in divergence was a key discriminatory variable of LD.
2. Auditory and visual, postural and vestibular senses contribute to an integrated associative system.
3. Binocular balance is a precursor of bi-hemispheric integration of visual information.
4. Binocular balance with foveal fusion provides bi-hemispheric discrimination of fine detail for reading print.
5. Foveal fixation and fusion is needed for attention to detail for working memory, which can be inferred from visual pre-requisites.
6. Visual-auditory synchrony provides access to the associative sensory network and phonemic memory, as phonics are the basic units of literacy.

10.3 Concerns and Conclusions
10.3.1 Standard optometric assessment
At present, o-m function is not part of standard vision tests or school vision screening. Consequently, these anomalies have gone unnoticed not only by the individuals themselves, but also by vision specialists, researchers, school personnel, and primary care-givers. All participants in these studies had previously been assessed in standard optometric tests as having “no visual problems”. This was not only misleading, but led to less helpful conclusions about causal factors of their LD. Intervention from this standpoint is misdirected and often ineffectual, thereby ‘confirming’ the paucity of the medical model of intractable neural deficit. The encouraging results from this study are that it offers a sensory quality model for use in further investigation into assessment, practices, and interventions, by adopting the expanded assessment protocol used in these studies.

10.3.2 Implications of neural neglect from ‘hidden’ o-m dysfunction
Schools face the problem of potentially ‘normal’ children whose basic learning tools of o-m function, perception and ‘symbolic’ memory are not fully intact. Current school vision
screening is not identifying these problems consequently a major preventative opportunity is being lost. The future of these children depends largely on how their lack of natural competence is managed, and management is crucial before school failure and alienation impact on their self-perception and self-esteem.

The therapist’s experience with adult dyslexics is that the impact of o-m dysfunction and interruption of bi-hemispheric integration has wider ramifications than limited memory span and weak phonics and literacy skills. Past experience, working as an Occupational Therapist in geriatrics, mental health and cerebral trauma rehabilitation, leads to the belief that this issue extends into geriatric, mental health and institutional care where o-m dysfunction may be overlooked, or considered irreversible. Not only does the left hemisphere contain the major speech and language areas it also contains a particular style of logic (Wolford et al 2000). This style directs analysis and consequently behavioural choices, as right hemisphere problem-solving maximises behaviour by estimating best outcomes, whereas the left hemisphere makes predictions based on frequency-matching and contextual awareness.

Binocularity provides stereopsis, which is also a metaphor for the entire integrated ‘output’ of the brain. Integration of the two hemispheres provides depth of resources and understanding, for an optimal basis for adaptive intelligence in life decisions. Bi-hemispheric integration involves more than visual information, as it provides integration from all specialised resources, from both sides of the brain. In effect ‘three dimensional thinking’, not only in interpretation of written texts, but also in the interpretation of our lives, in terms of style of logic, which in turn influences quality of decision-making and ‘personality’. From a Social Sciences perspective, discouragement and alienation associated with poorly managed LD can be seen as part of the equation, in a slowly evolving culmination of lost opportunities, mental health issues, and even corrective services concerns.

The positive results of these three studies indicated that early, thorough assessment of o-m function and vision training, sensory-motor integration and effectively targeted intervention programmes did make a significant difference to the development of the participants.

10.3.3 Adequacy of Optometric tests and School Vision screening
Results of these studies raise serious questions about present optometric management, which failed to uncover what have been shown to be ‘significant’ problems for the majority of the participants in these studies. Although it was generally found acuity was normal, insufficient convergence or ability to relax the eyes at near, resulted in these students’ eyes failing to work together adequately for them to achieve foveal binocularity, or their natural potential in
schooling. Normally, prescription lenses of +0.50 are prescribed by the Behavioural Optometrist, as even this small degree of magnification takes stress off the accommodation system, thus allowing convergence movements to strengthen with vision training and thus limiting fatigue. Such screening provides better access to the challenge of vision training.

Three optometric issues arose from these studies

1) The fragile nature of these students' visual system predisposes them to fatigue and distractibility, both visually and mentally, making it difficult to achieve an accurate profile of their true condition.

2) The need for an adequate definition of what constitutes 'clinical significance' related not only to clarity of vision but also to neural development, particularly for individuals of any age or situation with LD. From the findings and deliberations of this study, an expanded assessment protocol would therefore include:
   a) a sample of hand writing as indicating eye/hand co-ordination and perception;
   b) simple tests of phoria,
   c) vergence and
   d) fusional reserves, with referral to a Behavioural Optometrist for additional assessment of foveal fusion and access to vision training. Any problems causing a lack of ease and clarity for near focus are of critical concern. Long-sightedness also needs to be considered, because many optometrists mistakenly assume it is not a problem for fine work within near range.

3) A greater awareness and concern for the risk of overlooking hidden visual handicaps would mean that optometrists and vision specialists would make more allowances, to effectively identify and treat children who require this specialised attention. It needs to be known that visual problems that appear minor may still have serious secondary effects, with developmental consequences. Critical factors identified in this study are:
   a) weak binocular vision due to an imbalance in accommodation and vergence
   b) difficulty maintaining focus clearly at near, and/or
   c) problems related to foveal fusion. Without awareness of these factors, the fear of 'over-prescribing' appears to inhibit professional judgement. Unfortunately for these students, 'standard conventional practice' can become 'automatic conservatism' instead of 'adaptive intelligence', so in this respect these students need an advocate to argue their case.

Vision provides stimulation for growth and development of the neural system. There are two aspects of vision. One is general, "How clearly can I see?" as an aid to activities of daily living, normally addressed in acuity tests. The other aspect is developmental, "How reliably
does visual input contribute to the multi-modal integration and neural development? This is an aspect of vision that needs to be reflected in a paediatric vision assessment protocol if LD are to be overcome.

10.4 Future Directions

10.4.1 Future research

The value of the Developmental approach has been substantiated by the findings of the three studies. Results have opened another avenue for further in-depth research into the perplexing problem of LD. In the light of these findings, it was possible to ascertain how a potentially normal child might have motor-sensory imbalances that lead to mal-adaptive adjustment of neural pathways, resulting in a pattern of ‘LD’, as conjectured in this thesis. As Fletcher (2002, p. 64) affirmed, Intervention studies were an excellent starting point for determining effective treatment and working backwards from these results, towards a causal theory from results.

It would be beneficial to establish an expanded assessment protocol of vision testing, specifically for paediatric optometry to take account of the fact that vision is more than just eyesight. More research is required to establish which visual anomalies are of ‘clinical significance’ in terms of neural growth and what the optimal range might be. The results of this Intervention Study have set a higher benchmark for vergence range than current ‘norms’, before the dominance criteria was met, in order to unlock the ‘successful’ students learning potential.

Contemporary functional Magnetic Resonance Imaging has provided new insights into cognitive processing, which might in time sort through the various findings relating to causal factors in LD, and to be able to discriminate between primary and secondary effects. For example, the model canvassed in Chapter 8 showed how facial or sphenoid bone mal-alignment or displacement might compromise eye tracking. This might be investigated with fMRI, as images from the top of the head might uncover what is happening when students with LD are performing eye exercises with foveal suppression of one eye and whether the subtle mobility of facial bones is implicated in asymmetry of visual function. A starting point would be to replicate and validate the findings of this study, to encourage the implementation of these changes in theory and practice.

10.4.2 Expanded paediatric optometric protocol to incorporate o-m function

The range of fusional reserves achieved by students through vision training was 20–24 dioptres in convergence and divergence. This provides a natural benchmark against which therapeutic
potential might be compared. Specifically for the educational therapy aspect, to established a new baseline of what is of ‘clinical significance’ in relation children’s eye care. It became clear that LD or under-achievement required an expanded protocol for paediatric (as opposed to adult) vision testing. However, further research would be required in order to set age-related, paediatric functional criteria based on before- and after-tests of vision training and literacy.

As vision is a major source of stimulation for neural growth and development of sensory pathways, it would be particularly beneficial to establish an expanded assessment protocol of vision testing, specifically for paediatric optometry to take account of the fact that vision is more than just eyesight. More research is required to establish which visual anomalies are of ‘clinical significance’ in terms of neural growth and what the optimal range might be. The results of this Intervention Study have set a higher benchmark for vergence range than current ‘norms’, before the dominance criteria was met, in order to unlock the ‘successful’ students learning potential.

The purpose of an expanded protocol would be to ensure there was a clear baseline of what creates functional problems for individuals. A thorough investigation to uncover any o-m dysfunction would ensure that individuals are not suffering from a hidden handicap of foveal suppression. This expanded protocol would eliminate any false causal assumptions about neurological, genetic, or personality correlates of LD, because it would provide more clarity about cause and effect, with further insights into tertiary psychological and sociological flow-on effects. Further action research would be required to monitor the validity and reliability of this expanded protocol.

10.4.3 **Recommended changes:**

Should future research support these findings, further organisational changes are suggested:

a) **On the issue of infant assessment,**

Present practice does not reach the standards suggested by the Centre for Promotion of Child Development through Primary Care (Anderson, 2005). Of concern is asymmetry of eye size, lack of vergence control, tracking or focusing ability beyond 4–6 months, all of which respond well to Cranial Osteopathy balancing. Currently, Child Health nurses are alert to incipient strabismus, which they monitor carefully in the event that surgery is required, however. However there is a continuum of eye muscle imbalance that can be addressed before loss of control like strabismus occurs.
b) **Musculo-skeletal assessment**

By school age, paediatric optometry assessment and inclusion of podiatry and musculo-skeletal assessment are advisable for any student with LD.

c) **School vision screening**

There are two aspects of vision, general, and developmental, and both need to be reflected in a paediatric vision assessment protocol. Vision tests should not be a one-off event, as children’s vision status changes with growth and environmental stresses. Major growth spurts (notably at age 9 and 14) tend to be the occasion when visual changes may occur and o-m review is required. The concern is that ‘common occurrence’ i.e. within normal parameters, does not give assurance that the ‘minor’ anomalies discussed in this thesis do not have negative consequences for an individual. The purpose of this expanded assessment protocol would be to uncover any subtle, hidden o-m dysfunctions which may have developmental consequences for younger children, and serve to diminish older students’ performance capacity, education, and employment opportunities.

d) **Community awareness and further education.**

Community acceptance of a progression to an expanded strategy for LD management would entail a multi-disciplinary awareness of the integrated sensory system and its relationship to functional neuro-anatomy. The manual therapies have an understanding of the importance of sensory associative networks. However, as management of ‘LD’ requires a multi-disciplinary arena, decision-making would require an understanding of basic physiology to provide insights into a developmental model, for educational and allied professions. Too often functional deficits are assumed to be constitutional, due to genetic factors or minimal brain damage. If such a diagnosis is a misconception, it will close off help for individuals who could otherwise benefit from effective motor-sensory integration and vision training, as a ‘given’ aspect included in intervention programmes.

10.5 **Key Concepts**

10.5.1 **Evaluation of the foveal suppression proposal**

(i) **Function does not necessarily mirror neural architecture**

It is apparent that functionality does not always follow anatomical structures, as demonstrated by foveal suppression of one eye (uncovered with the use of stereoscopic lenses), without loss of images seen in peripheral ‘global’ vision. This is a ‘hidden’ deficit as the individual remains
unaware of any loss of vision. It was reasoned that, in this case, the visual system has self-adjusted by suppressing poorly matched or blurred foveal images to avoid perceptual ambiguity.

This supposition is consistent with the visual system’s natural reaction of saccadic suppression to avoid blurring and retain clarity of images, whereby a temporary break in the information flow is buffered by the Sensory Information Store (see Palmer 1999, p. 46). However, if it persists for too long or too often, this ‘natural reaction’ might become a basic impairment in selective attention, and for retaining and comparing perceptual traces in dyslexia (Ben-Yehudah & Ahissar 2001).

(ii) Naturally occurring visual suppression may become dysfunctional
Suppression may become dysfunctional, if the vital literacy pathway to the left angular gyrus is selectively suppressed, as a weaker right eye drifts out of range for foveal fixation. This intermittent event may be the ‘tipping point’ where a natural process becomes mal-adaptive. The argument, supported by the findings of this study, echoed the view of Howell and Peachey (1990) that severe, but constant and ‘compensated’ deficits, may be less disruptive to the developmental processes (see pages 25 & 39 (Author’s pages?), than neurological ‘neglect’ caused by intermittent and incomplete visual input reported in this thesis.

- This point has serious implications for standards of optometry assessment and what is considered to be ‘clinically significant’.

Support is provided by the Intervention study, where improved fusional reserves overcame right eye foveal suppression of one student, returning him to superior right eye function and a learning capacity congruent with his intelligence. A second student did not achieve improved foveal fusional reserves and his limited phonemic memory and spelling deficits remained unaltered, presumably as a consequence of continuing foveal suppression of the right eye. These findings may be regarded as:

- confirmation that foveal suppression may disrupt natural pathways and act as a predisposing factor in memory deficits and therefore LD.

(iii) The importance of binocularity and stable, ‘neural’ eye dominance
The conclusion from these findings is that stable visual dominance itself represents fully functioning o-m balance, strength and co-ordination and provides a measure for an affirmative answer the main research question: Is o-m dysfunction a contributing factor in LD? The results of the Intervention study show right eye dominance, made a significant difference in
memory and literacy gains. The Luria test of latent arm dominance, together with phonemic memory, was the most discriminatory factor in identifying LD. These results also illustrated that memory, oral reading, reading comprehension and spelling in combination, provided a more comprehensive measure of literacy status.

10.5.2 Conclusion
Assumptions expressed in this thesis represent part of the process that has led to the results reported from these studies. These in turn have provided principles for further action in Educational Therapy practice. It was predicted and confirmed that students with LD benefited from an expanded visual assessment and treatment for o-m dysfunction. Foveal suppression was found to be a secondary effect of difficulty with maintaining binocular vision for near work. Vision training and change from left to right eye dominance, congruent with the crossed-arm latent dominance (Luria 1966), resulted in significant gains in memory and literacy standards following a week-long intervention programme.

In conclusion, o-m dysfunction can not be said to be a ‘cause’ of LD, because many individuals have similar visual anomalies with limited binocularity, but have no difficulty with literacy. It is assumed that is because the visual pathway to the language area remains reliable and there is no ‘left hemisphere neglect’. Results of the Intervention study show that with vision training and ‘catch-up’ learning, students have largely ‘outgrown’ their LD. Therefore, o-m dysfunction can be considered as a contributing, even a pre-disposing factor, in LD that is readily amenable to treatment.
REFERENCES


Luria-Nebraska Neuropsychological Battery (1966). Accessed @ www.medicalglossary.org/neuropsychological_tests_lurianebraska_neuropsychological_battery_definitions.html


APPENDIX

APPENDIX A

Optometric terms and functions

**Accommodation**: allows rapid and accurate shifts of focal length, for visual inspection, with clarity at differing distances; it also signifies the ease with which visual attention can be sustained. In optometric terms, 'accommodation' is used to describe the crystalline lens changing shape when the ciliary muscle contracts.

**Acuity**: clarity of vision is the ability to identify an object clearly at a given distance i.e. short or long-sighted, astigmatism. The refraction of light through the lens onto the retina allows the eye and perceptual system to facilitate form sense, that is, of detail, shape and size of objects.

**Binocular foveal fixation**: is simultaneous, matched foveal images fused into one image, represented in both visual cortices. If the images do not match in the visual cortex, blurring and double vision can occur or even suppression of the weaker image [author's note see 3.1.1n].

**Binocular vision**: involves the co-ordination of both eyes in order to focus on an object. The ratio of vergence to accommodation is finely tuned until the two images in the cortex can be fused and the object seen as one perceptual image.

**Dioptre**: A dioptre is an optometric measure of the refractive power of a lens having a focal distance of one meter (Ref: Blakiston’s Medical Dictionary 1952).

**Fovea**: Acuity is most acute at the fovea as it is packed with cone cells which provide both colour sensitivity and edge discrimination for fine detail, and therefore important in advanced skills like literacy. The fovea is a very small, 0.5mm diameter area located in the macula, that is, central vision as opposed to peripheral vision. According to Emsley (1977) "cone cells are more comprehensively represented in the cortex so foveal impulses are the most intense ... the eyes can be rotated to bring the two foveae to bear upon a selected object in the binocular field ... this unique arrangement provides the basis for the super-position or "fusing" and synthesis of two aspects of the field, within which the chosen object - the point of fixation - stands out with special emphasis and distinctness. This enables concentrated and thoughtful attention to be given to this one object, and has been mainly responsible for the development of the higher faculties found in humans" (Vol.1, p. 28).
**Fusion:** stereopsis / depth of field perception are intimately related to movement control and focusing ability which allows simultaneous alignment of inspection for accurate and immediate symbol and object awareness. Difficulty in matching right and left fields of vision may result in strabismus where one eye turns in or outwards, suppression of images seen by one eye, or fatigue due to excessive compensatory effort.

**Fusional reserves:** the range of overlapped fields of vision, optimally two/thirds overlap to provide binocular fusion. A diminished range can result in weakened binocularity, double vision, or loss of foveal fixation of one eye (a key finding of this study).

**Phoria:** 'eye posture' or the position at rest - either converging esophoria, or diverging exophoria - that eyes would take if there was no sensory stimulus to fuse the two images into one. Heterophoria is "the tendency for the eyes to deviate from their primary position of central alignment when images are fused" and orthophoria is "perfectly balanced oculo-motor system" (Emsley, p. 40).

**Pursuits:** tracking a moving object, or smooth following movements, or moving from the end of one line to beginning of the next.

**Saccades:** eye movements from one point of fixation, like a clump of words, to the next. A good reader can make 70 saccadic jumps / minute while scanning along a line of print.

**Stereopsis** commonly termed 3D vision is depth of field perception in psychological terms, and stereopsis in optometric terms, all of which refer to the ability to detect three dimensional features of a scene, or interpret angled lines in a two dimensional image of the same scene. Matched retinal images are a pre-requisite for 3D perception so the differences between the two images can be 'computed' by the brain as depth of field perception. This concept is condensed into the term "binocular depth perception" for the results of perception exercises in this study, involving angled lines of perspective in a drawing, that is, a two dimensional representation of a three dimensional scene (see Chain link exercise results Figure 2, Section 6.4.5).

**Vergence control:** ability to turn the eyes in unison in contra-motion, either in convergence towards the nose, and outwards in divergence, in order to allow both eyes to aim at targets, near or far in concert with accommodation. Convergence insufficiency for near work may lead to double vision when reading, blur or suppression of one eye, and confusion leading to reduced speed, accuracy and comprehension. Near point convergence insufficiency- the distance from the nose at which double vision occurs.
APPENDIX B. SCHOOL SURVEY OPTOMETRY PROTOCOL

1. objective assessment - retinoscopy
   This is a measure of the refractive status of the eyes. Used to determine whether
   the child is long or short sighted/astigmatic/requires spectacles etc.
   Instrument used - retinoscope

2. muscle balance - distance and near
   A measure of the resting position of the eyes.
   Instrument used - Maddox Wing

3. stereopsis - random dot
   A measure of depth perception.
   Instrument used - Randot Stereogram

4. pursuits
   Measures tracking movements (smooth pursuit).
   Assessed by observation and judged as problematic, fair, good, excellent.
   Assessment made by professional judgement.

5. Saccadics
   Measures ability to change fixation from one point to another. Judgement is made
   on accuracy of saccade and ease of release of fixation.
   Assessed by observation and judged as problematic, fair, good, excellent.
   Assessment made by professional judgement.

6. dominance - distance and near
   Observation of preferred viewing eye - through hole in a card.
   At that time measured by having subject look at a target (distance and near)
   Assessed by observation and judged as problematic, fair, good, excellent.
   Assessment made by professional judgement.

7. near point convergence
   Measured by having subject look at a target as it slowly advances towards the
   subject's nose.
   Measured as the point nearest to the facial plane at which the target becomes
   'double'.
   Requires both eyes to be functioning adequately.

8. amplitude of accommodation
   Definition of accommodation;
   The facility enabling the change in dioptric power of the crystalline lens thereby
   altering the focus of the eye
   AmpAcc.
   Measured as the amount of accommodation the subject can exert at a point nearest
   to them while maintaining clear vision.

9. far / near convergence / accommodation cycles
   Facility of accommodation measured with "lens flippers"
APPENDIX C

Osteopathic practice

Osteopathy is a holistic discipline, which has complemented the podiatry input, in helping to correct spinal muscle imbalance and discomfort, and poor co-ordination. The following summary is a composite description, of main points gleaned from the internet, of Osteopathy principles written by osteopaths.

Osteopathic manipulative therapy is described as attempting to restore function to areas of the musculo-skeletal system. It is recognised that dysfunction may result from injury, but also as the result of the body's adaptation to erect posture, gravity being more demanding on an unstable, upright musculo-skeletal frame, than that of quadrupeds. Individual habits, inherited factors, attitudes, the development of inborn asymmetries and defects contribute in some way to the functional profile of adaptation and compensation. It is believed that in a self-regulating mechanism like the human body, the resulting structural changes take place at the expense of optimal function. As a result, local postural stresses, asymmetries, myofascial (soft tissue) tensions and irritations, and articular (joint) disturbances are common.

The spinal cord is the point of entry or reception of most of the information from posture, proprioception, kinaesthetic, vestibular, and visual senses, and organs and tissues of the body. The brain selectively uses pre-programmed patterns of movement, with each activity being subject to further modification and refinement, with adjustment by the feedback continually streaming in from the participating muscles, tendons and joints.

Over a five year university course, Osteopaths understand and are able to sense the structure and function of tissues deep within the body. Osteopathic diagnosis and treatment considers all of the elements that allow the body to function as a whole. Treatment integrates the internal forces generated by the body's own 'self-healing and self-regulating mechanism' in terms of body mechanics (of gravity and dynamic movement); nervous system of proprioception (body sensation / movement control); sympathetic nervous system (fright / flight / fight); parasympathetic nervous system (rest / digestion / repair); arterial circulation (oxygen and nutrition); venous (drainage); and lymphatic (drainage / immunity) systems. This gentle, non-invasive physical therapy involves using the body's own trigger points and reflex systems, and the bones as mechanical levers (Korr 1987, pp. 513-5).
APPENDIX D.

Chapter 9, Section 9.2 Inventory of Findings from the three Studies

1) Findings from the School Survey showed that:

- There was an even distribution of visual dysfunction across the school
- Not all students with visual dysfunction had learning difficulties,
- Generally, students with learning difficulties had clusters of o-m dysfunction, with the exception of a small proportion with auditory processing deficits.
- 12% junior and 19% senior girls had severe visual problems,
- 16% junior and 27% senior girls were more than two years behind their chronological age in academic tasks.
- Characteristics of the ‘learning difficulties’ sub-group
- They had reduced visual and auditory information processing capacity,
- Lack of dual transform in phonics was reflected in phonemic memory span deficits,
- The difference between normal and dysfunctional vision groups was significant, with a mean 8 month difference in reading.
- There was no significant difference between visual function groups in spelling. As this is a more demanding activity to evaluate, this finding was inconclusive.
- Memory was generally better for students with normal o-m function.
- There was a significant effect between memory deficit and literacy as the greater the memory deficit the lower the reading and spelling age.
- Students generally exhibited confused hand and eye dominance.
- Dominance was a key variable where arm / hand dominance was the most significant variable and showed a consistent difference between groups in reading, spelling, with a positive association between the four memory variables as shown in cross-tabulations and gamma tests results.
- However, eye / hand dominance showed no significant links with any other variables. In fact, the distribution of stable and unstable eye dominance was quite even across the entire sample. The question was: Did learning skills depend on which eye was dominant?

2) Findings from the Intervention Study, based on a ‘Developmental Model’:

- With vision training and a return to full functionality of both eyes, this included
- fusional reserves of full vergence range (24-30 dioptres, 10 centimetres reading span)
- right eye superiority in tracking speed capability (computer-based tracking exercise)
- mixed and left eye dominance changed to stable right eye dominance.
- There was a significant improvement of literacy and learning skills for students who achieved stable right eye dominance.
- Students who failed to achieve right eye dominance had disappointing results from a five day word-skills workshop.
- Consideration of the 'unsuccessful' group led to an observation of a the common pattern of anomalies of gait and postural imbalance as possibly part of the problem.

3) Findings from Current Practice Case Studies
- Pronation of the feet, spinal muscle imbalance, dyspraxia with poor balance and coordination, muscle tension of shoulder and one weak eye.
- Ideally these anomalies are treated by a podiatrist and cranial osteopath prior to Educational Therapy treatment.
- This programme now incorporates an integrative therapy approach, which as a general rule has achieved an overall improvement in outcomes of memory and literacy skills.