The Effect of Amblyopia on Motor and Psychosocial Skills in Children

Thesis submitted by

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Keywords

Amblyopia, strabismus, anisometropia, fine motor skills, eye movements, self-esteem, psychosocial, stereopsis, visual acuity, education
Abstract

Background/Aims In an investigation of the functional impact of amblyopia on children, the fine motor skills, perceived self-esteem and eye movements of amblyopic children were compared with that of age-matched controls. The influence of amblyogenic condition or treatment factors that might predict any decrement in outcome measures was investigated.

The relationship between indirect measures of eye movements that are used clinically and eye movement characteristics recorded during reading was examined and the relevance of proficiency in fine motor skills to performance on standardised educational tests was explored in a sub-group of the control children.

Methods Children with amblyopia (n=82; age 8.2 ± 1.3 years) from differing causes (infantile esotropia n=17, acquired strabismus n=28, anisometropia n=15, mixed n=13 and deprivation n=9), and a control group of children (n=106; age 9.5 ± 1.2 years) participated in this study. Measures of visual function included monocular logMAR visual acuity (VA) and stereopsis assessed with the Randot Preschool Stereoacuity test, while fine motor skills were measured using the Visual-Motor Control (VMC) and Upper Limb Speed and Dexterity (ULSD) subtests of the Brunicks-Oseretsky Test of Motor Proficiency. Perceived self esteem was assessed for those children from grade 3 school level with the Harter Self Perception Profile for Children and for those in younger grades (preschool to grade 2) with the Pictorial Scale of Perceived Competence and Acceptance for Young Children. A clinical measure of eye movements was made with the Developmental Eye Movement (DEM) test for those children aged eight years and above. For appropriate case-
control comparison of data, the results from amblyopic children were compared with age-matched sub-samples drawn from the group of children with normal vision who completed the tests. Eye movements during reading for comprehension were recorded by the Visagraph infra-red recording system and results of standardised tests of educational performance were also obtained for a sub-set of the control group.

**Results**  Amblyopic children (n=82; age 8.2 ± 1.7 years) performed significantly poorer than age-matched control children (n=37; age 8.3 ± 1.3 years) on 9 of 16 fine motor skills sub-items and for the overall age-standardised scores for both VMC and ULSD items (p<0.05); differences were most evident on timed manual dexterity tasks. The underlying aetiology of amblyopia and level of stereoacuity significantly affected fine motor skill performance on both items. However, when examined in a multiple regression model that took into account the inter-correlation between visual characteristics, poorer fine motor skills performance was only associated with strabismus (F_{1,75} = 5.428; p =0. 022), and not with the level of stereoacuity, refractive error or visual acuity in either eye.

Amblyopic children from grade 3 school level and above (n=47; age 9.2 ± 1.3 years), particularly those with acquired strabismus, had significantly lower social acceptance scores than age-matched control children (n=52; age 9.4 ± 0.5 years) (F_{(5,93)} = 3.14; p = 0.012). However, the scores of the amblyopic children were not significantly different to controls for other areas related to self-esteem, including scholastic competence, physical appearance, athletic competence, behavioural conduct and global self worth. A lower social acceptance score was independently associated with a history of treatment with patching but not with a history of strabismus or wearing
glasses. Amblyopic children from pre-school to grade 2 school level (n=29; age = 6.6 ± 0.6 years) had similar self-perception scores to their age-matched peers (n=20; age = 6.4 ± 0.5 years).

There were no significant differences between the amblyopic (n=39; age 9.1 ± 0.9 years) and age-matched control (n = 42; age = 9.3 ± 0.38 years) groups for any of the DEM outcome measures (Vertical Time, Horizontal Time, Number of Errors and Ratio (Horizontal time/Vertical time)). Performance on the DEM did not significantly relate to measures of VA in either eye, level of binocular function, history of strabismus or refractive error.

Developmental Eye Movement test outcome measures Horizontal Time and Vertical Time were significantly correlated with reading rates measured by the Visagraph for both reading for comprehension and naming numbers ($r>0.5$). Some moderate correlations were also seen between the DEM Ratio and word reading rates as recorded by Visagraph ($r=0.37$).

In children with normal vision, academic scores in mathematics, spelling and reading were associated with measures of fine motor skills. Strongest effect sizes were seen with the timed manual dexterity domain, Upper Limb Speed and Dexterity.

**Conclusions** Amblyopia may have a negative impact on a child’s fine motor skills and an older child’s sense of acceptance by their peers may be influenced by treatment that includes eye patching. Clinical measures of eye movements were not affected in amblyopic children.

A number of the outcome measures of the DEM are associated with objective recordings of reading rates, supporting its clinical use for identification of children
with slower reading rates. In children with normal vision, proficiency on clinical measures of fine motor skill are associated with outcomes on standardised measures of educational performance. Scores on timed manual dexterity tasks had the strongest association with educational performance.

Collectively, the results of this study indicate that, in addition to the reduction in visual acuity and binocular function that define the condition, amblyopes have functional impairment in childhood development skills that underlie proficiency in everyday activities. The study provides support for strategies aimed at early identification and remediation of amblyopia and the co-morbidities that arise from abnormal visual neurodevelopment.
List of Publications and/or Manuscripts arising from PhD research


ARVO Abstract


“The Effect of Amblyopia on Motor and Psychosocial Skills in Children”

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<td>BOTMP</td>
<td>Brunicks-Oseretsky Test of Motor Proficiency</td>
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<td>ULSD</td>
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<td>VMC</td>
<td>Visual Motor Control</td>
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<td>SPPC</td>
<td>Self Perception Profile for Children</td>
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<td>PSPCSA</td>
<td>Pictorial Scale of Perceived Competence and Social Acceptance for Young Children</td>
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<td>QUT</td>
<td>Queensland University of Technology</td>
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<tr>
<td>IHBI</td>
<td>Institute of Health and Biomedical Innovation</td>
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<td>HTA</td>
<td>Health Technology Assessment</td>
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Statement of original authorship

“The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief the thesis contains no material previously published or written by another person except where due reference is made.”

Signed:……………………………………..

Date:………………………..
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This work was supported by Queensland University of Technology (QUT) and the Institute of Health and Biomedical Innovation (IHBI).
Amblyopia is the most common cause of reduced vision in children and young people (Robaei et al. 2006b), with significant costs to both the individual and community in terms of screening and treatment. Amblyopia results from abnormal development of the visual system and affects approximately three percent of the adult population (Attebo et al. 1998; Brown et al. 2000). Clinically, amblyopia is diagnosed when there is a difference in visual acuity (VA) between the eyes of two lines or more, a pre-disposing amblyogenic condition is present, and there is no sign of visible ocular or visual pathway disease.

Amblyopia is usually classified according to the underlying cause, which, most commonly, are strabismus (misalignment of the eyes), anisometropia (significant difference in refractive error between eyes), or form deprivation (presence of media opacity such as cataract). These conditions create monocular blur or ocular misalignment, which if present during the critical period of visual development (up to about 7 years of age) (Daw 1998), can lead to a loss or rearrangement of neural connections within the visual cortex (Ciuffreda et al. 1991; Daw 2006).

While much has been reported about the visual characteristics of amblyopia, the natural history of the condition and appropriate detection and treatment strategies (Simons 2005), the functional disadvantage of amblyopia has not been fully explored, particularly in the childhood population in whom amblyopia is most often diagnosed and treated (Snowden and Stewart-Brown 1997a).

Community funded childhood vision screening programs target the presence of amblyopia and its risk factors, mainly strabismus or refractive error. These
screenings have aimed to provide a safety net by identifying children with risk factors for amblyopia while they are still within the critical period of treatment efficacy. However, the continued funding of vision screening has been questioned due to the lack of evidence on the long-term impact of amblyopia, the extent of disability that amblyopia and strabismus have, and their impact on quality of life (Snowden and Stewart-Brown 1997a; Carlton et al. 2008).

A 1997 Health Technology Assessment (HTA) review of literature into the conditions targeted in pre-school vision screening concluded that the literature is deficient in good quality research into the natural history of these conditions, the disability associated with them and the efficacy of available treatments (Snowden and Stewart-Brown 1997a). Following its publication, the HTA’s review conclusions were much debated in the literature, with criticism that its recommendations were not objective and that the shortage of data regarding the effectiveness of amblyopia treatment may result in a premature disassembly of pre-school vision screening programs (Rahi and Dezateux 1997; Stewart-Brown and Snowden 1998; Williams et al. 1998). However, a positive outcome of the publication was that it provided the impetus for a series of well-conducted randomised control trials particularly pertaining to amblyopia treatment (The Pediatric Eye Disease Investigator Group 2002a; Clarke et al. 2003; The Pediatric Eye Disease Investigator Group 2003b; The Pediatric Eye Disease Investigator Group 2003c; Holmes and Clarke 2006).

While the surge in publications regarding amblyopia treatment has provided clinicians with good evidence on which to base clinical treatment guidelines (Holmes and Clarke 2006; Webber 2007), there is still only limited published evidence
regarding the deficits in functional performance that may occur with abnormal
development of the visual system. A recent population based study of educational,
health and social outcomes, which failed to identify any “real life” functional impact
of the visual deficits associated with amblyopia, highlighted the need for further
research on what it means to be amblyopic (Rahi et al. 2006). A more recent HTA
review of the clinical benefits and cost-effectiveness of screening programs for
amblyopia and strabismus in children up to the age of 4-5 years has again
emphasised the paucity of evidence regarding the functional impact of amblyopia
(Carlton et al. 2008).

While the monocular performance of the amblyopic visual system has been
extensively explored, particularly for threshold measures of sensitivity or acuity in
order to gain an insight to visual neurodevelopment (McKee et al. 2003), there have
been only limited investigations of the performance of amblyopes under habitual
supra-threshold binocular viewing conditions (Grant et al. 2007). In particular, little
has been reported on the impact of amblyopia on the ability to complete activities of
daily living that impact on career opportunities or career choices (Snowden and
Stewart-Brown 1997b). Even though amblyopia is the most common disorder seen
in paediatric ophthalmic practice in industrialised countries, few studies report on the
impact of the condition on tasks relevant to the activities of children (Hrisos et al.
2003), or on tasks pertinent to the activities of amblyopic children and their
educational achievement (Carlton et al. 2008; Engel-Yeger 2008).

The study presented in this thesis aimed to investigate disability attributable to
amblyopia in children and to ascertain the impact of the condition and its treatment
in the childhood population targeted by vision screening programs. It is hoped that
the results of this study will inform clinicians working with amblyopic children of the decrements in developmental skills that may arise as an outcome of the condition or its treatment.

The performance of amblyopic children from a range of aetiologies was compared to that of age-matched control children with normal visual development on age-appropriate, standardised tests of motor and psychosocial skills. A standardised clinical assessment test of fine motor skills was selected to allow comparison of performance of both the amblyopic and control children to published normative data and to provide a guide to the clinical significance of motor performance results. The influence of aetiology and visual factors that might predict any decrement in motor performance was also explored.

The psychosocial impact of amblyopia was investigated by comparison of perceived self esteem scores between groups of amblyopic and control children. Age-appropriate standardised clinical questionnaires were used for measurement of self-perception scores and the influence of visual and treatment factors for amblyopia on self-perception scores was examined.

A standardised clinical indirect measure of eye movements was employed to assess the quality of oculomotor performance in amblyopic and control children aged from eight years of age. While a more direct recording of eye movements during reading was considered, recordings proved unreliable through the refractive correction worn by the majority of the amblyopic children. The outcomes of the indirect eye movement measure were tested for correlation with direct recordings of eye movements made during reading in a subset of the control children.
Outcomes on standardised educational tests were gathered in a subset of the control
children to provide a means of exploring the relationship between motor skills and
academic achievement. Approval to access standardised educational achievement
data of the children who attended a local primary school, Bulimba State School, was
granted by both the school principal and Education Queensland, the Department
responsible for state schools in Queensland. As the children who formed the
amblyopic sample attended many different schools and school districts around
South-East Queensland, it was not within the scope of this study to attain access to
comparable standardised educational data for the amblyopic group.

A number of publications have arisen from this study and form Chapters four to six
in the thesis. The development and writing of these papers was undertaken by the
first author and supported by Joanne Wood, Glen Gole and Brian Brown. The co-
authors have given permission for the papers to be included in this thesis.

The review of the literature provided in Chapter 2 is a summary of research relevant
to the current understanding of amblyopia, including the prevalence and risk factors
for amblyopia, the changes to visual function and underlying neural processing that
occur and recent studies of amblyopia treatment. Current evidence regarding the
functional and psychosocial impact of amblyopia and its treatment are discussed.
Particular attention has been focused on studies that report performance in paediatric
populations.

The specific research questions addressed in this thesis are identified and the
methodology used to provide data to investigate these questions is described in the
general methods chapter, Chapter 3. The chapter is organised around three main
topics: the participants, the standardised test procedures, and the statistical analysis.

The results of the investigation of fine motor skills are presented in Chapter 4 (Webber et al. 2008a). The performance of a sample of children with amblyopia of differing aetiologies on standardised, age-appropriate tests of fine motor skills performance under habitual binocular conditions was compared with that of an age-matched control group of children. The influence of patient aetiology and measured visual characteristics was examined by testing whether these factors were associated with outcome measures of fine motor skill.

The psychosocial skills assessment results are reported in Chapter 5. Perceived self esteem was assessed for those children of grade 3 school level and above with the Harter Self Perception Profile for Children (SPPC) and for those from preschool to grade 2 school level with the Pictorial Scale of Perceived Competence and Acceptance for Young Children (PSPCA). The use of different questionnaires for the age groups made it necessary to consider the data of these age groups separately. Chapter 5 Part A, reported the self-perception scores of amblyopic and control children of grade 3 school level and above (aged from eight years). The relationship between self-perception scores and various subject characteristics suggested by the literature as likely to have psychosocial impact (history of strabismus, wearing of glasses, patching regimen and visual acuity deficit) were tested (Webber et al. 2008b). In addition to the published results for the older cohort of children, the self-esteem of children from preschool to grade 2 (aged from five to eight years) was compared between amblyopic children and age-matched controls and is presented in Chapter 5 Part B.
The performance of amblyopic children on the Developmental Eye Movement (DEM) test, a commonly used clinical measure of saccadic eye movements, was compared with that of age-matched controls and is presented in Chapter 6 Part A. The influence of aetiology and visual characteristics on the outcome measures of the DEM was also explored (Webber et al. 2009). The correlation between DEM measures and infra-red recordings of eye movements during reading for comprehension in a group of children with normal vision is also presented as part of this chapter that reports on eye movements (Chapter 6 Part B).

The relationship between proficiency in fine motor skills and educational outcomes was explored by determining the correlations between outcome fine motor skills scores and standardised measures of numeracy and literacy in a group of children with normal vision who attended a local primary school. This analysis is presented in Chapter 7.

The results from all sections of the research completed as part of this thesis are considered and discussed collectively in terms of addressing the original research questions and hypotheses in the general discussion chapter (Chapter 8). The implications of the study findings for clinical practice and health policy are also discussed, along with the limitations of the present study and suggestions for further research directions.
Chapter 2 LITERATURE REVIEW

2.1 Background

Amblyopia is the consequence of disruption of the normal neurological development of the visual system and can occur with varying levels of severity. Deprivation of pattern vision or abnormal binocular interactions during early childhood can cause a decrease in visual acuity which is primarily unilateral. While amblyopia principally affects one eye, the non-amblyopic eye often has an array of small but measurable deficits (Simons 2005). There is no obvious ocular disease underlying the reduced visual acuity, rather there is some pre-disposing condition that influences the post-natal neuro-development of the visual system. The most common pre-disposing conditions for amblyopia are strabismus (causing disruption of binocular vision development), refractive error (particularly anisometropia or hyperopia), or, more rarely, media opacification (such as congenital cataracts) causing reduction in image quality. The relationship between strabismus and amblyopia is complex in that, as well as being a cause of amblyopia, strabismus and anisometropia can also both arise as a result of amblyopia (McKee et al. 2003). The visual impact is most severe with prolonged, early abnormal visual experience. That is, the earlier in post-natal visual development the predisposing condition presents and the longer the duration of abnormal visual experience, the worse the amblyopic deficit (Von Noorden 1996).

Binocular vision describes the integration of the images from the two eyes to achieve a single image. This has a sensory-motor component that describes the co-ordinated eye movements necessary to align the images from the two eyes, and a sensory
component that describes the cortical integration of the two images for resultant three-dimensional stereoscopic vision. Binocular vision can be degraded in amblyopia from suppression of the image in the amblyopic eye or abnormal retinal correspondence (Bloch and Wick 1991; McKee et al. 2003), both of which are thought to reduce the perception of diplopia that results from ocular misalignment. Clinically, the level of sensory binocular vision is measured by testing stereoacuity. Most amblyopes with a history of strabismus have little or no clinically measurable stereoacuity, even if VA has improved after treatment and no longer meets the clinical criteria of a two line difference in VA between eyes. In contrast, many anisometropic amblyopes have some residual stereoacuity that may be as good as the resolution of the amblyopic eye permits (McKee et al. 2003).

Amblyopia is usually classified according to the presenting visual condition believed to have caused the impaired visual development. An example of this classification is that used by Attebo et al. (1998), where amblyopia was identified in their population cohort as (1) anisometropic, if there was a difference in the spherical or cylindrical refractive error between the two eyes of one dioptre or more and no strabismus was present; (2) strabismic, if heterotropia or micro-squint was present without anisometropia or high refractive error; (3) mixed, if anisometropic amblyopia and strabismic amblyopia co-existed or (4) stimulus deprivation, if there was some obstruction to vision during the sensitive period of visual development (this included high refractive errors) (Attebo et al. 1998).

The term “isoametropic amblyopia” may be used with either unilateral or bilateral amblyopia secondary to a significant bilateral refractive error. Refractive correction
does not immediately correct vision, however, VA usually improves once the corrective lenses have been worn for a few months (Ciuffreda et al. 1991).

2.2 Prevalence

The reported prevalence of amblyopia varies, due to differences between studies regarding how amblyopia is defined and the characteristics of the sample (see Table 2.1). For example, studies involving populations attending ophthalmologists’ practices, such as those reported by Irvine and De Roeth (see Table 2.1), are not representative of the general population and typically report a relatively high prevalence of amblyopia. Australian adult population-based cohort studies that aimed to avoid such bias reported the prevalence of amblyopia to be 3.06% (n=4721) (Brown et al. 2000) and 3.2% (n=3654) when amblyopia was defined as a best corrected VA of 6/9 or worse (VA $\leq 0.2$ logMAR) (Attebo et al. 1998) in the absence of pathological causes of reduced vision. If the definition for amblyopia was instead given as two lines difference in VA, the prevalence amblyopia was reported to be 2.6% (Attebo et al. 1998).

Australian studies of childhood populations have reported that 1.8% of a sample of 6-year old children (n=1741) (Robaei et al. 2006a) and 1.7% of a sample of 12 year old children (n=2353) (Robaei et al. 2006b) either had amblyopia or had been treated for amblyopia (defined as VA $\leq 6/12$ and at least a two line difference in VA between eyes).
### Table 2.1: Reported prevalence of amblyopia

<table>
<thead>
<tr>
<th>Populations</th>
<th>Prevalence (%)</th>
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</thead>
<tbody>
<tr>
<td><strong>Recruited soldiers</strong></td>
<td></td>
</tr>
<tr>
<td>1.0 Irvine 1945*</td>
<td></td>
</tr>
<tr>
<td>1.0 Helveston 1965*</td>
<td></td>
</tr>
<tr>
<td>1.4 Theodore et al. 1946*</td>
<td></td>
</tr>
<tr>
<td>1.8 Evens and Kuypers 1967*</td>
<td></td>
</tr>
<tr>
<td>2.4 Glover and Brewster 1944*</td>
<td></td>
</tr>
<tr>
<td>3.2 Downing 1945*</td>
<td></td>
</tr>
<tr>
<td><strong>Preschool and school-age children</strong></td>
<td></td>
</tr>
<tr>
<td>0.5 Friedman et al. 1980*</td>
<td></td>
</tr>
<tr>
<td>1.3 Russell et al. 1961*</td>
<td></td>
</tr>
<tr>
<td>1.7 DaCunha and Jenkins 1961*</td>
<td></td>
</tr>
<tr>
<td>1.8 Flom and Neumaier 1966*</td>
<td></td>
</tr>
<tr>
<td>2.7 McNeil 1955*</td>
<td></td>
</tr>
<tr>
<td>3.1 Frandsen 1960*</td>
<td></td>
</tr>
<tr>
<td>3.5 Vereecken et al. 1966*</td>
<td></td>
</tr>
<tr>
<td>3.0 Thompson et al. 1991</td>
<td></td>
</tr>
<tr>
<td>1.1 Williams et al. 2003 ALSPAC– early screening</td>
<td></td>
</tr>
<tr>
<td>2.0 Williams et al. 2003 ALSPAC – late screening</td>
<td></td>
</tr>
<tr>
<td>1.0 (Eibschitz-Tsimhoni et al. 2000) – early screening</td>
<td></td>
</tr>
<tr>
<td>2.6 (Eibschitz-Tsimhoni et al. 2000) – late screening</td>
<td></td>
</tr>
<tr>
<td><strong>Adult general population</strong></td>
<td></td>
</tr>
<tr>
<td>2.9 Vinding et al. 1991*</td>
<td></td>
</tr>
<tr>
<td>3.1 Brown et al. 2000</td>
<td></td>
</tr>
<tr>
<td>3.2 Attebo et al. 1998</td>
<td></td>
</tr>
<tr>
<td><strong>Ophthalmic patients</strong></td>
<td></td>
</tr>
<tr>
<td>4.0 Irvine 1945*</td>
<td></td>
</tr>
<tr>
<td>4.5 De Roeth 1945*</td>
<td></td>
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<tr>
<td>5.3 Cole 1959*</td>
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</table>


The proportional distribution of various types of amblyopia also varies between studies, depending upon the characteristics of the study sample and the definition of amblyopia used. Attebo et al.’s (1998) Australian adult population study which defined amblyopia as best corrected VA of ≤ 6/9, reported the main cause of amblyopia to be anisometropia (50%), with strabismus being the pre-disposing
condition in 19%, mixed (both strabismus and anisometropia) in 27% and visual deprivation in 4% (Attebo et al. 1998). In a cohort of North American children undergoing treatment for moderate amblyopia (amblyopic VA of 6/12 to 6/30; n=409; mean age 5.3 years) the causes were found to be strabismus in 38%, anisometropia in 37%, and mixed in 24% of cases (The Pediatric Eye Disease Investigator Group 2002b). In children with severe amblyopia (amblyopic VA 6/30 to 6/120; n=175; mean age 4.8 years) the causes were found to be anisometropia in 34%, strabismus in 27% and mixed in 38% of cases (The Pediatric Eye Disease Investigator Group 2003b). In all studies the prevalence of deprivation amblyopia is relatively rare, reflective of the low incidence of underlying pathology such as infantile cataract (2 to 4.5 of every 10 000 births) (Rahi and Dezateux 1999; Holmes et al. 2003).

The Avon Longitudinal Study of Parents and Children (ALSPAC), a UK population birth cohort study, reported the prevalence of amblyopia at 7.5 years of age (Williams et al. 2003). Of 6,081 children, 16.7% had attended preschool vision screening (age 3-4 years) and all the children had been offered vision screening in the school reception class (age 4-5 years). The prevalence of amblyopia was significantly lower in those children who had received preschool screening and subsequent treatment for an amblyogenic condition compared with those who had not (1.1% v 2.0%, p=0.05). This finding supports that of an Israeli study which found a 1% prevalence of amblyopia in 8 year old children previously screened and treated for amblyopia (n=808), compared with 2.6% in a matched population that had not received treatment (n=782) (Eibschitz-Tsimhoni et al. 2000).
In summary, contemporary population studies of amblyopia indicate a prevalence of approximately 3% in untreated childhood populations and current adult populations. With detection and treatment of the amblyogenic condition by five years of age, the prevalence of clinically significant amblyopia reduces to around 2%. With detection and treatment before three years of age, the prevalence of clinically significant amblyopia reduces to around 1% (Eibscht-Tsimhoni et al. 2000; Williams et al. 2003).

2.3 Risk Factors for Amblyopia

Amblyopia is more than four times more common in premature infants or infants who are small for gestational dates (Tychsen 1992), or who have a first-degree relative with amblyopia (Abrahamsson et al. 1999). While it has been observed that a family history of strabismus is a significant predicting factor, few genetic loci for strabismus or amblyopia have been identified (Abrahamsson et al. 1999; Michaelides and Moore 2004).

In infants with neuro-developmental delay the prevalence of amblyopia is six times greater than in healthy, full-term infants (van Hof-Van Duin et al. 1989; Pike et al. 1994). Patients at most risk for amblyopia are infants who experience early stimulus deprivation. Visual deprivation prior to three months of age need not be prolonged to result in the development of amblyopia, and is highly correlated with later development of sensory nystagmus in bilateral cases and strabismus in both monocular and bilateral cases (Tychsen 1992).
In strabismus, the diplopia caused by misalignment of the visual axes can lead to binocular rivalry and suppression of input from the non-dominant eye at the level of the visual cortex. Infantile esotropia (otherwise known as congenital esotropia) generally presents before six months of age, when the developing visual system can be most at risk for amblyopia. Maintained or preferred fixation by the dominant eye, as opposed to freely alternating fixation, (unilateral versus alternating strabismus), increases the likelihood of amblyopia (Laws et al. 2000). If not corrected early, the resultant amblyopia can be profound and difficult to reverse. Even in patients who have had early surgery, with an outcome of good VA in both eyes, stereoacuity may not recover from the early disruption of binocular vision (McKee et al. 2003).

Refractive error represents a risk for developing amblyopia, either due to the creation of dissimilar images in anisometropic amblyopia, or as a driving factor for accommodative esotropia (acquired esotropia). Children identified at screening as at risk for amblyopia due to hyperopia greater than or equal to 3.5 D in any meridian, were 13 times more likely to become strabismic and six times more likely to show measurable acuity deficits by four years of age compared with controls (Atkinson et al. 1996). Wearing a partial spectacle correction reduced these risk ratios to 4:1 and 2.5:1 respectively and did not interfere with the process of emmetropisation (the reduction in magnitude of refractive error seen in young children) (Atkinson et al. 1996).

Strabismus, hyperopia and amblyopia are often present in the same children. In their report of prevalence and risk factors for common vision problems in children at the age of 7 years (n=7825), the ALSPAC team reported that of 365 children with hyperopia of at least +2.00 D in either eye, 124 (34%) had clinically significant
convergent strabismus and 158 (43.3%) had past or present amblyopia. Overall, 199 (54.5%) children with hyperopia had either strabismus or amblyopia, while 83 (22%) had both (Williams et al. 2008). The ALSPAC study also considered family social class and socioeconomic status, parental self-reported hyperopia, history of strabismus/amblyopia in first-degree relative, maternal smoking during pregnancy, child’s ethnicity, gestation, birth weight and gender in their analysis of potential risk factors for hyperopia, strabismus or amblyopia in seven year old children. They reported that children from the lowest occupational social class background were 1.82 times more likely to be hyperopic than children from the highest social class. Amblyopia and convergent strabismus also tended to increase as social class decreased (Williams et al. 2008).

### 2.4 Natural History

The studies of early treatment intervention regimens allow better understanding of the natural history of amblyopia. Randomised controlled treatment trials (Clarke et al. 2003), together with reviews of patients who have not been compliant with treatment (Simons and Preslan 1999), indicate that amblyopia does not recover without treatment. Populations that undergo early intervention and treatment have a lower prevalence of amblyopia than those that do not, implying that amblyopia does not improve of its own accord (Williams et al. 2003). Intervention is required to maximise potential VA in the affected eye, however, the age at which that intervention will still be effective has not been confirmed and is the subject of ongoing studies (The Pediatric Eye Disease Investigator Group 2004; The Pediatric Eye Disease Investigator Group 2005b).
2.5 Impact of amblyopia on visual function (psychophysics)

While amblyopia is usually diagnosed clinically from a difference in VA between the eyes, other monocular visual functions are also affected, including contrast sensitivity, vernier acuity, steadiness of fixation, motion perception and temporal processing (Asper et al. 2000a; McKee et al. 2003). Amblyopia results in marked losses of contrast sensitivity, particularly at high spatial frequencies (Ciuffreda et al. 1991). Amblyopic eyes can have decreased accommodative amplitude and increased accommodative lag (Asper et al. 2000a), and can display oculomotor deficits including inaccurate or unsteady fixation and inaccurate tracking pursuits; the tracking pursuits of the non-amblyopic eye can also be less accurate than in age-matched controls (Bedell et al. 1985).

Binocular vision, the cortical fusion of images arising from the two eyes necessary for fine levels of stereoacuity, is commonly disrupted in amblyopia, although the findings of a recent study suggest that binocular summation and inter-ocular suppression are present in strabismic amblyopia (Baker et al. 2008). In their study of 427 adults with amblyopia or with risk factors for amblyopia, McKee et al. (2003) reported that while only about ten percent of subjects with strabismus or both strabismus and anisometropia passed both of their tests of binocular vision (stereoacuity and binocular motion integration), nearly two thirds (64%) of subjects with anisometropia alone passed both tests of binocular vision (McKee et al. 2003).

The existence of multiple neural mechanisms underlying different visual functions is suggested by evidence of variation in the rates at which a particular visual function develops (Skoczenski and Norcia 2002). In the normal visual system, pattern detection and resolution (acuity measures) and position discrimination measures
(vernier acuity) mature at different rates; grating acuity reaches its adult-level at around six years of age, whereas vernier acuity shows an increasing phase after six years of age that lasts until ten to 14 years of age (Skoczenski and Norcia 2002). Visual-motor hand-eye co-ordination skills also mature over the period extending through infancy, beyond the critical period for amblyopia, until around 12 years of age (Grant et al. 2007).

The emphasis of psychophysical studies of amblyopia has been to explore the spatial, temporal and oculomotor characteristics of the abnormally developed visual system to gain an understanding of visual neurodevelopment. However, these studies do not necessarily provide a full representation of the impact of amblyopia on visually directed tasks in everyday circumstances. In normal everyday vision, stimuli have contrast levels well above the threshold levels reported in psychophysical studies. Functionally, it is important to investigate the extent to which the impairment of amblyopia influences performance under habitual supra-threshold conditions.

2.6 Impact of amblyopia on visual pathways (neural processing)

Studies of the neurophysiology of the visual pathways of amblyopes indicate that the most profound and consistent effects of amblyopia are at the striate cortex, with the pattern of changes in cortical neurophysiology dependant on the cause of amblyopia (Ciuffreda et al. 1991). A loss of binocularly driven neurons is found when amblyopia results from strabismus, while a loss of neurons driven by the deprived eye is found in animals with amblyopia created by occlusion of one eye (Ciuffreda et al. 1991). A selective loss of neurons tuned to higher spatial frequencies is found in animal models of anisometropia (Movshon et al. 1987). Human psychophysical
studies have also determined that the pattern of visual function characteristics varies between those with a history of blur (anisometropia and form deprivation) and those with a history of ocular misalignment (strabismus) (McKee et al. 2003)

Anatomical and functional studies indicate the presence of parallel visual pathways leading to the visual cortex via the lateral geniculate nucleus (LGN), known as the magnocellular (M) and parvocellular (P) pathways, and concurrent visual streams, the dorsal parietal and the ventral temporal pathways, have also been described beyond the striate visual cortex (Asper et al. 2000b). The dorsal stream is dominated by the M-type pathway, with some input from the P-type pathway. The dorsal pathway is primarily involved with perception of motion, depth, control of eye movements and localisation of targets in space (Asper et al. 2000b). The ventral pathway extends from the primary visual cortex to the inferior temporal cortex (IT) of the temporal lobe and has input from both M and P-type cells. The ventral pathway is mainly involved in the identification of pattern, resolution of fine detail and colour perception (Asper et al. 2000b). However, the division into parallel visual pathways may not be clear cut with evidence accumulating both of convergence of the M and P inputs and of functional interactions between the neural mechanisms involved in the processing of shape (ventral) and motion (dorsal) information about objects (Simmers et al. 2005).

Contemporary animal studies, psychophysical and human neuro-imaging studies suggest that deficits may exist beyond the striate cortex in the amblyopic visual system (Barnes et al. 2004), particularly in extra-striate pathways that predominantly process motion information (Simmers et al. 2005). While changes to extra-striate pathways are reported (Barnes et al. 2004; Simmers et al. 2005), the extent of
alterations to neural connections beyond the striate cortex in amblyopia is yet to be fully explored.

Controversy regarding the neurophysiological site of the visual deficit occurring in amblyopia has arisen from conflicting results in electrophysiological studies (Hess 2001). While it has been suggested that some visual dysfunction in amblyopia may exist at the retinal level, the balance of evidence still suggests that the primary site of the deficit associated with amblyopia is at the visual cortex (Hess 2001; Westheimer 2004).

The functional impact of the neurological changes in the amblyopic visual system on visual-motor processing, and how that may affect the performance of visually directed tasks under habitual binocular viewing conditions, has not been established. The differences between strabismic and anisometropic amblyopia in the patterns of monocular and binocular visual loss suggest two distinct developmental anomalies (Tolchin and Lederman 1977; Bloch and Wick 1991; McKee et al. 2003). If the neurophysiological changes that occur in amblyopia are different as a result of monocular blur versus oculo-motor misalignment, then we might expect differences in functional ability between amblyopes of differing aetiologies.

2.7 Amblyopia treatment

Amblyopia treatment usually entails correction of the underlying pre-disposing condition followed by a period of deprivation or penalisation of the dominant eye to promote maximum visual experience for the amblyopic eye. Some conditions that cause amblyopia, such as infantile esotropia, present very early in life and are
therefore treated early in life, while other acquired strabismic conditions may not manifest until later in early childhood. Differences between aetiological groups also exist in treatment regimens, in that some amblyopic children will require surgery for strabismus or media opacity, while others have refractive correction for accommodative strabismus or anisometropia. Some children will undergo patching for up to six months while others with greater depth of amblyopia, as is often the case with deprivation amblyopia, may continue with patching for more prolonged periods.

A number of multi-centre randomised controlled treatment trials of amblyopia treatment have been conducted over the last decade by the Pediatric Eye Disease Investigator Group (PEDIG) (Holmes and Clarke 2006). Together with trials that have monitored the dose of occlusion received (Stewart et al. 2005), the PEDIG studies demonstrate that the younger the child when treatment commences, the more rapid the response to treatment and the better the visual outcome. However, the upper age limit at which improvements in VA can be achieved is yet to be established, with reports of improvement with treatment or after loss of the non-amblyopic eye even into adulthood (Klaeger-Manzanell et al. 1994; Mohan et al. 2004; The Pediatric Eye Disease Investigator Group 2008b).

2.7.1 Refractive correction

It is well established that correction of any underlying refractive error is critical in amblyopia treatment (Bloch and Wick 1991). However, it is only more recently that the extent to which the correction of refractive error alone might reduce amblyopia has been explored (Moseley et al. 2002; Stewart et al. 2004a; The Pediatric Eye Disease Investigator Group 2008b).
Disease Investigator Group 2006; Cotter et al. 2007). Correction of refractive error alone for a period of 18 weeks resulted in significant improvements in VA of the amblyopic eye in newly diagnosed amblyopic children (n=65; mean age 5.1 years) (mean improvement of 0.24 logMAR). This improvement did not differ significantly as a function of the type of amblyopia, or the age of the patient (Stewart et al. 2004a). Refractive adaptation prior to commencement of occlusion or penalisation therapy may have significant benefits, including improved VA during occlusion which may assist compliance and, in some cases, unnecessary patching can be avoided (Stewart et al. 2004b; The Pediatric Eye Disease Investigator Group 2006; Stewart et al. 2007). Refractive correction is now considered a distinct component of amblyopia treatment and it is recommended that the benefit of refractive correction be fully realised before commencing occlusion or penalisation treatment (Holmes and Clarke 2006).

2.7.2 Correction of abnormal ocular alignment or opacity

It has been conservatively estimated that 17% of patients with amblyopia will undergo alignment surgery, 1.5% will require cataract extraction and 1.5% will require ptosis surgery (Membreno et al. 2002). While population-based studies addressing the distribution and incidence of each type of strabismic amblyopia are not available, a cost-utility analysis study estimated from case series and anecdotal experience that approximately 60-75% of strabismic amblyopes are accommodative, with 60% of patients with accommodative esotropia not fully correctable with spectacles and requiring surgery for ocular alignment (Membreno et al. 2002). The subgroup of strabismus patients with amblyopia who would require alignment
surgery was estimated to be between 48% and 62% of all amblyopic patients with strabismus (Membreno et al. 2002).

2.7.3 Occlusion and penalisation

The mainstay of treatment for amblyopia for the last 250 years has been occlusion of the better eye by an opaque patch (patching). However, therapeutic regimens have lacked standardisation, with the length of patching ranging from a few minutes a day to all waking hours, and in some cases treatment may last many months or even years. Recent studies that have investigated the relative merits of patching and atropine penalisation have commented on the considerable variation in treatment practices between eye care practitioners with regard to the number of hours of initial patching prescribed (The Pediatric Eye Disease Investigator Group 2002b). PEDIG (2002b) reported that, while the number of hours of patching prescribed had no relationship to patient age, it was related to the VA in the amblyopic eye (i.e. depth of amblyopia).

While randomised controlled treatment trials have shown patching and atropine penalisation therapy to be successful in treating amblyopia in children younger than seven years (The Pediatric Eye Disease Investigator Group 2002a; The Pediatric Eye Disease Investigator Group 2002b; Stewart et al. 2004b), the question of the upper age limit for successfully treating amblyopia has still not been fully addressed. Preliminary treatment studies in children older than seven years have indicated that VA can be improved in these older children and adolescents (The Pediatric Eye Disease Investigator Group 2004; The Pediatric Eye Disease Investigator Group 2008b). While a preliminary study found an average of one extra logMAR line of
improvement when the patient performed near activities during occlusion or penalisation (The Pediatric Eye Disease Investigator Group 2005a), the benefits of active versus passive therapy during patching were not confirmed by randomised controlled treatment trial (The Pediatric Eye Disease Investigator Group 2008a).

2.7.4 Emotional impact of treatment

Amblyopia treatment may create negative behaviour changes in children and have an impact on family life (The Pediatric Eye Disease Investigator Group 2003a; Choong et al. 2004; Hrisos et al. 2004). Parents of children undergoing patching for amblyopia report distress or an increase in conflict at home, even for relatively short periods of patching, which most parents linked with a decrease in child’s confidence from poor vision under occlusion conditions (Searle et al. 2000). These behaviour changes appear to be more profound in children with a greater level of amblyopia. What has not been established is whether these behavioural changes are due to greater visual impairment under penalised conditions in children with worse amblyopia, or, due to the longer duration of penalisation treatment that tends to be prescribed in those with worse amblyopia. Even though not all parents report that their child’s activities are affected, the degree of compliance with treatment and observations of changes in patterns of behaviour has been found to depend on the level of amblyopia (Parkes 2001). The behaviour of the child during treatment influences compliance, which raises the possibility that the efficacy of treatment could be reduced by poor compliance in those children with the greatest need (Simons et al. 1997).
Children prescribed patching were found to be more upset and showed more resistance to their treatment than those prescribed glasses alone (Hrisos et al. 2004). However, in congenital monocular cataract patients ($n=22$) who had their better eye patched for a significant percentage of their early childhood years, no significant evidence of developmental delay or increased behavioural problems were found when compared to their siblings who had normal visual development (Smith et al. 1991).

More recent studies have found that most children report feeling self-conscious and ashamed during amblyopia treatment, particularly due to patching or wearing glasses, and that it was the responses of their peers that most influenced their feelings of embarrassment (Koklanis et al. 2006). Children currently wearing glasses or with a history of wearing eye patches are also approximately 35% more likely to be victims of physical or verbal bullying (Horwood et al. 2005; Koklanis and Georgievski 2007).

Reports regarding the impact of patching on parental distress or stress levels, however, vary. Hrisos et al. (2004) report that many parents experienced difficulty with patching and were more likely to be upset by this treatment than parents whose children were treated with glasses alone, although, the levels of distress and difficulty reported by parents were quite low (Hrisos et al. 2004). Conversely, Choong et al. (2004) found that carers of children undergoing patching did not experience significantly more stress or perceive their child as exhibiting less psychosocial wellbeing than carers of children who were not patched. In addition, carers’ stress level and child’s psychosocial well-being within the patched group did not change significantly following the onset of occlusion therapy (Choong et al. 2004).
2004). PEDIG report that although results on their Amblyopia Treatment Index questionnaire indicated that both patching and atropine treatments were well tolerated by the child and family, atropine received more favourable scores overall, and for all three questionnaire subscales (adverse effects of treatment; difficulty with compliance; social stigma) (The Pediatric Eye Disease Investigator Group 2003a).

While these studies have examined the psychosocial impact of amblyopia treatment on treated children and their families, they have involved a number of shortcomings, including the use of specifically developed questionnaires, for which normative data were not available for comparison, and failure to address psychosocial issues that may extend beyond the treatment period.

### 2.7.5 Functional impact of treatment

The ability to perform everyday tasks while undertaking amblyopia treatment has not been documented in children with amblyopia, even though this is often cited as the reason for poor compliance with occlusion or penalisation (Hiscox et al. 1992; Simons et al. 1997). During patching all input from the affected eye is blocked, thereby reducing field of vision, eliminating residual stereoacuity, and limiting VA to that of the amblyopic eye, while with atropine treatment the child may experience significant glare from the dilated pupil (Holmes and Clarke 2006). However, there is a lack of studies specifically investigating functional disability during treatment from reduced VA and reduction in binocular input on tasks of importance to children.
2.8 Disability associated with amblyopia

Evidence based reviews of the literature regarding amblyopia and its treatment have highlighted the lack of evidence on the long-term impact of amblyopia, the extent of disability that amblyopia and strabismus produce and their impact on quality of life. In particular, measures of how the condition or its treatment affect ability to perform tasks of daily living or psychological well-being have not been reported (Snowden and Stewart-Brown 1997a; Carlton et al. 2008).

Approximately two-thirds of parents of amblyopic children were reported to express concerns regarding the disability associated with amblyopia (Campbell and Charney 1991). Parents of children with an earlier diagnosis of amblyopia (before the age of five years) were more likely to consider amblyopia a very serious problem than parents of children with a later diagnosis, even though parents of children with later diagnoses more frequently reported that their child had problems attributed to amblyopia. Problems reported by the parents of children with amblyopia were typically those of school performance rather than related to social or athletic activities (Campbell and Charney 1991). These findings contradict those of Snowdon and Stewart-Brown (1997b) who conducted semi-structured interviews with a small number of parents of children with amblyopia (n=11). These parents did not regard amblyopia as a disabling condition, with little impact on career choice or motor function. The overall conclusions of the study were that treatment of amblyopia by patching may result in more disabling outcomes than the condition itself. However, the study conclusions are limited by the small sample size, and the lack of information provided regarding VA, stereopsis or aetiology of the amblyopic children and the absence of a control group (Snowden and Stewart-Brown 1997b).
There is little data pertaining to the negative impact of amblyopia from a population perspective. Chua and Mitchell (2004) examined the consequences of amblyopia for education, occupation and long-term vision loss and reported that amblyopia did not affect lifetime occupational class, although relatively few amblyopes obtained university degrees (Chua and Mitchell 2004). In their population based study of the educational, health and social outcomes of a 1958 birth cohort (n=8861), Rahi et al. (2006) reported that children with amblyopia did as well as their peers in age appropriate tests of mathematics, reading, comprehension, and perceptual and motor skills at ages 7, 11 and 16 years. They showed that children with amblyopia were generally not more likely to have significant behavioural problems or maladjustment at home or school than those without amblyopia. However, amblyopes with a moderate to severe VA deficit were significantly more likely to report having had a road accident when they were the driver that resulted in injury requiring hospital care. This study highlighted the need for further research from a patient perspective on what it means to be amblyopic (Rahi et al. 2006).

Utility measures are preference-based estimates of health-related quality of life, and are increasingly being used in economic evaluations of healthcare interventions. Good vision in both eyes provided a substantial improvement in utility value, a patient’s perception of quality of life, as compared with good vision in only one eye (Membreno et al. 2002; König and Barry 2004). Patient feedback indicates that the psychological stress of having only one good seeing eye to rely on and the apprehension resulting from the knowledge that many eye diseases eventually affect both eyes, is likely to play a major role in decreasing an individual’s quality of life (Brown et al. 2001). In a cost-utility reference-case analysis, treatment for
amblyopia resulted in a gain of between $US 2053 and $US 2509 per quality-adjusted life-year (Membreno et al. 2002).

The potential visual disability due to loss of visual function of the non-amblyopic eye can be calculated and is an argument for amblyopia treatment to maximise visual potential in each eye. A UK study found that of 102 employed people with amblyopia who lost vision in their better eye, only 36 were able to continue in paid employment due to the subsequent vision impairment, and patients with amblyopia have a projected lifetime risk of vision impairment following loss of the fellow eye of at least 1.2% (Rahi et al. 2002). Based upon a population based cohort of subjects aged 55 years or over (n=5220) of whom 192 (3.7%) were amblyopic, van Leeuwen et al. (2007) reported that amblyopia nearly doubles the lifetime risk of bilateral vision impairment.

Poor VA in the worst eye can impact on ability to achieve the minimum visual standard required for some career choices and a commercial driver’s licence. Patients with amblyopia are excluded from a wide range of jobs, which increases with the severity of the amblyopia (Adams and Karas 1999). Table 2.2 reports a summary of occupations that would not be possible for those with poor VA in one eye.
Table 2.2: Visual standards required to enter UK occupations  (Adams and Karas 1999).

<table>
<thead>
<tr>
<th>Visual Acuity in worse eye with correction</th>
<th>Job excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 6/60</td>
<td>Merchant Navy (engine room, radio staff, catering department, surgeon)</td>
</tr>
<tr>
<td>6/60</td>
<td>All army regiments</td>
</tr>
<tr>
<td>6/36</td>
<td>All Royal Naval duties</td>
</tr>
<tr>
<td>6/18</td>
<td>Large goods vehicle driver</td>
</tr>
<tr>
<td></td>
<td>Bus driver</td>
</tr>
<tr>
<td></td>
<td>Post Office driver</td>
</tr>
<tr>
<td></td>
<td>Metropolitan cab driver</td>
</tr>
<tr>
<td></td>
<td>Private pilot</td>
</tr>
<tr>
<td></td>
<td>Train driver</td>
</tr>
<tr>
<td></td>
<td>London Transport line duties</td>
</tr>
<tr>
<td></td>
<td>Fork lift truck driver</td>
</tr>
<tr>
<td></td>
<td>Police</td>
</tr>
<tr>
<td></td>
<td>Prison officer</td>
</tr>
<tr>
<td>6/12</td>
<td>Commercial pilot</td>
</tr>
<tr>
<td></td>
<td>Flight navigator</td>
</tr>
<tr>
<td></td>
<td>Flight engineer</td>
</tr>
<tr>
<td></td>
<td>Air traffic control officer</td>
</tr>
<tr>
<td></td>
<td>All non-flying Royal Air Force personnel</td>
</tr>
<tr>
<td></td>
<td>Merchant seaman (deck duties)</td>
</tr>
<tr>
<td></td>
<td>Life boat crew</td>
</tr>
<tr>
<td>6/9</td>
<td>Royal Air Force pilot</td>
</tr>
<tr>
<td></td>
<td>Royal Air Force navigator</td>
</tr>
<tr>
<td></td>
<td>Royal Air Force aircrew</td>
</tr>
<tr>
<td></td>
<td>Fire Brigade</td>
</tr>
<tr>
<td></td>
<td>Army regiments where minimum 6/6 in each eye is specified</td>
</tr>
<tr>
<td></td>
<td>Royal Navy aircrew and certain branches of Royal Marines</td>
</tr>
</tbody>
</table>

The ability to appreciate the depth of one object relative to another is often required for efficient and safe job performance. While the monocular cues to depth (e.g. overlay, motion parallax, and atmospheric haze) are often all that are required, when precise judgment of relative depth is essential to job performance there may be justification for a binocular vision (i.e., stereopsis) requirement. Examples of
occupations in which stereopsis may be required include crane and forklift operators.

A demonstration of a moderate degree of stereopsis (i.e., 80 arc seconds) has been suggested as a binocular vision standard for occupational safety (Good et al. 1996).

The benefit of an improvement in visual ability in the amblyopic eye can also be quantified by quality of life scores and can result in positive cost-analysis of treatment (Membreno et al. 2002; Konig and Barry 2004).

2.8.1 Impact of amblyopia on motor skills

Many amblyopes have little or no stereopsis, the functional significance of which has rarely been reported (Fielder and Moseley 1996). Most studies that have investigated the benefit of binocular vision have compared performance under monocular and binocular conditions (Jones and Lee 1981; Joy et al. 2001), and have generally concluded that stereoscopic binocular vision facilitates control of manipulation, reaching and balance (Jones and Lee 1981). People who lack stereopsis are found to have difficulty performing tasks which rely on three dimensional visual cues, however, there are many individuals who perform well on tests of manual dexterity even though their stereopsis is poor (Murdoch et al. 1991). In a study of reaching and grasping deficits, adults with amblyopia have been shown to have visuo-motor deficits, mainly in movement planning, under both binocular and non-dominant eye viewing conditions (Grant et al. 2007). The differences between amblyopic subjects and controls included prolonged execution times and more errors, the extent of which co-varied with the depth of amblyopia, although not its aetiology. These authors proposed that a speed-accuracy trade-off operates when quantifying the reaching and grasping behaviour in amblyopes, that is, amblyopes may slow down their approach
to an object to allow them more time to accurately judge its position (Grant et al. 2007).

Parents of strabismic children whose eyes have been aligned surgically have reported that the child’s visuo-motor skills have suddenly and vastly improved following surgery (Von Noorden 1996). This observation was confirmed in a study that assessed infants’ performances on a standardised test of child developmental milestones (the Bayley Scale of Infant Development), both before and after surgery for infantile esotropia. Following surgery, 35% of children showed an increase in performance on tests of fine motor skills and 41% of children recorded an improvement in visually directed reaching and grasping. The greatest post-operative improvement was found in the subtest item that involved depth perception, where the child was required (without monocular clues such as a difference in colour) to identify a depression in a piece of wood (Rogers et al. 1982).

In an investigation of motor control skills in a group of children with congenital esotropia aged four to six years, untreated strabismic children had poorer total scores on the Movement Assessment Battery for Children (Movement ABC) than age-matched controls and particularly performed worse on the subscale that assessed manual dexterity (Caputo et al. 2007). Children who had undergone surgery for congenital esotropia (strabismus) showed post-operative improvements in motor performance, however, these improvements did not correlate with measured improvements in stereopsis (Caputo et al. 2007).

In non-strabismic, pre-school children with reduced acuity in one eye (6/9 to 6/60), stereoacuity, independent of VA, was significantly associated with performance on tasks requiring fine visuo-motor control (bead threading task) (Hrisos et al. 2006).
No significant differences were found between these children and age-matched controls on other items in the battery (measures of visuo-motor integration, visual spatial processing, visual attention, and gross visuo-motor skills) (Hrisos et al. 2006).

In summary, while it has been assumed that the reduced depth perception or reduced resolution that accompany amblyopia would result in reduced fine motor skill performance there is little published evidence to support these assertions. The performance of amblyopic children on standardised clinical tests of fine motor skills that allow comparison with published normative data has not been reported, and the relative performance of amblyopic children from differing aetiologies has not been compared.

2.8.2 Impact of amblyopia on eye movements

While the visual anomalies known to be associated with amblyopia, such as reduced VA in both the affected and fellow eye, reduced or absent stereopsis, and poor fixation control may be expected to have an impact on the fluency of eye movements under habitual binocular viewing conditions, the performance of amblyopic children on clinical tests of eye movements has not previously been reported.

Amblyopes have poorer control of fixation in both the amblyopic and non-amblyopic eye (Kandel et al. 1980) and binocular coordination of saccades is impaired in strabismic amblyopes, particularly those with large angle strabismus (Kapoula et al. 1997). Anomalous oculomotor behaviour was also reported in both the fellow and amblyopic eyes of strabismic amblyopes (Bedell et al. 1985). Even though abnormal eye movement control and poor accuracy and stability of fixation have been
suggested as direct causes of the poor reading skills of some individuals (Eden et al. 1993; Kulp and Schmidt 1997; Coulter and Shallo-Hoffmann 2000; Maples 2003), there has been little study of reading skills in amblyopes. While a functionally relevant reading impairment (reduced maximum reading speed under binocular viewing conditions) has been reported in micro-strabismic children (n=20, age 11.5 ± 1.1 years) (Stifter, Burggasser et al. 2005), how this may relate to the control of binocular eye movements required for reading text across a page has not been investigated in amblyopic subjects.

Understanding the influence of amblyopia on clinical test performance is important for clinicians when interpreting test results and for providing advice to parents regarding the consequences of amblyopia. Clinical treatment plans for amblyopia aim to improve VA and binocular function outcomes. However, the relationship between degraded vision and performance on commonly used clinical tests of eye movements is yet to be fully established and warrants further study.

2.8.3 Impact of amblyopia on psychosocial skills

The psychosocial impact of strabismus and amblyopia and the relationship between amblyopic characteristics and scores on vision-related quality of life questionnaires have been described in the last decade (Burke et al. 1997; Choong et al. 2004; van de Graaf et al. 2004; Archer et al. 2005; Koklanis et al. 2006). While early literature mainly presented anecdotal references to the psychological impact of cosmetically obvious strabismus (Alberman et al. 1971), more recent studies have examined the effect of strabismus and amblyopia on an individual’s self-esteem, interpersonal relationships and employability (Packwood et al. 1999; Coats et al. 2000).
These studies provide an understanding of the adults’ perspective on the psychosocial impact of amblyopia, but have not specifically investigated the impact of the condition from the perspective of a child with amblyopia. While studies have reported child victimisation or bullying associated with amblyopia (Horwood et al. 2005), the self-esteem of children treated for amblyopia has not been previously described.

Forty-one percent of parents whose children had strabismus surgery believed that strabismus adversely affected their child’s psychological development or self-esteem (Eustis and Smith 1987), while adults with strabismus reported difficulty with self-image, securing employment, interpersonal relationships, school, work and sports (Satterfield et al. 1993). Two studies have demonstrated that cosmetically obvious strabismus creates a significant negative social prejudice for patients which can significantly reduce an applicant’s ability to obtain employment (Olitsky et al. 1999; Coats et al. 2000).

Amblyopic adults without strabismus reported that amblyopia interfered with both school and work to some degree, and felt it affected their lifestyle (Packwood et al. 1999). Sixty percent of amblyopes were concerned by associated teasing or ridicule, with the majority reporting some concern that amblyopia had an effect on self-image.

Children from about six years of age develop a negative perception towards individuals with strabismus and children with noticeable strabismus are viewed negatively by teachers (Uretmen et al. 2003). While strabismus surgery results in improvements in social, emotional and functional measures of a child’s health status
(Archer et al. 2005), it is not clear how a previous history of strabismus affects self-esteem in children in the longer term.

Many children with amblyopia need to wear glasses to correct their refractive error, even after completion of occlusion or penalisation amblyopia therapy. Individuals who wear glasses rate themselves lower in terms of their physical attractiveness (Terry and Brady 1976), which, as well as affecting psychological well-being, can affect motivation and behaviour (Harter 1999). Also, children currently wearing glasses or with a history of wearing eye patches are approximately thirty-five percent more likely to be victims of physical or verbal bullying than children with normal vision (Horwood et al. 2005).

How amblyopia or its treatment may impact on self-esteem in children, or the relative influence of condition or treatment factors that may be associated with reduced self-esteem, have not previously been reported. Exploring self-esteem in different aetiological sub-groups may be informative, as well as examining both the wearing of glasses and the influence of patching regimes within the analysis of self-esteem in amblyopic children.

2.8.4 Impact of amblyopia on educational outcomes

Education, occupation and employment are considered key life outcomes, and, while these have been studied at a population level (Rahi et al. 2006), there have not been case-control studies that have specifically measured and compared educational outcomes of amblyopes to their peers with normal vision. Ritty et al. (1993) determined from observations made in 4th and 5th grade classrooms, that VA, contrast
resolving abilities, accommodation and convergence abilities and oculomotor
activities make up the primary demands placed on the visual system by classroom
ergonomics. In their study, seventy-five percent of the time related to academic tasks
in the classroom was found to be spent on reading and writing at near distances and
on tasks that require alternate near to distance viewing. They concluded that
classroom ergonomic conditions require extensive near work and students with
ocular motor dysfunctions may have difficulty meeting the expectations of the
classroom (Ritty et al. 1993). Despite measurable deficits in vision that may be
expected to create difficulty with visually directed tasks in the classroom, the
educational outcomes of children with amblyopia have had little mention in the
literature.

2.9 Summary

Amblyopia is the most common cause of reduced vision in children and young
people, with significant costs to both the individual and community for screening and
treatment. Recent randomised controlled trials of treatment for amblyopia and early
screening and treatment studies have provided evidence regarding the natural history
of amblyopia and efficacy of treatment, however, reports of disability for the patient
with amblyopia are not conclusive and do not specifically address skills that are of
importance to children. Psychophysical and electrophysiological studies of
amblyopia have sought to explore the visual characteristics associated with the
condition to aid understanding of the neurological changes that occur in abnormal
development, rather than seeking to describe the impact of the condition on activities
important from a quality of life perspective.
Under everyday binocular viewing conditions, reduced monocular visual function in the amblyopic eye may have little detrimental effect on visual resolution or detection, however, deficits in depth perception may represent the main functional visual impairment of amblyopes in everyday circumstances. The impact of these vision anomalies on tasks important to children warrants investigation and is the focus of the research described in this thesis.

While a number of functionally relevant deficits in tasks that contribute to quality of life have now been reported (Grant et al. 2007), the educational, health and social life outcomes of amblyopes do not appear to be affected (Rahi et al. 2006). Parental concern regarding the amblyopic child’s performance has been described, however, specific research into which visually directed tasks may be impaired by amblyopia is limited to studies with only small sample sizes. Few studies have investigated the performance of amblyopes under habitual binocular viewing conditions and, even though amblyopia is the most common disorder seen in paediatric ophthalmic practice in industrialised countries, there has been only limited research regarding the impact of the condition on tasks pertinent to the activities of children, such as drawing and copying or fine manual dexterity tasks.

Even after treatment is completed, patients with a history of amblyopia commonly still have some visual function anomaly, such as reduced stereoacuity or binocular fusion, abnormal accommodation or poor ocular-motor function. In addition to determining the extent of functionally relevant deficits in performance that may result from abnormal visual development, it is important to have an understanding of how children with amblyopia perform on clinical tests commonly used in paediatric practice.
There are reports in the literature regarding the impact of amblyopia therapy on family life, however, none of these studies have adequately addressed the effect of treatment on health-related quality of life from the child’s perspective. The need for studies to quantify the quality of life impact of amblyopia and/or strabismus, during childhood as well as during the longer term, has been identified with an appeal for studies to quantify the effects of amblyopia and strabismus during childhood (Carlton et al. 2008).

To aid evaluation of the effectiveness of preschool vision screening, Snowden and Stewart-Brown (1997a) specifically identified the need for research regarding the extent of the disability attributable to the target conditions of vision screenings. The study reported in this thesis examined the impact of amblyopia on motor and psychosocial skills in children. It aimed to characterise the nature and degree of limitation to skills that underlie tasks common in childhood and how this relates to type or severity of amblyopia. As well as leading to a greater understanding of the disability that may be associated with amblyopia to advise public policy, the findings of the study will inform clinicians working with amblyopic children of the consequences of the condition and its treatment.
Chapter 3  GENERAL METHODS

The study presented in this thesis measured the motor and psychosocial skills of children with a history of treatment for amblyopia and compared their performance to children with normal visual development. Specifically, fine motor skills, clinical eye movements and self-esteem were assessed, employing standardised, age-appropriate clinical tools whose validity and reliability has been established in the literature. Visual acuity and stereoacuity were measured and data regarding aetiology and treatment was gathered. The relevance of proficiency in motor performance to educational outcomes was explored in children with normal visual development. Figure 3.1 outlines the research plan of the study.

**Figure 3.1 Research Plan**
3.1 Research Questions

The specific research questions of the study were:

(1) Do children with amblyopia have poorer fine motor skills than age-matched control children? Can a decrement in fine motor skills score be predicted from visual characteristics?

(2) Do children with amblyopia have poorer self-esteem than age-matched children with normal vision development? Can self-esteem scores be predicted from condition or treatment information?

(3) Do children with amblyopia have poorer outcomes on clinical measures of eye movements than children with normal vision development? Can performance on clinical tests of eye movements be predicted from measured vision characteristics?

(4) How do measures of fine motor skill relate to measures of educational performance in children with normal visual development?

3.2 Participants

One hundred and eighty-eight children participated in this study, including 82 children who had been diagnosed and treated for amblyopia or amblyogenic conditions (age 8.2 ± 1.3 years; range 4.5 to 14.0 years) from differing causes (infantile esotropia n=17, acquired strabismus n=28, anisometropia n=15, mixed n=13 and deprivation n=9), and 106 control subjects (age 9.5 ± 1.2 years; range 5.5 to 10.7 years). All participants were carried in full-term pregnancies and had no
known neurological or ocular disorder (other than refractive error or their amblyogenic conditions).

### 3.2.1 Amblyopic subjects

Amblyopic subjects were identified from the files of a private paediatric ophthalmology practice (co-supervisor Dr Glen Gole). Parents of potential subjects were contacted by letter and telephone to invite them to participate; 34% could not be contacted. Of those who were contacted, 90% agreed to participate. Information regarding previous treatment, cycloplegic refraction (within the previous 12 months) and clinical diagnosis was obtained from patient records. Current refractive correction (less than one year old) was worn for all tests.

From clinical diagnosis, confirmed by the treating ophthalmologist (GG), the subjects were grouped with respect to amblyopic aetiology (Donahue 2007) as shown in Table 3.1.

**Table 3.1: Aetiological grouping of amblyopic participants**

<table>
<thead>
<tr>
<th>Aetiological group</th>
<th>Definition used</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infantile esotropia</td>
<td>History of esotropia prior to 12 months of age</td>
<td>17</td>
</tr>
<tr>
<td>Acquired strabismus</td>
<td>History of strabismus occurring after 12 months of age</td>
<td>28</td>
</tr>
<tr>
<td>Anisometropic</td>
<td>≥1.00 D difference in mean spherical refractive error and/or ≥ 1.50 D difference in astigmatism between eyes</td>
<td>15</td>
</tr>
<tr>
<td>Mixed</td>
<td>History of both strabismus and anisometropia</td>
<td>13</td>
</tr>
<tr>
<td>Deprivation</td>
<td>History of disturbance of monocular image clarity e.g. monocular cataract</td>
<td>9</td>
</tr>
</tbody>
</table>
3.2.2 Control subjects

Control subjects were recruited from two sources. Firstly, from a local primary (elementary) school (Bulimba State School BSS) (n=73) via a letter sent home to parents outlining the purpose of the study; 60% of invited students were granted parental consent to participate. Secondly, control children were recruited from subjects recalled from the Infant Photo-Screening Study (Royal Children’s Hospital RCH) (n=33). The Infant Photo-Screening study originally recruited from birth records in Brisbane in 1995. In letters sent to RCH infant photoscreening study participants that requested a review of VA and stereoacuity, an additional request was made for them to participate as a control subject for this study of motor and psychosocial skills. Those who indicated willingness to participate in this study were contacted by telephone to confirm their understanding of the purpose of the study and to book an appointment time.

The BSS group was drawn from a small geographic catchment area according to the enrolment management plan of the school, whereas the RCH group was drawn from the greater Brisbane area, reflective of original recruitment from birth records in 1995. Comparison was made of the outcome scores on the tests of vision, fine motor skills, saccadic eye movements and self-esteem between the two control groups to confirm that the BSS group was representative of children from a broader geographic catchment. No significant difference was found between the two control groups in all fine motor skills outcome scores or Developmental Eye Movement (DEM) test outcomes (p>0.05) and in all but one self-esteem measure; in the self-esteem measure that scored self-perception of behavioural conduct, the RCH group scored
significantly lower (3.01 ± 0.57) than the BSS group (3.28 ± 0.51) (F(2,93) = 3.95; p=0.023).

### 3.2.3 Age-matching

The age of the amblyopic children ranged from 4.5 to 14.0 years. The fine motor skills test employed in the study, the Brunicks-Oseretsky Test of Motor Proficiency (BOTMP), can be used to assess skills in children from four to fourteen years of age and was conducted on all recruited children.

Children aged less than eight years of age were not tested with the DEM test due to poor reliability and high variation in number naming skills in younger children. Prior to eight years of age most children are still developing their reading skills and assessment of reading fluency parameters is highly variable, with many preschool aged children being unable to complete the DEM test (Kulp and Schmidt 1997). The DEM test was thus conducted on thirty-nine amblyopic children (age 9.1 ± 0.9 years).

The self-esteem questionnaire formats were different for children in grade 3 or older versus those in younger grades. Perceived self-esteem was assessed for those children in grade 3 or higher at school with the Harter Self Perception Profile for Children (SPPC), which tested across six self-esteem domains. Forty-seven amblyopic children (age 9.2 ± 1.3 years) completed the SPPC. Those children from pre-school to grade 2 were tested with the Pictorial Scale of Perceived Competence and Acceptance for Young Children (PSPCA) that tested across three self-esteem domains. Twenty-nine amblyopic children (age 6.6 ± 0.6 years) completed the pictorial self-esteem questionnaires that were suitable for children from preschool to
grade 2 school level. The use of different questionnaires for the two age groups made it necessary to consider the data of these age groups separately.

For appropriate case-control comparison of data, the results from amblyopic children were compared with age-matched sub-samples drawn from the group of children with normal vision who completed the tests. Age-matched control groups were created by ranking control children by age and excluding those whose age fell outside the age range of the amblyopic children in that particular sample. Table 3.2 describes the amblyopic and age-matched control groups analysed in sub-sections of the study.

<table>
<thead>
<tr>
<th></th>
<th>Amblyopic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Age (years)</td>
</tr>
<tr>
<td>Fine Motor Skills</td>
<td>82</td>
<td>8.2 ± 1.7</td>
</tr>
<tr>
<td>Self-Esteem (SPPC)</td>
<td>47</td>
<td>9.2 ± 1.3</td>
</tr>
<tr>
<td>Self-Esteem (PSPCA)</td>
<td>29</td>
<td>6.6 ± 0.6</td>
</tr>
<tr>
<td>DEM</td>
<td>39</td>
<td>9.1 ± 0.9</td>
</tr>
</tbody>
</table>

3.3 Ethical clearance

The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee. Permission to conduct research within a school was obtained from Education Queensland prior to recruitment of participants from BSS. Permission to recruit participants from the photoscreening study was obtained from the RCH Ethics Committee. All
participants were given a full explanation of the experimental procedures and written informed consent was obtained from both parent and child. The option to withdraw from the study at any time was explained to both parent and child. All protocols were in accord with the guidelines of the Declaration of Helsinki.

3.4 Test setting

Amblyopic children were tested in standard clinical consulting rooms either at the practice of Dr Glen Gole or of the PhD candidate. Illumination was standard overhead fluorescent full room lighting for all tests. New testing equipment was specifically purchased for the project and used in all testing situations. For VA testing the child stood at a marked line three metres from a wall mounted Bailey-Lovie logMAR chart. The child was seated opposite the examiner (the PhD candidate) at a height appropriate table setting for tests of stereopsis, fine motor skills and DEM and for completion of the self-esteem questionnaire.

Testing of BSS control children was conducted individually in a separate room made available by the school. Full room illumination by overhead fluorescent lighting matched the standard clinical setting. Testing of RCH control children was either at the practice of the PhD candidate or in a clinical consulting room made available by QUT School of Optometry Clinic.

All testing was conducted by the candidate and the standard scoring procedures as outlined in the test manuals was followed. Complete assessment of vision, fine motor skills, perceived self esteem and DEM took about 45 minutes per subject. All tests were completed within one test session by all subjects. Visagraph eye movement recording was performed on a separate occasion for control subjects from
grades 4 and 5 BSS (n=59). Recording time was approximately 15 minutes per subject.

3.5 Vision Assessment

3.5.1 Visual Acuity

Visual acuity (VA) was measured using a three metre Bailey-Lovie logMAR chart following a screening/threshold procedure based on the Amblyopia Treatment Study VA protocol (The Pediatric Eye Disease Investigator Group et al. 2001). The child read the first letter of each row from the top of the logMAR chart until an error was made (screening). The child was then redirected to two rows above the screening error row and asked to attempt each letter until four incorrect responses were made (threshold). The VA for each eye was scored on a letter by letter basis in 0.02 logMAR increments. A schematic of the screening/threshold VA protocol used is shown in Figure 3.2.

Figure 3.2: Schematic of screening/threshold VA protocol employed
3.5.2 Stereoacuity

The level of stereoacuity was assessed with the three book Randot Preschool Stereoacuity test (Birch et al. 1997), chosen for its lack of monocular cues and because the task could easily be completed in a short time by the age group being tested (Figure 3.3). Viewing distance for all stereoacuity tests was 40 cm. Testing was conducted according to the test manufacturer’s instructions. Each book contains two sets of four random dot shapes (one is blank, the other three contain shapes) that can be named or matched to the easily visible black-and-white shapes on the other side of the book. Book 1 was presented first to test 200 arcsec and 100 arcsec levels of disparity. If the child was able to correctly identify two of three shapes at both of the disparity levels then Book 2 was presented next to test 60 arcsec and 40 arcsec disparity. If the child was unable to identify two of the three shapes at 200 arcsec disparity then Book 3 was presented instead to test 800 arcsec and 400 arcsec disparity.

![Randot Preschool Stereoacuity Test](image)

**Figure 3.3: Randot Preschool Stereoacuity Test**

Stereoacuity was defined as the smallest disparity at which the child was able to correctly identify at least two of three shapes. A maximum of 18 correct responses
was possible if the child identified the six shapes for all three books. For analysis, stereoacuity was scored according to the number of correct responses made. For example, a score of 18 indicated that the child correctly identified all disparity objects in the books, including the three 40 arcsec. A score of zero indicated that the child did not identify any of the 800 arcsec disparity objects. Stereoacuity response was grouped as follows: “nil” if no stereoscopic response could be measured, “reduced” if response indicated stereopsis between 800 and 60 seconds of arc and “normal” if response indicated stereopsis better than or equal to 40 seconds of arc.

If the child was unable to identify any disparity objects in the Randot Stereoacuity test, suppression was confirmed by the Mirror-Pola technique (Siderov 2001). The child wore the polarised glasses of the stereoacuity test and viewed themselves in a mirror. The child was asked to report the colour of the polarised lenses as seen in the mirror. If the child was not suppressing, both lenses would appear grey when viewed by the child in the mirror. If the child was suppressing, the lens before the suppressed eye would appear black, while the lens before the dominant eye would appear grey. Suppression was confirmed by this technique in all children who were unable to identify any disparity objects in the Randot Stereoacuity test.

### 3.6 Fine Motor Skills Assessment

The Brunicks-Oseretsky Test of Motor Proficiency (BOTMP) was used to evaluate fine motor skills using Item 7 Visual Motor Control (VMC) and Item 8 Upper Limb Speed and Dexterity (ULSD) (Bruininks 1978). The BOTMP is an individually administered test that gives a measure of motor proficiency, as well as separate measures of both gross and fine motor skills of children from 4 to 14 years of age.
The VMC item comprises eight sub-items to measure the ability to integrate visual responses with highly controlled motor responses. The ULSD item comprises eight timed sub-items that measure hand and finger dexterity, hand speed and arm speed. The sub-items are described in Table 3.3 and Figure 3.4 shows examples of the tasks undertaken in the ULSD item.

Figure 3.4: Examples of tasks performed in Upper Limb Speed and Dexterity domain of BOTMP

In addition to being appealing to children, the BOTMP has been designed to provide uniform testing conditions and to facilitate ease of administration and scoring (Bruininks 1978). Performance on each sub-item is expressed as either the number of units completed within a fixed time period or as the number of errors made in performing the task. Point scores for each sub-item allow raw scores to be converted to a common set of scale values which are then added together for each of the two fine motor skills items (Bruininks 1978). Results are converted to subtest age-standardised scaled scores of performance relative to published normative values (Bruininks 1978).
Table 3.3: Sub-items comprising Visual-motor control and Upper-limb speed and dexterity items of BTOMP (Bruininks 1978)

**Visual Motor Control -** all tasks are done with preferred hand

<table>
<thead>
<tr>
<th>Sub item</th>
<th>Description</th>
<th>Record</th>
</tr>
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<tbody>
<tr>
<td>1: Cutting circle</td>
<td>Cuts out a bold circle embedded within six concentric circles.</td>
<td>Number of errors</td>
</tr>
<tr>
<td>2: Drawing through crooked path</td>
<td>Draws a pencil line through a crooked path.</td>
<td></td>
</tr>
<tr>
<td>3: Drawing through straight path</td>
<td>Draws a pencil line through a straight path.</td>
<td></td>
</tr>
<tr>
<td>4: Drawing through curved path</td>
<td>Draws a pencil line through a curved path.</td>
<td></td>
</tr>
<tr>
<td>5: Copying circle</td>
<td>Copies a geometric shape.</td>
<td>Accuracy of shape reproduction following specific scoring guidelines</td>
</tr>
<tr>
<td>6: Copying triangle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7: Copying diamond</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8: Copying overlapping shapes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Upper Limb Speed and Dexterity –** all tasks are done with preferred hand except for item 2 (which requires both hands). A practice trial precedes each test run.

<table>
<thead>
<tr>
<th>Sub item</th>
<th>Description</th>
<th>Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Placing pennies in a box</td>
<td>Places pennies one at a time into an open box.</td>
<td>The number of pennies placed into the box correctly in 15 seconds</td>
</tr>
<tr>
<td>2: Placing pennies in two boxes with both hands</td>
<td>Simultaneously picks up a penny with each hand and places the pennies into separate boxes. The subject is given a maximum of 50 seconds to place seven pairs of pennies into the boxes correctly.</td>
<td>The time taken to complete the task. A time of 50 seconds is recorded if the subject places fewer than seven pairs of pennies into the boxes correctly.</td>
</tr>
<tr>
<td>3: Sorting shape cards</td>
<td>Sorts a mixed deck of red and blue cards into two piles, separating them by colour.</td>
<td>The number of cards correctly sorted in 15 seconds.</td>
</tr>
<tr>
<td>4: Stringing beads</td>
<td>Strings beads onto a shoelace.</td>
<td>The number of beads placed correctly in 15 seconds.</td>
</tr>
<tr>
<td>5: Displacing pegs</td>
<td>Displaces pegs with 2 mm base diameter on a pegboard, moving each peg to the hole directly above it.</td>
<td>The number of pegs displaced correctly in 15 seconds.</td>
</tr>
<tr>
<td>6: Drawing vertical lines</td>
<td>Draws straight lines between pairs of horizontal lines.</td>
<td>The number of vertical lines drawn correctly in 15 seconds. Accuracy following specific test guidelines.</td>
</tr>
<tr>
<td>7: Making dots in circles</td>
<td>Makes a pencil dot inside each of a series of circles</td>
<td>The number of circles dotted correctly in 15 seconds.</td>
</tr>
<tr>
<td>8: Making dots</td>
<td>Makes pencil dots on a blank page</td>
<td>The number of separate dots made in 15 seconds.</td>
</tr>
</tbody>
</table>
The scoring procedure as outlined in the test manuals was followed. To ensure scoring was appropriate, a sub-sample of score sheets (n=20) were re-scored by an independent researcher to confirm accuracy of scoring. The re-scored subset included results from both amblyopes (n=10) and controls (n=10), however, score sheets were de-identified so that the scorer was masked to participant group. Paired-samples t-tests indicated no significant difference in scoring between examiners on 15 of 16 subtests. Table 3.4 gives mean and standard deviation of test scores for the fine motor skills sub-items and results of paired t-tests for the difference between scorers. Bold italics highlights items that were significantly different between scorers (Item 8.6 drawing vertical lines); the principal examiner (the PhD candidate) scores were slightly higher (mean score 5.6 ± 1.7) than the second examiner (mean score assigned 4.6 ± 1.7).
Table 3.4 Paired Samples Test for difference between scorers. **Bold Italics** identifies the item that had a sig. difference in scores (p<0.05)

<table>
<thead>
<tr>
<th>Item</th>
<th>Principal Examiner</th>
<th>Second Examiner</th>
<th>t (df=19)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ITEM 7 Visual Motor Control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Cutting circle</td>
<td>3.65 (0.93)</td>
<td>3.45 (1.28)</td>
<td>1.21</td>
<td>0.214</td>
</tr>
<tr>
<td>2: Drawing through crooked path</td>
<td>3.60 (0.82)</td>
<td>3.65 (0.67)</td>
<td>-1.00</td>
<td>0.330</td>
</tr>
<tr>
<td>3: Drawing through straight path</td>
<td>3.60 (0.68)</td>
<td>3.55 (0.76)</td>
<td>0.57</td>
<td>0.577</td>
</tr>
<tr>
<td>4: Drawing through curved path</td>
<td>2.90 (1.17)</td>
<td>2.70 (1.26)</td>
<td>1.29</td>
<td>0.214</td>
</tr>
<tr>
<td>5: Copying circle</td>
<td>1.85 (0.37)</td>
<td>1.85 (0.37)</td>
<td>0.00</td>
<td>1.000</td>
</tr>
<tr>
<td>6: Copying triangle</td>
<td>2.00 (0.00)</td>
<td>1.95 (0.22)</td>
<td>1.00</td>
<td>0.330</td>
</tr>
<tr>
<td>7: Copying diamond</td>
<td>1.85 (0.37)</td>
<td>1.80 (0.41)</td>
<td>0.44</td>
<td>0.666</td>
</tr>
<tr>
<td>8: Copying overlapping shapes</td>
<td>1.55 (0.69)</td>
<td>1.60 (0.68)</td>
<td>-0.57</td>
<td>0.577</td>
</tr>
<tr>
<td><strong>ITEM 8 Upper Limb Speed and Dexterity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Placing pennies in a box</td>
<td>4.40 (1.23)</td>
<td>4.40 (1.23)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2: Placing pennies in two boxes with both hands</td>
<td>9.25 (0.91)</td>
<td>9.25 (0.91)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3: Sorting shape cards</td>
<td>4.30 (1.46)</td>
<td>4.05 (1.39)</td>
<td>1.00</td>
<td>0.330</td>
</tr>
<tr>
<td>4: Stringing beads</td>
<td>2.2 (1.01)</td>
<td>2.25 (1.07)</td>
<td>-1.00</td>
<td>0.330</td>
</tr>
<tr>
<td>5: Displacing pegs</td>
<td>4.20 (0.83)</td>
<td>4.25 (.79)</td>
<td>-1.00</td>
<td>0.330</td>
</tr>
<tr>
<td>6: <strong>Drawing vertical lines</strong></td>
<td><strong>5.60 (1.73)</strong></td>
<td><strong>4.65 (2.11)</strong></td>
<td><strong>3.44</strong></td>
<td><strong>0.003</strong></td>
</tr>
<tr>
<td>7: Making dots in circles</td>
<td>4.85 (1.53)</td>
<td>4.65 (1.50)</td>
<td>1.29</td>
<td>0.214</td>
</tr>
<tr>
<td>8: Making dots</td>
<td>5.50 (2.12)</td>
<td>5.55 (2.06)</td>
<td>-1.00</td>
<td>0.330</td>
</tr>
</tbody>
</table>
3.7 Eye Movements Assessment

3.7.1 Developmental Eye Movement Test

Saccadic eye movements of all of the amblyopes aged eight years and above were assessed with the DEM test (Garzia 1990). Thirty-nine amblyopic children (aged 9.1 ± 0.9 years) completed the DEM. Their results were compared with an age-matched subgroup of forty-two control children (aged 9.3 ± 0.4 years).

The test consisted of two subtests with 40 numbers arranged in vertical columns (Tests A and B), and a subtest with 80 irregularly spaced numbers arranged in 16 horizontal rows (Test C) (Figure 3.5). The child was asked to name aloud the single digit numbers as quickly and accurately as possible. The times taken to read aloud the 80 numbers in both the four vertical columns (vertical time) and the sixteen line horizontal array (horizontal time) were recorded. The number of omission and addition errors was recorded and test times were adjusted for errors made.

Upon completion of the test, a ratio was calculated by dividing the time taken to read the 80 numbers in the horizontal array by the total time for reading the 80 numbers in vertical subsets. The outcomes from the DEM test are Vertical time, Horizontal time, Number of Errors and Ratio(horizontal time/vertical time). Results were converted to standard scores and percentile ranks based on published age-normative data for this test (Richman and Garzia 1987).
3.7.2 Visagraph Eye Movement Recording

Eye movements were also assessed in participants in grades 4 and 5 in the BSS control group (n=59) (mean age 9.7 ± 0.6; range 8.6 to 10.8 years) by the Visagraph III which is an eye-movement recording system that uses goggles containing infrared sensors to capture eye position information during reading (Taylor & Associates).\(^1\) Visagraph recordings of amblyopic children were also attempted, however, recordings were unreliable through the spectacle correction worn by the majority of the amblyopic group of children. Figure 3.6 shows a participant wearing the Visagraph goggles during recording.

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\(^1\) Taylor&Associates. 200 E. Second St., Suite 2, Huntington Station, NY 11746.
There are three types of recording tests with the Visagraph III: a reading recording where the eye movements made when reading a short age-appropriate paragraph text are captured; a numbers recording where the test card is a series of numbers between 1 and 5; and a visual skills recording where stability of fixation and accuracy of motility are assessed. Comprehension tests were administered following the reading evaluation to confirm that the child was reading for comprehension rather than merely giving the appearance of reading.

From the Visagraph recordings a number of measures of eye movements made during the reading task are summarised in a Reading Report. Outcome measures used for analysis were the number of fixations per 100 words, number of regressions per 100 words, span of recognition, average duration of fixations and reading rates. Average span of recognition effectively refers to the amount of print that is perceived and processed with each fixation. The span of recognition was specified in units of “words” and was calculated by dividing the number of fixations into the number of words in the specified paragraph. Fixation duration refers to the length of time that the eye pauses or remains fixated on a word. Reading rate refers to the number of words read per unit time and was specified in words per minute (Ciuffreda and Tannen 1995a). Normative data have been established for these measures for readers.
from grade 1 through to college level. For the numbers task the measures reported included: fixations per 100 numbers, regressions per 100 numbers, average duration of fixation and reading rate both with and without re-reads (numbers per minute). Normative data has not been established for the numbers task. As the data obtained for each eye separately differed by less than five percent, findings for right and left eye were averaged for analysis of Visagraph outcomes for both the reading and number naming tasks.

3.8 Self-Esteem Assessment

3.8.1 Children from grade 3 school level

Self-esteem in children aged eight years and above was assessed with the Self Perception Profile for Children (SPPC), an age-appropriate, standardised measure that has been used extensively to measure self-esteem in several different groups of children (Harter and Pike 1984; Harter 1985; Granleese and Joseph 1994). The psychometric properties of the SPPC, including validity and reliability, have been independently established (Marsh and Holmes 1990). This instrument, which has been used in studies of self-esteem in myopic children (Dias et al. 2002; Dias et al. 2005), was chosen because it provides testing across several domains important to children’s lives as well as testing global self-worth. The child completed a 36 item self-reporting scale consisting of six specific domains described below. Six questions were asked in each domain, each consisted of two logically opposed statements, for example, “Some kids would rather play outdoors in their spare time BUT other kids would rather watch TV”. To reduce response bias, half of the items started with the more positive statement. The child indicated which statement was
“more true” of themselves and indicated whether the statement was “really true for me” or “sort of true for me”. Items were scored from one to four, where four indicated the most and one represented the least adequate self-judgment. Subscale scores were calculated by averaging the responses to each item within a domain. Thus, the SPPC gives six mean values, one from each domain, that range from one to four. Age-appropriate normative data are available for the SPPC test (Harter 1985).

The six domains assessed by the SPPC are:

- **Scholastic Competence** – the child’s perception of competence or ability within the realm of scholastic or school related performance.

- **Social Acceptance** - the degree to which the child is accepted by peers or feels popular.

- **Athletic Competence** – the child’s perception of competence in sports and outdoor games.

- **Physical Appearance** – the degree to which the child is happy with the way he/she looks, likes his/her height, weight, body, face, hair, or feels that they are good-looking.

- **Behavioural Conduct** – the degree to which children like the way they behave, do the right thing, act the way they are supposed to, avoid getting into trouble and do the things they are supposed to do.

- **Global Self-Worth** - the extent to which the child likes him/herself as a person, is happy with the way they are leading their life and is generally happy with him/herself. This is a global judgement of worth as a person, rather than a domain specific competence or adequacy.
Forty-seven children who had been treated for amblyogenic conditions (age $9.2 \pm 1.3$ years) completed the SPPC questionnaire. Their scores were compared with those of an age-matched subgroup of control subjects ($n=52$; age $9.4 \pm 0.5$ years).

### 3.8.2 Children preschool to grade 2 school level

A pictorial presentation questionnaire, the Pictorial Scale of Perceived Competence and Acceptance for Young Children, was used for children who were preschool to grade 2 school level (Harter and Pike 1984). The children were presented with a pictorial questionnaire of 18 situations and asked to identify which child in that situation they are most like. The questionnaire taps into three domains: cognitive competence, physical competence and peer acceptance. The child was given a sample item at the beginning of the questionnaire and was instructed to choose which child in the pictorial situation they are most like. The choice is refined further by asking if they are “very like” the child in the situation chosen or “a little like” the child in the situation. Figure 3.7 is an example from the pictorial questionnaire for grade 1 to grade 2 boys.

![Figure 3.7: Example from Pictorial Questionnaire](image)
Items were scored from 1 to 4, where 4 indicated the most adequate self-judgment and 1 represented the least adequate self judgment. Items with each subscale were counter-balanced such that three items were worded with the most adequate statement on the left and three items were worded with the most adequate statement on the right. Scores from the child’s protocol were transferred onto a data coding sheet where all items for a given subscale were grouped together to facilitate the calculation on the mean for each subscale. Scoring resulted in a total of six subscale means that defined a given child’s profile.

The outcome measure is a score between 1.0 and 4.0 on subscales. The results can be compared with reported mean and standard deviations for different aged children.

Twenty-nine children with a history of treatment for amblyopia (age = 6.6 ± 0.6 years) and twenty age-matched controls (age = 6.4 ± 0.5 years) completed the Pictorial Scale of Perceived Competence and Acceptance for Young Children.

3.9 Assessment of Educational Achievement

Educational data on standardised measures of literacy and numeracy measured internally by the school at the start of the school year were collected on the BSS control children who were in either grade 4 or grade 5 (n=57; two were absent from school on the day of testing). Mathematics, reading and spelling were tested using standardised assessment tools by the classroom teacher in class time at the beginning of the school year. Mathematics level was assessed with the Progressive Achievement Test in Mathematics (Australian Council for Educational Research 2005), spelling was assessed using the Single Word Spelling Test (SWST) (Sacre
and Masterson 2001) and reading was assessed with the Reading Progress Test (RPT) (Vincent et al. 1997).

In addition, results on Queensland Years 3, 5 and 7 tests in Aspects of Literacy and Numeracy (QSA 3,5,7) were also obtained from the school for 29 of the 57 children (those children in grade 5 who sat the tests), allowing validation of the achievement scores obtained by the classroom teachers. The QSA 3,5,7 tests, developed specifically for Queensland students and managed by the Queensland Studies Authority on behalf of the Queensland Government (Queensland Studies Authority 2004), are based on Queensland syllabuses and are designed to cover a wide range of children's abilities across the State. As for the internal school-based educational assessment, the children completed the tests in their classroom with their regular classroom teacher, and answer booklets were marked external to the school by the Queensland Studies Authority. Aspects of Measurement and Data, Number, and Space are assessed in the Numeracy Test. Aspects of Reading and Viewing, Spelling, and Writing, are assessed in the Literacy Test.

In order to access QSA test results, permission was obtained from the principal of BSS together with that of each child’s parent. As the amblyopic children were drawn from a paediatric ophthalmology practice and the RCH control children were originally identified from their hospital of birth they attended different state schools, catholic schools or independent schools within South-East Queensland. Obtaining permission to access QSA test results from each school department authority and school principal was logistically outside the scope of this study.
3.10 Statistical Analysis

All data were tested for normality using the Kolmogorov-Smirnov test. Where the data were normally distributed, the results from the amblyopes were compared with those of the control group using one-way ANOVA or t-tests with a significance level of 0.05 (Statistical Package for the Social Sciences – SPSS V14). When statistically significant differences were found between means, Bonferroni post-hoc tests were used. Non-parametric tests were used where the data were not normally distributed. Pearson’s correlation co-efficients were calculated to explore the relationships between vision characteristics and skills performance with Bonferroni correction to account for multiple comparisons (Curtin and Schulz 1998).

General linear multiple regression models were examined to investigate the independent influence of subject visual characteristics on skills scores. The impact of collinearity among explanatory factors was examined by calculation of variance inflation factors (VIF) (Ryan 1997); multi-collinearity (unacceptably high degree of correlation between investigated factors) was defined as a VIF value of 3 or more (Ryan 1997).

Correlation analysis was undertaken to test for association between the two measures of educational outcomes (internal BSS tests and QSA tests), and to test for association between measures of fine motor skills and clinical eye movements and educational outcomes.
Chapter 4 RESULTS
FINE MOTOR SKILLS

"The effect of amblyopia on fine motor skills in children."


4.1 Abstract

**Aim:** To investigate the functional impact of amblyopia in children, the fine motor skills of amblyopes and age-matched controls were compared. The influence of visual factors that might predict any decrement in fine motor skills was also explored.

**Methods:** Vision and fine motor skills were tested in a group of amblyopic children (n=82; age 8.2 ± 1.7 years) of differing causes (infantile esotropia n=17, acquired strabismus n=28, anisometropia n=15, mixed n=13 and deprivation n=9), and age-matched controls (n=37; age 8.3 ± 1.3 years). Visual-Motor Control (VMC) and Upper-Limb Speed and Dexterity (ULSD) items of the Bruininks-Oseretsky Test of Motor Proficiency were assessed and logMAR visual acuity (VA) and Randot stereopsis were measured. Multiple regression models were used to identify the visual determinants of fine motor skills performance.
Results: Amblyopes performed significantly poorer than controls on 9 of 16 fine motor skills sub-items and for the overall age-standardised scores for both VMC and ULSD items ($p<0.05$); effects were most evident on timed tasks. Amblyopia aetiology and level of binocular function significantly affected fine motor skill performance on both items; however, when examined in a multiple regression model that took into account the inter-correlation between visual characteristics, poorer fine motor skills performance was associated with strabismus ($F_{1,75} = 5.428; p = 0.022$), but not with the level of binocular function, refractive error or VA in either eye.

Conclusions: Fine motor skills were reduced in amblyopic children, particularly those with strabismus, compared to controls. The deficits in motor performance were greatest on manual dexterity tasks requiring speed and accuracy.

Keywords:

Amblyopia, fine motor skills, stereopsis, binocular vision, strabismus
4.2 Introduction

Amblyopia, affects approximately three percent of the population (Attebo et al. 1998; Brown et al. 2000) and is clinically defined as a two line or greater difference in visual acuity (VA) between the eyes in the presence of a pre-disposing amblyogenic condition, and in the absence of visible ocular or visual pathway pathology. The condition is most commonly associated with strabismus (misalignment of the oculomotor system), anisometropia (significant difference in refractive error between eyes), or form deprivation (presence of media opacity such as cataract) and is usually classified according to these underlying aetiological conditions. If present during the critical period of visual development (up to about seven years of age) (Daw 1998) the optical or oculomotor deficits lead to abnormal neurodevelopment of the visual system, with a loss or rearrangement of neural connections within the visual cortex (Daw 2006).

An extensive body of literature describes the adaptations in spatial vision that occur in the amblyopic eye including reductions in optotype VA, grating acuity, contrast sensitivity and vernier acuity (McKee et al. 2003). In addition, the non-amblyopic eye often displays small but measurable deficits, such as slightly poorer VA, compared to the dominant eye of normal observers (McKee et al. 2003; Simons 2005). Disruption of binocular function with resultant reduction in stereopsis is common, particularly in amblyopes with a history of strabismus (McKee et al. 2003; Simons 2005). Differences in spatial vision and binocular adaptations exist between aetiological groups, suggesting that different neural changes occur under the influence of monocular blur in the case of anisometropia and form deprivation, as opposed to ocular misalignment in strabismus (McKee et al. 2003). The severity of
the amblyopic deficit, as defined by VA deficit and binocular adaptations, depends on many factors, including the cause of amblyopia, the age of the patient at diagnosis, the duration of abnormal visual experience and the presence of complicating factors (McKee et al. 2003).

While much is known about the visual characteristics of amblyopia, the natural history of the condition and appropriate detection and treatment strategies (Simons 2005), the functional disadvantage of amblyopia has not been fully explored (Snowden and Stewart-Brown 1997a). A recent population based study of educational, health and social outcomes, which failed to identify any “real life” functional impact of the visual deficits associated with amblyopia, highlighted the need for further research on what it means to be amblyopic (Rahi et al. 2006). Few studies have investigated the performance of amblyopes under habitual binocular viewing conditions and, even though amblyopia is the most common disorder seen in paediatric ophthalmic practice in industrialised countries, there has been only limited research on the impact of the condition on drawing and copying or fine manual dexterity tasks pertinent to the activities of children.

Many amblyopes have little or no stereopsis, the functional significance of which has rarely been reported (Fielder and Moseley 1996). Most studies that have investigated this issue have compared performance under monocular and binocular conditions (Jones and Lee 1981; Joy et al. 2001), generally concluding that binocular vision facilitates control of manipulation, reaching and balance (Jones and Lee 1981), and that people who lack stereopsis have difficulty performing tasks which rely on three dimensional visual cues (Murdoch et al. 1991). There are, however, many individuals who perform well on tests of manual dexterity even though their stereopsis is poor.
(Murdoch et al. 1991), and a recent study of children who had undergone surgery for congenital esotropia (strabismus) showed post-operative improvements in motor performance which were not correlated with measured improvements in stereopsis (Caputo et al. 2007).

If the neurophysiological changes that occur in amblyopia are different under conditions of monocular blur versus oculo-motor misalignment, then we might expect differences in performance between amblyopes with a history of strabismus and those without. Alternatively, if resolution is an influencing factor, performance may be limited by the level of VA in the better eye, as this predicts VA under binocular conditions (Rubin et al. 2000). Presence of hyperopic refractive error, a common finding in children with amblyopia, is associated with mild delays across many aspects of visuo-cognitive and visuo-motor development (Atkinson et al. 2005; Atkinson et al. 2007), therefore the magnitude of hyperopic refractive error should be considered when investigating the determinants of fine motor skill performance.

The present investigation compared the performance of a sample of children with amblyopia of differing aetiologies on standardised, age-appropriate tests of fine motor skill performance under habitual binocular conditions with an age-matched group of children without amblyopia. The influence of patient aetiology and measured visual characteristics was examined by testing whether these factors were associated with outcome measures of fine motor skills.
4.3 Methods

4.3.1 Participants

One hundred and nineteen children participated in this study, including 82 children who had been diagnosed and treated for amblyopia or amblyogenic conditions (age 8.2 ± 1.7 years) and 37 age-matched control subjects (age 8.3 ± 1.3 years). The amblyopic group included children who had been successfully treated and children who still had a residual VA deficit (greater than 0.2 logMAR difference in VA between eyes). Amblyopic subjects were identified from the files of a private paediatric ophthalmology practice. Parents of potential subjects were contacted by letter and telephone to invite them to participate; 34% could not be contacted. Of those who were contacted, 90% agreed to participate. Control subjects were recruited from a local primary (elementary) school via a letter to parents outlining the purpose of the study; 60% of invited students were granted parental consent to participate. All children were carried in full-term pregnancies and had no known neurologic or ocular disorder (other than refractive error or their amblyogenic conditions).

Information regarding previous treatment, cycloplegic refraction (within previous 12 months) and clinical diagnosis was obtained from patient records. Refractive correction (typically less than one year old) was worn for all tests. From clinical diagnosis, confirmed by the treating ophthalmologist (GG), the subjects were grouped with respect to amblyopic aetiology (Donahue 2007) as follows:

- Infantile esotropia - history of esotropia prior to 12 months of age (n=17).
- Acquired strabismus - history of strabismus occurring after 12 months of age (n=28).
The effect of amblyopia on fine motor skills in children.  

4.3.2 Vision Assessment

Visual acuity was measured using a 3 m logMAR chart using a screening/threshold procedure based on the Amblyopia Treatment Study VA protocol (The Pediatric Eye Disease Investigator Group et al. 2001). The child read the first letter of each row from the top of the logMAR chart until an error was made (screening). The child was then redirected to two rows above the screening error row and asked to attempt each letter until four incorrect responses were given (threshold). Resultant VA for each eye was scored on a letter by letter basis. Level of binocular function was assessed with the Randot Preschool stereopsis test (Birch et al. 1997), chosen for its lack of monocular cues and because the task could easily be completed in a short time by the age group being tested. Suppression was confirmed by the Mirror-Pola technique (Siderov 2001) if no stereoscopic response was obtained on the Randot test.

4.3.3 Fine Motor Skills Assessment

Fine motor skills were evaluated using Item 7 Visual Motor Control (VMC) and Item 8 Upper Limb Speed and Dexterity (ULSD) of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks 1978). The BOTMP is an individually administered test that gives a measure of motor proficiency as well as separate measures of both gross and fine motor skills of children from 4 to 14 years of age.
The VMC item comprises eight sub-items to measure the ability to integrate visual responses with highly controlled motor responses. The ULSD item comprises eight timed sub-items that measure hand and finger dexterity, hand speed and arm speed. The sub-items are described in Table 4.1. In addition to being appealing to children, the BOTMP has been designed to provide uniform testing conditions and to facilitate ease of administration and scoring (Bruininks 1978).

Performance on each sub-item is expressed as either the number of units completed within a fixed time period or as the number of errors made in performing the task. Point scores for each sub-item allow raw scores to be converted to a common set of scale values which are then added together for each of the two fine motor skills items (Bruininks 1978). Results are converted to subtest age-standardised scaled scores of performance relative to published normative values (Bruininks 1978).

Subjects also completed a self-esteem questionnaire and developmental eye movement (DEM) test of digit naming speed during the test session; these findings will be presented elsewhere. Complete assessment of vision, fine motor skills, perceived self esteem and DEM took about 45 minutes per subject and were completed within one test session by all subjects.

The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee. All participants were given a full explanation of the experimental procedures and written informed consent was obtained from both parent and child. The option to withdraw from the study at any time was explained to both parent and child. All protocols were in accord with the guidelines of the Declaration of Helsinki.
4.3.4 Statistical Analysis

All data were tested for normality using the Kolmogorov-Smirnov test. Where the data were normally distributed, the results from the amblyopes were compared with those of the control group using one-way ANOVA (Statistical Package for the Social Sciences – SPSS V14), with a significance level of 0.05. When statistically significant differences were found between means, Bonferroni post-hoc tests were used. Non-parametric tests were used where the data were not normally distributed. Pearson’s correlation co-efficients were calculated to explore the relationships between vision characteristics and fine motor skills performance; to account for multiple comparisons, statistical significance was adjusted to 0.01 (Curtin and Schulz 1998). General linear multiple regression models were examined to investigate the independent influence of subject visual characteristics on fine motor skills scores. The impact of collinearity among explanatory factors was examined by calculation of variance inflation factors (VIF) (Ryan 1997); multi-collinearity (unacceptably high degree of correlation between investigated factors) was defined as a VIF value of 3 or more (Ryan 1997).
Table 4.1: Sub-items comprising Visual-motor control and Upper-limb speed and dexterity items of BTOMP (Bruininks 1978)

<table>
<thead>
<tr>
<th>Sub item</th>
<th>Description</th>
<th>Record</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual Motor Control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Cutting circle</td>
<td>Cuts out a bold circle embedded within six concentric circles.</td>
<td></td>
</tr>
<tr>
<td>2: Drawing through crooked path</td>
<td>Draws a pencil line through a crooked path.</td>
<td>Number of errors</td>
</tr>
<tr>
<td>3: Drawing through straight path</td>
<td>Draws a pencil line through a straight path.</td>
<td></td>
</tr>
<tr>
<td>4: Drawing through curved path</td>
<td>Draws a pencil line through a curved path.</td>
<td></td>
</tr>
<tr>
<td>5: Copying circle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6: Copying triangle</td>
<td>Copies a geometric shape.</td>
<td>Accuracy of shape reproduction following specific scoring guidelines</td>
</tr>
<tr>
<td>7: Copying diamond</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8: Copying overlapping shapes</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Upper Limb Speed and Dexterity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1: Placing pennies in a box</td>
<td>Places pennies one at a time into an open box.</td>
<td>The number of pennies placed into the box correctly in 15 seconds</td>
</tr>
<tr>
<td>2: Placing pennies in two boxes with both hands</td>
<td>Simultaneously picks up a penny with each hand and places the pennies into separate boxes. The subject is given a maximum of 50 seconds to place seven pairs of pennies into the boxes correctly.</td>
<td>The time taken to complete the task. A time of 50 seconds is recorded if the subject places fewer than seven pairs of pennies into the boxes correctly.</td>
</tr>
<tr>
<td>3: Sorting shape cards</td>
<td>Sorts a mixed deck of red and blue cards into two piles, separating them by colour.</td>
<td>The number of cards correctly sorted in 15 seconds.</td>
</tr>
<tr>
<td>4: Stringing beads</td>
<td>Strings beads onto a shoelace.</td>
<td>The number of beads placed correctly in 15 seconds.</td>
</tr>
<tr>
<td>5: Displacing pegs</td>
<td>Displaces pegs with 2 mm base diameter on a pegboard, moving each peg to the hole directly above it.</td>
<td>The number of pegs displaced correctly in 15 seconds.</td>
</tr>
<tr>
<td>6: Drawing vertical lines</td>
<td>Draws straight lines between pairs of horizontal lines.</td>
<td>The number of vertical lines drawn correctly in 15 seconds. Accuracy following specific test guidelines.</td>
</tr>
<tr>
<td>7: Making dots in circles</td>
<td>Makes a pencil dot inside each of a series of circles</td>
<td>The number of circles dotted correctly in 15 seconds.</td>
</tr>
<tr>
<td>8: Making dots</td>
<td>Makes pencil dots on a blank page</td>
<td>The number of separate dots made in 15 seconds.</td>
</tr>
</tbody>
</table>
4.4 Results

The amblyopic children had a greater inter-ocular difference in VA than age-matched control children, had poorer VA in their best seeing eye and were less likely to have normal stereopsis (p<0.05). Sixty-five of the amblyopic subjects (80%) and one control subject (3%) wore a hyperopic refractive correction. No significant differences in age or gender were found between the amblyopic and control groups. Table 4.2 summarises the mean and standard errors for the age, gender and vision characteristics of the two groups and presents the results of statistical analysis for differences between the groups.

On average the subjects with amblyopia had 0.09 logMAR VA in the better eye and 0.38 logMAR in the worst eye. In the control group there was very little difference between eyes (-0.006 logMAR in the better eye; 0.004 logMAR in the worst eye). In addition to significant differences between the amblyopia and control groups (F(1,117) = 21.59; p<0.000) and between sub-groups (F(5,113) = 5.58; P<0.000), post hoc testing indicated significant differences in VA in the better eye between the control group and the infantile esotropia and acquired strabismus amblyopic sub-groups.

Amblyopic subjects with acquired strabismus had the least inter-ocular difference in VA (0.13 logMAR), whilst those with deprivation amblyopia had the greatest mean difference in inter-ocular VA (1.27 logMAR). These variations between sub-groups were statistically significant (F(5,113) = 17.95; P<0.000), with the differences also reaching significance between the deprivation group and all other amblyopia sub-groups and the control group (Table 4.2).

The stereopsis scores were not normally distributed, but rather there was a floor and ceiling effect because there were many subjects whose stereopsis was equal to or better than the highest stereoacuity level tested (40") and many who could not pass
the test at any level. Subjects were therefore grouped according to their stereopsis level; “nil” if no stereoscopic response could be measured, “reduced” if response indicated stereopsis between 800 and 60 seconds of arc and “normal” if response indicated stereopsis better than or equal to 40 seconds of arc. The majority of control group subjects (89%) had normal stereopsis ($\leq 40$ seconds of arc) (Fielder and Moseley 1996) compared with only six percent of the amblyopic group. Most subjects with infantile esotropia (88%) had no measurable stereopsis, whilst, 73% of anisometropic ambylopes had reduced levels of stereopsis, with 20% of the anisometropes having normal stereopsis. The variation in level of stereopsis was significant both between the amblyopic and control groups ($\chi^2_{(df=2)} = 82.47$; $p<0.000$) and between subgroups ($\chi^2_{(df=10)} = 111.22$; $p<0.000$)(Table 4.2).

Fine motor skills involving VMC tasks and ULSD tasks were poorer in amblyopic subjects than in control subjects, both in terms of overall scores and sub-item results. Significant differences in performance were found between the amblyopic and control groups on three of the eight sub-items measured in the VMC subtest (drawing straight path, copying triangle, copying diamond) and on six of the eight sub-items measured in the ULSD item (pennies in box, sorting cards, stringing beads, displacing pegs, drawing vertical lines, making dots). Median and range for sub-items scores and sub-item sums (which determine the item scores) are given in Table 4.3, together with significance values for tests of difference between groups. These data are not normally distributed and so non-parametric tests were used.
Table 4.2: Age, gender and vision characteristics of test and age-matched control groups.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Total Amblyopia Group</th>
<th>STATISTICAL SIGNIFICANCE Between Amblyopia and Control Group</th>
<th>Infantile Esotropia</th>
<th>Acquired Strabismus</th>
<th>Anisometropia</th>
<th>Mixed</th>
<th>Deprivation</th>
<th>STATISTICAL SIGNIFICANCE One-Way ANOVA Between amblyopic aetiology groups and control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td>N=37</td>
<td>N=82</td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>8.3 (1.3)</td>
<td>8.2 (1.7)</td>
<td>0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.807</td>
<td>7.79 (.44)</td>
<td>8.11 (.30)</td>
<td>8.47 (.38)</td>
<td>8.33 (.58)</td>
<td>8.64 (.40)</td>
</tr>
<tr>
<td>Gender (% Female)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>48.6%</td>
<td>54.9%</td>
<td>0.26&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.613</td>
<td>52.9%</td>
<td>67.9%</td>
<td>26.7%</td>
<td>53.8%</td>
<td>66.7%</td>
</tr>
<tr>
<td>Stereopsis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>8 (11%)</td>
<td>27 (33%)</td>
<td>82.47&lt;sup&gt;c&lt;/sup&gt;</td>
<td>&lt;0.000</td>
<td>2 (12%)</td>
<td>8 (29%)</td>
<td>11 (73%)</td>
<td>4 (31%)</td>
<td>2 (22%)</td>
</tr>
<tr>
<td>Inter Ocular Difference in VA (logMAR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>0.02 (0.00)</td>
<td>0.31 (0.06)</td>
<td>10.97&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.001</td>
<td>0.26 (0.12)</td>
<td>0.13 (0.03)</td>
<td>0.22 (0.03)</td>
<td>0.22 (0.04)</td>
<td>1.27 (0.37)</td>
</tr>
<tr>
<td>VA in Best Eye (logMAR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>-0.01 (0.01)</td>
<td>0.10 (0.01)</td>
<td>21.59&lt;sup&gt;d&lt;/sup&gt;</td>
<td>&lt;0.000</td>
<td>0.10 (0.03)</td>
<td>0.12 (0.03)</td>
<td>0.08 (0.03)</td>
<td>0.09 (0.03)</td>
<td>0.02 (0.04)</td>
</tr>
<tr>
<td>VA in Worst Eye (logMAR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>0.00 (0.01)</td>
<td>0.38 (0.05)</td>
<td>29.55&lt;sup&gt;d&lt;/sup&gt;</td>
<td>&lt;0.000</td>
<td>0.36 (0.11)</td>
<td>0.25 (0.04)</td>
<td>0.30 (0.42)</td>
<td>0.31 (0.05)</td>
<td>1.08 (0.24)</td>
</tr>
<tr>
<td>Refractive error (dioptres)&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>0.08 (0.08)</td>
<td>2.30 (0.25)</td>
<td>48.47&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>&lt;0.000</td>
<td>1.21 (0.42)</td>
<td>3.72 (0.48)</td>
<td>3.00 (0.40)</td>
<td>4.03 (0.39)</td>
<td>0.53 (0.43)</td>
</tr>
</tbody>
</table>

<sup>a</sup> one-way ANOVA F<sub>(5,113)</sub>  
<sup>b</sup> Chi-Square df = 5 for AGE; df = 1 for Binocular for amblyopic v control and df = 5 for aetiology subgroup analysis  
<sup>c</sup> Spherical equivalent refractive error averaged between eyes
Age-standardised scaled scores, calculated from the sub-item sum (Bruininks 1978), were significantly lower in the amblyopic group compared with the control group for both the VMC item and the timed ULSD item ($p<0.05$). The magnitude of difference between groups was greater for the timed ULSD item, with the amblyopes scoring on average 3.70 standard points lower than controls in this item, whilst the difference between amblyopes and controls was 1.73 standard points for the VMC item (Table 4.4).

An estimate of the level of clinical performance on an overall item can be derived from the age-standardised scaled score by referring to published normative data (Bruininks 1978). For both fine motor skills domains, a greater proportion of the amblyopic group had below average scores than the control group and less of the amblyopic group achieved above average scores (VMC $\chi^2 = 6.5; p=0.040$; ULSD $\chi^2 = 9.35; p=0.009$) (Figure 4.1). Differences were also evident between subgroups (VMC $\chi^2 = 19.13; p=0.039$; ULSD $\chi^2 = 20.18; p=0.028$) (Table 4.5).

### Table 4.5: Proportion of amblyopic and control groups in clinical performance bands

<table>
<thead>
<tr>
<th></th>
<th>Amblyopic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual Motor Control</strong></td>
<td>% of Group</td>
<td></td>
</tr>
<tr>
<td>Below Average</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>Average</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>Above Average</td>
<td>20%</td>
<td>40%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Amblyopic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Limb Speed and Dexterity</strong></td>
<td>% of Group</td>
<td></td>
</tr>
<tr>
<td>Below Average</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>Average</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>Above Average</td>
<td>20%</td>
<td>40%</td>
</tr>
</tbody>
</table>

**Figure 4.1: Proportion of amblyopic and control groups in clinical performance bands**
Table 4.3: Median (Range) for fine motor skills sub-tests for amblyopic and age-matched control subjects** stat sig 0.05 level

<table>
<thead>
<tr>
<th>Control N=37</th>
<th>All Amblyopes N=82</th>
<th>χ²</th>
<th>p</th>
<th>Infantile Esotropia N=17</th>
<th>Acquired Strabismus N=28</th>
<th>Anisometropia N=15</th>
<th>Mixed N=13</th>
<th>Deprivation N=9</th>
<th>Kruskal Wallis p</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-1 CUTTING CIRCLE</td>
<td>4 (0 - 4)</td>
<td>4 (0 – 4)</td>
<td>0.065</td>
<td>4 (0 - 4)</td>
<td>4 (0 - 4)</td>
<td>4 (2 - 4)</td>
<td>4 (3 - 4)</td>
<td>4 (3 - 4)</td>
<td>.138</td>
</tr>
<tr>
<td>7-2 DRAWING CROOKED PATH</td>
<td>4 (2 - 4)</td>
<td>4 (0 – 4)</td>
<td>0.053</td>
<td>4 (1 - 4)</td>
<td>4 (0 - 4)</td>
<td>4 (2 - 4)</td>
<td>4 (2 - 4)</td>
<td>4 (2 - 4)</td>
<td>.157</td>
</tr>
<tr>
<td>7-3 DRAWING STRAIGHT PATH</td>
<td>4 (2 - 4)</td>
<td>4 (0 – 4)</td>
<td>0.017**</td>
<td>3 (2 - 4)</td>
<td>4 (2 - 4)</td>
<td>4 (1 - 4)</td>
<td>3 (0 - 4)</td>
<td>4 (4 - 4)</td>
<td>.001**</td>
</tr>
<tr>
<td>7-4 DRAWING CURVED PATH</td>
<td>3 (0 - 4)</td>
<td>3 (0 – 4)</td>
<td>0.352</td>
<td>2 (0 - 4)</td>
<td>3 (2 - 4)</td>
<td>4 (0 - 4)</td>
<td>2 (0 - 4)</td>
<td>4 (2 - 4)</td>
<td>.063</td>
</tr>
<tr>
<td>7-5 COPYING CIRCLE</td>
<td>2 (1 - 2)</td>
<td>2 (0 – 2)</td>
<td>0.147</td>
<td>2 (1 – 2)</td>
<td>2 (0 – 2)</td>
<td>2 (2 – 2)</td>
<td>2 (2 – 2)</td>
<td>2 (2 – 2)</td>
<td>.024**</td>
</tr>
<tr>
<td>7-6 COPYING TRIANGLE</td>
<td>2 (2 - 2)</td>
<td>2 (0 – 2)</td>
<td>0.027**</td>
<td>2 (1 - 2)</td>
<td>2 (0 – 2)</td>
<td>2 (1 – 2)</td>
<td>2 (1 – 2)</td>
<td>2 (2 – 2)</td>
<td>.064</td>
</tr>
<tr>
<td>7-7 COPYING DIAMOND</td>
<td>2 (1 - 2)</td>
<td>1 (0 – 2)</td>
<td>0.004**</td>
<td>1 (0 – 2)</td>
<td>1 (0 – 2)</td>
<td>2 (0 – 2)</td>
<td>2 (0 – 2)</td>
<td>2 (1 – 2)</td>
<td>.021**</td>
</tr>
<tr>
<td>7-8 COPYING PENCILS</td>
<td>2 (0 - 2)</td>
<td>2 (0 – 2)</td>
<td>0.861</td>
<td>2 (0 – 2)</td>
<td>1 (0 – 2)</td>
<td>2 (0 – 2)</td>
<td>2 (0 – 2)</td>
<td>2 (1 – 2)</td>
<td>.167</td>
</tr>
<tr>
<td>SUM ITEM 7</td>
<td>22 (10 - 24)</td>
<td>21 (6 - 24)</td>
<td>0.014**</td>
<td>19 (6 - 24)</td>
<td>20.50 (8 - 24)</td>
<td>22 (12 - 24)</td>
<td>20 (8 - 23)</td>
<td>23 (22 - 24)</td>
<td>.002**</td>
</tr>
</tbody>
</table>

** UPPPER LIMB SPEED AND DEXTERITY

<table>
<thead>
<tr>
<th>Control N=37</th>
<th>All Amblyopes N=82</th>
<th>χ²</th>
<th>p</th>
<th>Infantile Esotropia N=17</th>
<th>Acquired Strabismus N=28</th>
<th>Anisometropia N=15</th>
<th>Mixed N=13</th>
<th>Deprivation N=9</th>
<th>Kruskal Wallis p</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-1 PENNIES IN BOX</td>
<td>5 (1 - 6)</td>
<td>4 (1 – 6)</td>
<td>0.003**</td>
<td>4 (1 - 6)</td>
<td>3.5 (1 - 5)</td>
<td>4 (2 - 6)</td>
<td>4 (3 - 5)</td>
<td>5 (3 - 6)</td>
<td>.012**</td>
</tr>
<tr>
<td>8-2 PENNY PAIRS IN BOX</td>
<td>10 (6 – 10)</td>
<td>9 (1 - 10)</td>
<td>0.088</td>
<td>9 (1 - 10)</td>
<td>9 (4 - 10)</td>
<td>10 (7 - 10)</td>
<td>9 (7 -10)</td>
<td>10 (9-10)</td>
<td>.014**</td>
</tr>
<tr>
<td>8-3 SORTING CARDS</td>
<td>4 (1 – 7)</td>
<td>3 (1 -7)</td>
<td>0.036**</td>
<td>3 (1 - 7)</td>
<td>3 (1 - 5)</td>
<td>3 (2 - 6)</td>
<td>3 (2 - 7)</td>
<td>4 (3 - 6)</td>
<td>.045**</td>
</tr>
<tr>
<td>8-4 STRINGING BEADS</td>
<td>2 (1 – 5)</td>
<td>2 (1 – 4)</td>
<td>0.023**</td>
<td>2 (1 - 4)</td>
<td>1.5 (1 - 3)</td>
<td>2 (1 - 3)</td>
<td>2 (1 – 3)</td>
<td>2 (1 - 3)</td>
<td>.097</td>
</tr>
<tr>
<td>8-5 DISPLACING PEGS</td>
<td>4 (3 – 7)</td>
<td>4 (2 – 7)</td>
<td>0.046**</td>
<td>4 (2 - 5)</td>
<td>4 (2 -5)</td>
<td>4 (3 - 6)</td>
<td>4 (3 - 6)</td>
<td>5 (4 - 7)</td>
<td>.043**</td>
</tr>
<tr>
<td>8-6 DRAWING VERT LINES</td>
<td>6 (3 – 8)</td>
<td>5 (0 -8)</td>
<td>0.000**</td>
<td>5 (1 - 8)</td>
<td>4 (0 - 6)</td>
<td>5 (2 - 7)</td>
<td>5 (2 - 7)</td>
<td>5 (4 - 6)</td>
<td>.003**</td>
</tr>
<tr>
<td>8-7 DOTS IN CIRCLES</td>
<td>5 (2 – 7)</td>
<td>4 (1 – 8)</td>
<td>0.062</td>
<td>5 (2 - 7)</td>
<td>4 (1 - 6)</td>
<td>5 (2 - 7)</td>
<td>4 (3 -7)</td>
<td>6 (4 - 8)</td>
<td>.001**</td>
</tr>
<tr>
<td>8-8 MAKING DOTS</td>
<td>6 (3 – 7)</td>
<td>5 (1 -9)</td>
<td>0.048**</td>
<td>6 (1 - 9)</td>
<td>4.5 (2 - 8)</td>
<td>6 (2 -8)</td>
<td>6 (1 - 8)</td>
<td>6 (5 - 8)</td>
<td>.022**</td>
</tr>
<tr>
<td>SUM ITEM 8</td>
<td>42 (24 - 53)</td>
<td>37 (11 - 50)</td>
<td>0.000**</td>
<td>39 (11 - 49)</td>
<td>35 (17 - 42)</td>
<td>40 (23 - 48)</td>
<td>37 (26 - 46)</td>
<td>41 (35 - 50)</td>
<td>.000**</td>
</tr>
</tbody>
</table>
Table 4.4: Mean (standard error) for age standardised fine motor skills scores for amblyopic and age-matched control subjects

**Bold italic font indicates stat sig differences between groups**

**Post hoc Bonferroni indicates sig diff**

<table>
<thead>
<tr>
<th></th>
<th>Control N=37</th>
<th>All Amblyopes N=82</th>
<th>ANOVA F(1,117)</th>
<th>p</th>
<th>Infantile Esotropia N=17</th>
<th>Acquired Strabismus N=28</th>
<th>Anisometropia N=15</th>
<th>Mixed N=13</th>
<th>Deprivation N=9</th>
<th>ANOVA F(5,113)</th>
<th>p</th>
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<tbody>
<tr>
<td><strong>STANDARD SCORE VMC</strong></td>
<td></td>
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</tr>
<tr>
<td>Control</td>
<td>20.57 (0.55)</td>
<td>18.84 (0.46)</td>
<td><strong>4.95</strong></td>
<td><strong>0.028</strong></td>
<td>18.94 (0.87)</td>
<td>18.07 (0.82)</td>
<td>19.33 (1.15)</td>
<td>17.92 (1.30)</td>
<td>21.56 (0.75)</td>
<td><strong>2.31</strong></td>
<td><strong>0.049</strong></td>
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<tr>
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<tr>
<td>Acquired Strabismus N=28</td>
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</tr>
<tr>
<td><strong>STANDARD SCORE ULSD</strong></td>
<td>19.89 (0.86)**</td>
<td>16.46 (0.58)</td>
<td><strong>12.65</strong></td>
<td><strong>0.001</strong></td>
<td>17.29 (1.22)</td>
<td>14.71(1.01)**</td>
<td>16.27 (1.28)</td>
<td>17.23 (1.60)</td>
<td>19.56(1.35)</td>
<td><strong>3.946</strong></td>
<td><strong>0.002</strong></td>
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<td>Control</td>
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<tr>
<td>Acquired Strabismus N=28</td>
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<td>Anisometropia N=15</td>
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<td>Deprivation N=9</td>
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</tr>
<tr>
<td><strong>TOTAL FMS SCORE</strong></td>
<td>40.73(1.11)**</td>
<td>35.30 (0.79)</td>
<td><strong>15.536</strong></td>
<td><strong>&lt;0.000</strong></td>
<td>36.24 (1.64)</td>
<td>32.79 (1.28)**</td>
<td>35.60 (1.74)</td>
<td>35.15(1.87)</td>
<td>41.11 (2.25)**</td>
<td><strong>5.472</strong></td>
<td><strong>&lt;0.000</strong></td>
</tr>
</tbody>
</table>

Table 4.5: Proportion of sub-groups scoring in above average or higher ranges on fine motor skills tasks

<table>
<thead>
<tr>
<th>AMBLYOPIC SUBGROUPS</th>
<th>Above Average</th>
<th>Average</th>
<th>Below Average</th>
<th>Above Average</th>
<th>Average</th>
<th>Below Average</th>
<th>Above Average</th>
<th>Average</th>
<th>Below Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infantile Esotropia</td>
<td>8 (47%)</td>
<td>13 (46%)</td>
<td>0 (0%)</td>
<td>6 (35%)</td>
<td>9 (53%)</td>
<td>2 (12%)</td>
<td>28 (55%)</td>
<td>14 (46%)</td>
<td>9 (53%)</td>
</tr>
<tr>
<td>Acquired Strabismus</td>
<td>14 (50%)</td>
<td>5 (33%)</td>
<td>1 (7%)</td>
<td>7 (29%)</td>
<td>10 (67%)</td>
<td>2 (13%)</td>
<td>15 (28%)</td>
<td>6 (36%)</td>
<td>2 (12%)</td>
</tr>
<tr>
<td>Anisometropia</td>
<td>9 (60%)</td>
<td>7 (54%)</td>
<td>1 (8%)</td>
<td>5 (39%)</td>
<td>6 (46%)</td>
<td>2 (15%)</td>
<td>15 (28%)</td>
<td>6 (36%)</td>
<td>2 (12%)</td>
</tr>
<tr>
<td>Mixed</td>
<td>5 (38%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>3 (20%)</td>
<td>3 (33%)</td>
<td>0 (0%)</td>
<td>15 (28%)</td>
<td>6 (36%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>Deprivation</td>
<td>9 (100%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>6 (67%)</td>
<td>3 (33%)</td>
<td>0 (0%)</td>
<td>15 (28%)</td>
<td>6 (36%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>All Amblyopes</td>
<td>45 (55%)</td>
<td>34 (41%)</td>
<td>3 (4%)</td>
<td>27 (33%)</td>
<td>41 (50%)</td>
<td>14 (17%)</td>
<td>57 (63%)</td>
<td>22 (59%)</td>
<td>9 (50%)</td>
</tr>
<tr>
<td>Control N=37</td>
<td>29 (78%)</td>
<td>8 (22%)</td>
<td>0 (0%)</td>
<td>22 (59%)</td>
<td>14 (38%)</td>
<td>1 (3%)</td>
<td>38 (43%)</td>
<td>14 (52%)</td>
<td>2 (12%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>χ² (df=10)</th>
<th>Asymp. Sig. (2-sided)</th>
<th>p</th>
<th>χ² (df=2)</th>
<th>Asymp. Sig. (2-sided)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Motor Control</td>
<td>19.13</td>
<td>0.039</td>
<td>6.46</td>
<td>0.040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Limb Speed and Dexterity</td>
<td>20.18</td>
<td>0.028</td>
<td>9.35</td>
<td>0.009</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.4.1 Impact of aetiology

Subgroup aetiology significantly impacted on the age-standardised scaled score for both VMC and ULSD items and the overall fine motor skills score (ANOVA, $F(5,113); p <0.05$.) (Table 4.4 and Figures 4.2 and 4.3). Post hoc testing identified a significant difference between the acquired strabismic and the control group in the timed ULSD item, and the acquired strabismic group scored significantly poorer than both the control and deprivation groups for the overall fine motor skills score.

4.4.2 Impact of binocularity

The level of stereopsis significantly impacted score achieved for both the visual motor control (VMC) item ($F_{2,116} = 4.712; p=0.011$) and the upper limb speed and dexterity (ULSD) item ($F_{2,116} = 4.178; p=0.018$) as well as on the total fine motor skills score ($F_{2,116} = 6.405; p=0.002$). Post hoc analysis indicated that the subgroup with normal stereopsis performed significantly better than both the no stereopsis and reduced stereopsis groups both on the ULSD item and overall fine motor skills score and performed better than the reduced stereopsis group on the VMC item (Table 4.6).

Table 4.6: Fine motor skills scores for stereoscopic groups

* ‡ Post hoc Bonferroni indicates sig diff

<table>
<thead>
<tr>
<th></th>
<th>No stereopsis N=50</th>
<th>Reduced stereopsis N=31</th>
<th>Normal Stereopsis N=38</th>
<th>ANOVA $F(2,116)$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Motor Control (VMC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard score</td>
<td>19.02 (0.58)</td>
<td>18.03 (0.77)*</td>
<td>20.84 (0.53)*</td>
<td>4.712</td>
<td>0.011</td>
</tr>
<tr>
<td>Upper Limb Speed and</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Dexterity (ULSD) Standard</td>
<td>16.62 (0.74)‡</td>
<td>16.45 (0.90)*</td>
<td>19.47 (0.83)*</td>
<td>4.178</td>
<td>0.018</td>
</tr>
<tr>
<td>Score</td>
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<tr>
<td>Fine Motor Skills</td>
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<td></td>
</tr>
<tr>
<td>Total Score</td>
<td>35.82 (1.02)‡</td>
<td>34.81 (1.39)*</td>
<td>40.32 (1.00)*‡</td>
<td>6.405</td>
<td>0.002</td>
</tr>
</tbody>
</table>
The effect of amblyopia on fine motor skills in children.

Chapter 4

Figure 4.2: Visual-motor control standardised score for amblyopia and control groups.

Figure 4.3: Upper-limb speed and dexterity standardised score for amblyopia and control groups.
4.4.3 Determinants of fine motor skills performance

There were a number of significant correlations between the visual characteristics measured in this study, as well as between some of the vision factors and the fine motor skills scores (p<0.01) (Table 4.7). Multiple regression analysis was employed to determine which visual characteristics could best predict any decrements in fine motor skills performance when the inter-correlation between the visual factors was taken into account.

Table 4.7: Intercorrelations between vision parameters examination and fine motor skills performance  

**indicates statistically significant correlation

<table>
<thead>
<tr>
<th>Vision Characteristics</th>
<th>VMC Standard Score</th>
<th>ULSD Standard Score</th>
<th>Total Fine Motor Skills Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strabismus</td>
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<tr>
<td>Binocular</td>
<td>-.601**</td>
<td>-.484**</td>
<td>.080</td>
</tr>
<tr>
<td>Average Refractive Error</td>
<td>-.304**</td>
<td>-.388**</td>
<td>-.270**</td>
</tr>
<tr>
<td>VA Worse Eye</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA Best Eye</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Refractive Error</td>
<td>.195</td>
<td>.324**</td>
<td>-.182</td>
</tr>
<tr>
<td>VA Worse Eye</td>
<td>-.243**</td>
<td>.013</td>
<td>-.074</td>
</tr>
<tr>
<td>VA Best Eye</td>
<td>-.147</td>
<td>-.018</td>
<td>-.093</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

The influence of VA (in either eye) and refractive error, together with history of strabismus, (which included participants with a history of infantile esotropia, acquired strabismus or mixed aetiology) and level of binocular function were investigated in a general linear model to determine their independent influences on fine motor skills scores. The model was tested to determine the influence of these participant qualities on the overall fine motor skills score (sum of VMC and ULSD standardised scores). The general linear multiple regression model indicated that when the inter-relationships between these subject characteristics was taken into account, fine motor skills performance was significantly associated with a history of
The effect of amblyopia on fine motor skills in children. Chapter 4

strabismus ($F_{1,75} = 5.428; p = 0.022$) but not to the level of binocular function, measures of refractive error, or of VA in best and worst eyes (Table 4.8).

**Table 4.8: Multiple linear regression model of fine motor skills performance in total group.** *Bold Italics indicates statistically significant association*

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std error</th>
<th>Regression coefficient (B)</th>
<th>Std. Error</th>
<th>F</th>
<th>significance</th>
<th>Partial Eta $^2$</th>
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<td>Strabismus</td>
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<tr>
<td>Yes</td>
<td>58</td>
<td>34.43</td>
<td>1.27</td>
<td>36.109</td>
<td>40.715</td>
<td>2.218</td>
<td>5.428</td>
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<tr>
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<td>61</td>
<td>39.04</td>
<td>1.09</td>
<td></td>
<td>1.119</td>
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<tr>
<td>Nil</td>
<td>50</td>
<td>37.64</td>
<td>1.26</td>
<td>-0.063</td>
<td>2.385</td>
<td>1.862</td>
<td>1.60</td>
<td>.032</td>
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<tr>
<td>Reduced</td>
<td>31</td>
<td>34.86</td>
<td>1.25</td>
<td>-2.836</td>
<td>1.968</td>
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<tr>
<td>Normal</td>
<td>38</td>
<td>37.70</td>
<td>1.55</td>
<td>0(a)</td>
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<tr>
<td>Average Refractive Error</td>
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<td>-.517</td>
<td>.329</td>
<td>2.470</td>
<td>.119</td>
<td>.022</td>
<td></td>
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<tr>
<td>VA in Worst Eye</td>
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<tr>
<td>VA in Best Eye</td>
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</table>

a This parameter is set to zero because it is redundant.

**4.5 Discussion**

Visual acuity and binocular vision were assessed in a group of amblyopic children, and their fine motor skills were tested under habitual binocular viewing conditions, using an age-appropriate standardised test. Their performance was compared with that of an age-matched control group and the influence of aetiology and binocularity on fine motor skills performance was examined in a multiple regression model that accounted for inter-correlation between possible explanatory factors.

Fine motor skills performance of children with amblyopia was poorer than age-matched control children on 9 of 16 fine motor skills sub-items. The mean age-standardised scores for both visual motor control (VMC) and upper limb speed and dexterity (ULSD) items were lower in the amblyopic group than the control group. The deficits in performance for amblyopic compared to the control children were more marked in the timed tasks of manual dexterity that comprise the ULSD item.
Importantly, comparison of the distributions of overall scores indicated that the consistent decrement in the amblyopic group was not a consequence of a few individuals showing large deficits, but rather a global reduction in performance overall. The median scores were lower in the amblyopic group however, the negative skews of the distributions were not greater.

When the fine motor skill performance scores were compared to published normative data, a range in motor skills ability is seen in both groups, however, a larger proportion of the amblyopic group had scores which fell in the below average performance range and a smaller proportion performed in the above average range for both fine motor skills domains (Figure 4.1). The difference between amblyopia and control groups was more profound in the battery of tasks that required speed and dexterity (ULSD) rather than tasks that required accuracy and control (VMC). This finding agrees with the results reported in a recent study that used the Movement Assessment Battery for Children (Movement ABC) to investigate motor control in a group of children with congenital esotropia aged four to six years (Caputo et al. 2007), where it was found that, in addition to poorer total scores, the strabismic children performed worse than age-matched controls on the subscale that assessed manual dexterity (Caputo et al. 2007). A speed-accuracy trade-off has been proposed when quantifying the reaching and grasping behaviour in amblyopic subjects (Grant et al. 2007). During the timed ULSD tasks, where for the majority of sub-items only 15 seconds was allowed to perform the tasks, there was less opportunity for visual feedback to influence the outcome score and no opportunity for compensatory slowing of response times. It is possible that the amblyopic children adopted a compensatory strategy of slowing down their response in order to
accurately complete the drawing tasks required for the VMC tasks, because slowed response times provide opportunity for visual feedback during the task.

In a study of prehension (reaching and grasping) characteristics in adults with amblyopia, Grant et al. (2007) found that amblyopic subjects, under both binocular and non-dominant eye viewing conditions, showed a range of deficits in their approach to an object and when closing and applying grasp. The differences between their amblyopic subjects and controls included prolonged execution times and more errors, the extents of which co-varied with the existing depth of amblyopia, although not its aetiology. Our finding that ULSD tasks are impacted to a greater extent by the presence of amblyopia than VMC tasks agrees with the finding of Grant et al. (2007) that amblyopes have the greatest difficulties with motor performance tasks when they are timed. Grant et. al. (2007) suggested that the level of binocular function could discriminate the degree of impairment on some, but not all, key indices of prehension control and that depth of amblyopia influences performance on average movement execution time. However, the confounding influence of inter-correlation between VA deficit and loss of binocular function, whilst acknowledged, was not accounted for in their analysis.

We anticipated that the aetiology of amblyopia could influence performance on fine motor skills tasks due to hypothesised differences in visual neural development between those with a history of blur (anisometropia and form deprivation) and those with a history of ocular misalignment (strabismus). Indeed, we found significant differences in performance between subgroups and that not all amblyopic groups displayed a deficit in fine motor skills. Whilst we recognise that the deprivation group had the smallest sample size (n=9), their fine motor skills performance
equalled that of the control group and all of this group performed in either the average or above average performance levels, even though this group had the highest inter-ocular VA deficit and few of these subjects had binocular perception. Subjects with acquired strabismus, whose ocular misalignment was diagnosed later than 12 months of age, had the lowest fine motor skills scores, even though this group had the least inter-ocular VA deficit. This suggests that factors other than the depth of amblyopia influence performance on the fine motor skills tasks measured. It has been suggested that two distinct developmental anomalies account for the differential pattern of vision losses in amblyopia between aetiological groups (McKee et al. 2003). Hand-eye co-ordination skills are normally acquired over the period extending through infancy, beyond the critical period for amblyopia, until around 12 years of age (Grant et al. 2007). Our finding that strabismus has the greatest negative influence on fine motor skills performance may indicate that the neurological changes associated with strabismus have a detrimental influence on the development of hand-eye co-ordination skills.

The variation in the proportion of subjects in each aetiological group who had binocular function was similar to that reported by McKee et al. (McKee et al. 2003), who found that all the normal control subjects and two thirds of anisometropes passed their two tests of binocular function, whilst only about 10% of strabismics showed a binocular response. In our study, many of the strabismic amblyopia subjects who had VA in the treated eye almost equal to that of the preferred eye gave no binocular response, however, the majority (93%) of the anisometropic subgroup had some level of measurable stereopsis, even though only 20% of the anisometropes had normal levels of stereopsis. Fine motor skills performance was worst in the binocular function group that had reduced stereopsis, compared with those who had
normal stereopsis and also those who had no measurable stereopsis (suppression confirmed by Mirror-Pola). However, when analysed in the multiple regression model that takes into account the inter-correlation between strabismus and stereopsis, the influence of level of stereopsis was not found to be significant.

Previous studies have attempted to correlate performance on fine motor skills with a deficit in VA or reduced stereopsis (Hrisos et al. 2006; Mazyn et al. 2007). When ball catching skills are assessed, subjects with poor stereopsis have poorer interceptive performance under temporal constraints and respond less well to specific training to improve performance (Mazyn et al. 2007). Lack of stereopsis has been suggested to account for delayed neuro-developmental performance of infants with strabismus (Rogers et al. 1982), and in non-strabismic amblyopes, stereopsis, independent of visual acuity, was found to influence performance on visual motor integration (design copying) (Hrisos et al. 2006). However, a recent study that reported improvements in motor co-ordination in children who underwent late surgery for congenital esotropia (strabismus) could not relate the changes to post-operative changes in stereopsis (Caputo et al. 2007). Our finding that VA in the better eyes of normal subjects was on average slightly better than that in the dominant eyes of amblyopic subjects, agrees with previous studies (McKee et al. 2003; Grant et al. 2007), and post hoc testing confirmed that subjects with a history of infantile esotropia or acquired strabismus had the poorest VA in their better eye. However, VA in either the better or worse eye did not influence performance on fine motor skills and therefore cannot account for the difference in motor skills scores observed between the groups. Reductions in VA and reduced stereopsis are highly related making it difficult to disentangle the relative contributions of each to motor control. We have tried to account for these known inter-relationships by examining
fine motor skills scores in a multiple regression model that took into account the inter-correlation that exists between vision characteristics. When our general linear model which included the history of strabismus and the level of binocular function and measures of VA in better and worse eyes and mean refractive error was applied, only the presence of strabismus emerged as a significant influencing factor on fine motor skills outcome performance.

This study explored the possible functional impact associated with amblyopia in a childhood population and has demonstrated that amblyopia has a functional impact that goes beyond the monocular VA deficit and loss of binocular function that define the condition. We have shown that children with amblyopia perform more poorly on a range of standardised, age-appropriate tasks designed to assess the motor skills needed in practical, everyday tasks. This particularly applies to amblyopic children with strabismus, and the impact of amblyopia was greatest on manual dexterity tasks that require speed and accuracy. Importantly, our results represent the first time that the relative contribution of various vision characteristics on fine motor skills performance has been determined in a large sample of amblyopic subjects from a range of aetiologies. This study has not separated the amblyopic children into treated and untreated cohorts, therefore we cannot comment on whether successful treatment of amblyopia results in a relative reduction in the magnitude of a fine motor skills deficit. We are currently exploring the relationship between these fine motor skills scores and standardised measures of educational performance in a larger group of normal children. Clinicians may wish to make parents and carers of children diagnosed with amblyopia aware of this more global impact when discussing the consequences of the condition.
4.6 Acknowledgements

This work was supported by Queensland University of Technology (QUT) and the Institute of Health and Biomedical Innovation (IHBI). The authors thank all the participants for their co-operation; the staff of Dr Gole’s practice for their help in recruitment; and Diana Battisutta and Cameron Hurst of IHBI for assistance with biostatistics. This manuscript is based on data presented as a poster at the Association for Research in Vision and Ophthalmology meeting in May 2007, Fort Lauderdale, Florida.
Chapter 5 RESULTS

SELF ESTEEM

Part A

"The effect of amblyopia on self-esteem in children."


5.1 Abstract

Aim: In an investigation of the psychosocial impact of amblyopia on children, the perceived self-esteem of children who had been treated for amblyopia was compared with that of age-matched controls. The influence of amblyopia condition or treatment factors that may impact self-perception scores was also explored.

Methods: Children with a history of treatment for amblyopia (n=47; age 9.2 ± 1.3 years) and age-matched controls (n=52; age 9.4 ± 0.5 years) completed a standardised age-appropriate questionnaire based evaluation of perceived self-esteem (Harter Self Perception Profile for Children). Their vision characteristics and treatment regimen were also recorded. Bivariate correlation analysis was used to investigate the amblyopic characteristics and treatment factors that may have influenced self-perception scores in the amblyopic group.
Results: Children treated for amblyopia had significantly lower social acceptance scores than age-matched control children. In other areas related to self-esteem, including scholastic competence, physical appearance, athletic competence, behavioural conduct and global self worth, amblyopic children gave scores similar to those of control children. Within the amblyopic group, a lower social acceptance score was significantly correlated with a history of treatment with patching but not with a history of strabismus or wearing of glasses.

Conclusions: Self-perception of social acceptance was lower in children treated for amblyopia compared with age-matched controls. A reduction in these scores was associated with a history of patching treatment but not with a history of strabismus or spectacle wear.

Keywords

Amblyopia, strabismus, self-esteem, psychosocial,
5.2 Introduction

Amblyopia is the most prevalent visual disorder in children, affecting approximately three percent of the population (Attebo et al. 1998; Brown et al. 2000). It is clinically defined by a difference of two lines in visual acuity between eyes in the absence of ocular pathology, and in the presence of a predisposing amblyogenic factor (such as strabismus, anisometropia or deprivation) during the period of development of the visual system (from birth to about 8 years of age) (Daw 2006). Amblyopia is usually treated by correction of the underlying condition (surgery or refractive correction with glasses or contact lenses) followed by a period of occlusion or atropine penalisation of the non-amblyopic eye to promote neurodevelopment of the affected visual pathways. Treatment has traditionally been applied only during childhood, the time of optimum plasticity of visual development, although recent randomised controlled treatment trials have provided evidence for successful treatment outcomes in older children and adolescents (The Pediatric Eye Disease Investigator Group 2005b).

The psychosocial impact of strabismus and amblyopia and their treatment on an individual’s quality of life have gained recent attention in the literature (Burke et al. 1997; Choong et al. 2004; Archer et al. 2005; Koklanis et al. 2006). Early literature, mainly anecdotal, reported on the psychological implications of cosmetically obvious strabismus (Alberman et al. 1971; Tolchin and Lederman 1977), but more recent studies have examined the effect of strabismus and amblyopia on an adult’s self-esteem, interpersonal relationships and employability (Olitsky et al. 1999; Coats et al. 2000; Williams and Harrad 2006). These studies have provided an understanding of the adult’s perspective on the psychosocial impact of amblyopia,
but few studies have specifically investigated the impact of the condition and its
treatment from the perspective of a child with amblyopia.

While the presence of cosmetically obvious strabismus does not appear to influence
how young children, aged from three to eight years, select a playmate (Johns et al.
2005), children from about six years of age have been reported to develop a negative
perception towards individuals with strabismus and children with noticeable
strabismus are viewed negatively by teachers (Uretmen et al. 2003). However,
following strabismus surgery improvements in social, emotional and functional
measures of a child’s health status have been reported (Archer et al. 2005).

Many children with amblyopia need to wear glasses to correct their refractive error,
even after completion of occlusion or penalisation amblyopia therapy. Individuals
who wear glasses rate themselves lower in terms of their physical attractiveness
(Terry and Brady 1976), which, as well as affecting psychological well-being, can
affect motivation and behaviour (Harter 1999). While quality of life scores are lower
in adult spectacle wearers than in either contact lens wearers or adults who have had
refractive surgery (Pesudovs et al. 2006), recent studies of self-esteem in myopic
children have found self-perception scores are not associated with spectacle wear
(Dias et al. 2002; Lyon et al. 2002; Dias et al. 2005), nor do they change when
refractive correction was changed to contact lenses (Terry et al. 1997). A child who
wears glasses may be perceived by their peers to look smarter, but attitudes about
their shyness, honesty, attractiveness, athleticism and play selection are not
influenced by whether they wear glasses (Wallline et al. 2008).

Treatment of amblyopia by either occlusion or atropine penalisation was found to be
reasonably well accepted by both the child and the parent during randomized
controlled treatment trials (The Pediatric Eye Disease Investigator Group 2003a; Choong et al. 2004; Hrisos et al. 2004). However, more recent studies have found that most children report feeling self-conscious and ashamed during amblyopia treatment, particularly due to patching or wearing glasses, and that it was the responses of their peers that most influenced their feelings of embarrassment (Koklanis et al. 2006), and children currently wearing glasses or with a history of wearing eye patches are approximately 35% more likely to be victims of physical or verbal bullying (Horwood et al. 2005).

Some conditions that cause amblyopia, such as infantile esotropia, present very early in life and are therefore treated early in life, while other acquired strabismic conditions may not manifest until later in early childhood. Treatment regimens also differ between aetiological groups, in that some amblyopic children will have undergone surgery for strabismus or media opacity, while others will have required refractive correction for accommodative strabismus or anisometropia. Some children will undergo patching for up to six months while others with greater depth of amblyopia, as is often the case with deprivation amblyopia, may continue on patching for more prolonged periods. Perhaps children detected and treated by patching before they enter school and begin to more formally socialise with their peer group are less likely to feel self-conscious or ashamed of treatment than those who are of school age when patched and are acquiring a sense of self in general and self-esteem in particular (Harter 1988).

The self-esteem of a child that has been treated for amblyopia or the relative influence of condition or treatment factors that may be associated with reduced self-esteem have not previously been reported. Exploring self-esteem results across
aetiological sub-groups may be informative as well as examining both the wearing of glasses and influence of patching regime within the analysis of self-esteem in amblyopic children.

In this study we measured the self-perception profile of children who had been treated for amblyopia from a range of causes and compared their results with an age-matched control group. The relationships between self-perception scores and various subject characteristics implied by the literature to have psychosocial impact (history of strabismus, wearing of glasses, patching regimen and visual acuity deficit) were tested.

5.3 Methods

5.3.1 Participants

Ninety-nine children participated in this study, including 47 children who had been treated for amblyogenic conditions (age 9.2 ± 1.3 years) and 52 age-matched control subjects (age 9.4 ± 0.5 years). Parents of potential amblyopic group subjects were identified from the files of a private paediatric ophthalmology practice. Sixty-six percent of potential subjects were contactable by letter and telephone and were invited to participate; of these 90% agreed to participate in the study. Control subjects were recruited from a local primary (elementary) school via a letter to parents outlining the purpose of the study; 60% of invited students were granted parental consent to participate in the study. Signed consent was obtained from participating children and their parent.

All children had received ophthalmological treatment for the underlying amblyogenic condition (surgery or refractive correction) so did not have cosmetically
obvious strabismus at the time of the study and had concluded occlusion or penalisation treatment. All subjects were carried in full-term pregnancies and had no known neurological or ocular disorder (other than refractive error or their amblyogenic conditions).

5.3.2 Vision assessment

Information regarding clinical diagnosis, cycloplegic refraction (within the previous 12 months) and previous treatment, particularly with regard to patching regimen, was obtained from the patient records of the amblyopic subjects. From this clinical information, the subjects were grouped with respect to amblyopic aetiology (Donahue 2007) as follows:

- Infantile esotropia – history of esotropia prior to 12 months of age (n=7).
- Acquired strabismus – history of strabismus occurring after 12 months of age (n=15).
- Anisometropic – ≥1.00 D difference in mean spherical refractive error and/or ≥ 1.50 D between the eyes in astigmatism (The Pediatric Eye Disease Investigator Group 2006) (n=9)
- Mixed – history of both strabismus and anisometropia (n=9)
- Deprivation – history of disturbance of monocular image clarity e.g. monocular cataract (n=7)

Strabismic subjects were all aligned to within 15 prism dioptres by refractive correction, by previous surgery or by both.

Subjects who were treated with patching (n=32) were grouped with respect to their age when patched and duration of patching as follows:

- Age when patched
The effect of amblyopia on self-esteem in children.

Chapter 5

- Wore patch when of school age (greater than 5 years of age) (n= 23)
- Wore patch before school age (less than 5 years of age) (n=9)
- Duration of patching
  - Period of treatment by patching extended beyond 12 months (n=21)
  - Period of treatment by patching was less than 12 months (n=11)
- Period elapsed since last patched
  - Patched within previous 12 months (n=5)
  - Not patched within previous 12 months (n=27)

Visual acuity (VA) was measured using a 3 m logMAR chart, and scored on a letter by letter basis for each eye separately with the current optical correction (based on cycloplegic refraction measured within previous 12 months). Level of binocular function was assessed with the Randot Preschool Stereoacuity test (Birch et al. 1997), chosen for its lack of monocular cues and because the task could easily be completed in a short time by the age group being tested. Suppression was confirmed by the Mirror-Pola technique (Siderov 2001) if no stereoscopic response was obtained on the Randot test.

5.3.3 Self-esteem assessment

Self-esteem was assessed with the Self Perception Profile for Children (SPPC), an age-appropriate, standardised measure with established validity and reliability that has been used extensively to measure self-esteem in children in several different groups of children. (Harter and Pike 1984; Harter 1985; Granleese and Joseph 1994) The psychometric properties of the SPPC, including validity and reliability, have been independently established (Marsh and Holmes 1990). This instrument, which has been used in studies of self-esteem in myopic children (Dias et al. 2002; Dias et
al. 2005), was chosen because it provides testing across several domains important to children’s lives as well as testing global self-worth. The child completed a 36 item self-reporting scale consisting of six specific domains described below. Six questions were asked in each domain, each consisted of two logically opposed statements, for example, “Some kids would rather play outdoors in their spare time BUT other kids would rather watch TV”. To reduce response bias, half of the items started with the more positive statement. The child indicated which statement was “more true” of themselves and indicated whether the statement was “really true for me” or “sort of true for me”. Items were scored from one to four, where four indicated the most and one represented the least adequate self-judgment. Subscale scores were calculated by averaging the response to each item within a domain. Thus, the SPPC gives six mean values, one from each domain, that range from one to four. Age-appropriate normative data are available for the SPPC test (Harter 1985). The six domains assessed by the SPPC are:

- **Scholastic Competence** – self perception of competence or ability within the realm of scholastic or school related performance.
- **Social Acceptance** – how much the child feels accepted by peers or popular.
- **Athletic Competence** – the child’s perception of competence in sports and outdoor games.
- **Physical Appearance** – the degree to which the child is happy with the way he/she looks, likes his/her height, weight, body, face, hair, or feels that they are good-looking.
- **Behavioural Conduct** – the degree to which children like the way they behave, do the right thing, act the way they are supposed to, avoid getting into trouble and do the things they are supposed to do.
• Global Self-Worth - the extent to which the child likes him/herself as a person, is happy with the way they are leading their life and is generally happy with him/herself. This is a global judgement of worth as a person, rather than a domain specific competence or adequacy.

Subjects also completed tests of fine motor skills (Bruiniks Oseretsky Test of Motor Proficiency (Bruininks 1978)) and the developmental eye movement test (DEM) (Garzia 1990) during the test session. Complete assessment of perceived self-esteem, vision, fine motor skills and DEM took about 45 minutes per subject and was completed within one test session by all subjects. The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee and the guidelines of the Declaration of Helsinki.

5.3.4 Statistical Analysis

The results from the amblyopic group were compared with those of the control group using independent samples t-test (Statistical Package for the Social Sciences – SPSS V14), the criterion for statistical significance was 0.05. One-way ANOVA was used to test for differences between aetiological sub-groups. When statistically significant differences were found between sub-group means, Bonferroni post-hoc tests were used to examine where differences lay. Where the data were not normally distributed, non-parametric chi-squares tests were used to test for differences between groups. Pearson’s correlation coefficients were calculated to explore the relationships between amblyopia condition and treatment characteristics and self perception scores; the criterion for statistical significance was 0.05.
5.5 Results

5.5.1 Sample characteristics

Table 5.1 presents the mean age, gender, and vision measures for the amblyopic and control children together with the proportion of the groups with a history of strabismus, history of patching and who wore glasses. These data are also shown for each amblyopia aetiology sub-group. The amblyopic and control groups were not significantly different in age or gender.

On average the subjects with amblyopia had 0.07 logMAR VA in the better eye and 0.44 logMAR in the worst eye. In the control group there was very little difference between eyes (-0.03 logMAR in the better eye; -0.01 logMAR in the worst eye). In addition to significant differences between the amblyopic and control group and between subgroups (p<0.05), post hoc testing indicates that participants whose amblyopia was caused by visual deprivation had the worst VA in their amblyopic eye and the greatest inter-ocular VA difference compared to all other amblyopia subgroups and controls.

The stereopsis scores were not normally distributed, but rather there was a floor and ceiling effect because there were many control subjects whose stereopsis was equal to or better than the highest stereoacuity level tested (40") and many amblyopes who could not pass the test at any level. Subjects were therefore grouped according to their stereopsis level; “nil” if no stereoscopic response could be measured, “reduced” if response indicated stereopsis between 800 and 60 seconds of arc and “normal” if response indicated stereopsis better than or equal to 40 seconds of arc. The majority of control group subjects (96%) had normal stereopsis (≤ 40") (Fielder and Moseley 1996) compared with only six percent of the amblyopic group.
Table 5.1: Mean (SD) Age, visual acuity and refractive characteristics of groups. *Bold Italics font indicates statistically significant differences between groups.*

<table>
<thead>
<tr>
<th></th>
<th>Total Amblyopia Group</th>
<th>Control</th>
<th>Tests for difference Between Amblyopia and Control Group</th>
<th>Infantile Esotropia</th>
<th>Acquired Strabismus</th>
<th>Anisometropia</th>
<th>Mixed</th>
<th>Deprivation</th>
<th>One-Way ANOVA Between Amblyopic aetiology groups and control group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 47</td>
<td>N=52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.2 (1.3)</td>
<td>9.4 (0.5)</td>
<td>-1.086 *</td>
<td>0.280</td>
<td>9.2 (1.4)</td>
<td>9.1 (1.3)</td>
<td>9.5 (0.9)</td>
<td>9.2 (1.9)</td>
<td>9.1 (0.9)</td>
</tr>
<tr>
<td>Gender (% Female)</td>
<td>23 (49%)</td>
<td>24 (46%)</td>
<td>0.07 b</td>
<td>0.47</td>
<td>3 (43%)</td>
<td>10 (67%)</td>
<td>3 (33%)</td>
<td>3 (33%)</td>
<td>4 (57%)</td>
</tr>
<tr>
<td>Strabismic (% Yes)</td>
<td>31 (66%)</td>
<td>0 (0%)</td>
<td>4.93 b</td>
<td>&lt;0.001</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Wears glasses (% Yes)</td>
<td>39 (83%)</td>
<td>4 (8%)</td>
<td>56.95 b</td>
<td>&lt;0.001</td>
<td>4 (57%)</td>
<td>15 (100%)</td>
<td>9 (100%)</td>
<td>9 (100%)</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>Wore Patch (% Yes)</td>
<td>32 (68%)</td>
<td>0 (0%)</td>
<td>52.31 b</td>
<td>&lt;0.001</td>
<td>4 (57%)</td>
<td>10 (67%)</td>
<td>3 (33%)</td>
<td>9 (100%)</td>
<td>6 (86%)</td>
</tr>
<tr>
<td>Stereopsis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nil</td>
<td>30 (64%)</td>
<td>0 (0%)</td>
<td>80.632 c</td>
<td>&lt;0.001</td>
<td>7 (100%)</td>
<td>12 (80%)</td>
<td>0 (0%)</td>
<td>6 (67%)</td>
<td>5 (71%)</td>
</tr>
<tr>
<td>800 – 60 sec arc</td>
<td>14 (30%)</td>
<td>2 (4%)</td>
<td></td>
<td></td>
<td>0 (0%)</td>
<td>2 (13%)</td>
<td>7 (78%)</td>
<td>3 (33%)</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>≤ 40 sec arc</td>
<td>3 (6%)</td>
<td>50 (96%)</td>
<td></td>
<td></td>
<td>0 (0%)</td>
<td>1 (7%)</td>
<td>2 (22%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>VA Best Eye (logMAR)</td>
<td>0.07 (0.11)</td>
<td>-0.03 (0.05)</td>
<td>5.687 *</td>
<td>&lt;0.000</td>
<td>0.10 (0.13)</td>
<td>0.08 (0.09)</td>
<td>0.04 (0.09)</td>
<td>0.08 (0.12)</td>
<td>0.03 (0.13)</td>
</tr>
<tr>
<td>VA Worst Eye (logMAR)</td>
<td>0.44 (0.67)</td>
<td>-0.01 (0.05)</td>
<td>4.849 *</td>
<td>&lt;0.001</td>
<td>0.33 (0.25)</td>
<td>0.21 (0.20)</td>
<td>0.29 (0.19)</td>
<td>0.25 (0.19)</td>
<td>1.51 (1.29)**</td>
</tr>
<tr>
<td>Inter-Ocular Difference in VA</td>
<td>0.38 (0.65)</td>
<td>0.02 (0.03)**</td>
<td>3.945 *</td>
<td>&lt;0.001</td>
<td>0.23 (0.27)</td>
<td>0.13 (0.16)</td>
<td>0.21 (0.12)</td>
<td>0.22 (0.15)</td>
<td>1.47 (1.19)**</td>
</tr>
</tbody>
</table>

*Bold Italics font indicates statistically significant differences between groups.*
All subjects with infantile esotropia had no measurable stereopsis, whilst, all anisometropic amblyopes had some measurable level of stereopsis, with 22% of the anisometropes having normal stereopsis. The variation in level of stereopsis was significant both between the amblyopic and control groups ($\chi^2_{(df=2)} = 80.63; p<0.001$) and between subgroups ($\chi^2_{(df=10)} = 117.06; p<0.001$)(Table 5.2).

Amblyopic children were more likely to have had strabismus, to have worn a patch and to wear glasses. Sixty-six percent of the amblyopic group had a history of strabismus, 83% wore glasses and 68% had a history of having worn a patch. Of the control group, none had a history of strabismus or patching and four children (8%) currently wore glasses. All of the amblyopic children and all but one of the controls had been advised to wear their glasses full time. Of the 32 amblyopic children who had been patched, 23 (72%) were more than 5 years old when patched and 21 (66%) were patched for more than 12 months duration. Whilst none of the amblyopic group was currently undergoing patching, five had been patched within the 12 months prior to participation in the study.

**5.5.2 Perceived Self-Esteem Scores**

Table 5.2 presents the self-perception domain score mean and standard deviation for the amblyopic and control children. Children with amblyopia had significantly lower scores on the social acceptance domain “feels accepted by peers” or “feels popular” than age-matched control children ($t_{(df=97)} = -2.553, p = 0.012$). No significant differences were found between the amblyopic and control groups in the other four domain specific judgments (scholastic competence, athletic competence, physical appearance and behavioural conduct) or in global perception of worth or esteem as a person (global self worth).
Table 5.2: Mean (standard deviation) SPPC domain scores. *Bold Italics font indicates statistically significant differences between groups*

<table>
<thead>
<tr>
<th>Domain</th>
<th>Amblyopic (n=47)</th>
<th>Control (n=52)</th>
<th>t(df=97)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scholastic competence</td>
<td>3.03 (0.65)</td>
<td>2.89 (0.63)</td>
<td>1.030</td>
<td>0.306</td>
</tr>
<tr>
<td>Social acceptance</td>
<td><strong>3.00 (0.70)</strong></td>
<td><strong>3.31 (0.50)</strong></td>
<td>-2.553</td>
<td>0.012</td>
</tr>
<tr>
<td>Athletic competence</td>
<td>3.07 (0.67)</td>
<td>3.15 (0.58)</td>
<td>-0.646</td>
<td>0.520</td>
</tr>
<tr>
<td>Physical appearance</td>
<td>3.35 (0.45)</td>
<td>3.42 (0.42)</td>
<td>-0.711</td>
<td>0.479</td>
</tr>
<tr>
<td>Behavioral conduct</td>
<td>3.20 (0.69)</td>
<td>3.23 (0.53)</td>
<td>-0.261</td>
<td>0.794</td>
</tr>
<tr>
<td>Global self-worth</td>
<td>3.50 (0.47)</td>
<td>3.53 (0.40)</td>
<td>-0.257</td>
<td>0.796</td>
</tr>
</tbody>
</table>

5.5.3 Impact of aetiology

There were significant differences between the amblyopic subgroups in social acceptance scores ($F_{(5,87)}=3.14$, $p = 0.012$), and *post hoc* Bonferroni tests confirmed these differences were significant between the acquired strabismus and control groups (Table 5.3). The deprivation group recorded the same mean score as the acquired strabismus group, however, this was not identified by *post hoc* tests as significantly different from the control group, due to smaller sample size and larger standard deviation. Similarly, the anisometropia group scored as highly has the control group (Figure 5.1).

Table 5.3: Social Acceptance scores mean (standard deviation) for amblyopic subgroups and control group. **Post Hoc Bonferroni confirms significant difference between groups (p<0.05)**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Infantile Esotropia</th>
<th>Acquired Strabismus</th>
<th>Anisometropia</th>
<th>Mixed</th>
<th>Deprivation</th>
<th>Control</th>
<th>Sig. One-Way ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOCIAL ACCEPTANCE</td>
<td>3.07 (0.81)</td>
<td><strong>2.76 (0.70)</strong>**</td>
<td>3.44 (0.39)</td>
<td>3.07 (0.56)</td>
<td>2.76 (0.91)</td>
<td><strong>3.31 (0.50)</strong>**</td>
<td>3.14</td>
</tr>
</tbody>
</table>
5.5.4 Determinants of social acceptance score within amblyopic group

Table 5.4 presents the Pearson correlation coefficients calculated within the amblyopic sample between social acceptance score and amblyopia condition factors (history of strabismus and VA measures) and treatment factors (wears glasses and history of treatment by patching). As well as a number of significant correlations between the condition and treatment characteristics measured in this study, only a history of patching significantly correlated with social acceptance score (p<0.05).
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Table 5.4: Correlations between vision and treatment characteristics and social acceptance score of amblyopic group. Pearson correlation co-efficients presented. ** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level (2-tailed).

<table>
<thead>
<tr>
<th></th>
<th>Wears glasses</th>
<th>History of patching</th>
<th>VA in Best Eye</th>
<th>VA in Worst Eye</th>
<th>Inter-ocular VA difference</th>
<th>Social Acceptance Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of Strabismus</td>
<td>0.272</td>
<td>0.182</td>
<td>0.201</td>
<td>-0.383**</td>
<td>-0.427**</td>
<td>-0.152</td>
</tr>
<tr>
<td>Wears glasses</td>
<td>0.054</td>
<td>0.047</td>
<td>-0.031</td>
<td>0.139</td>
<td>0.148</td>
<td>-0.328*</td>
</tr>
<tr>
<td>History of patching</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA in Best Eye</td>
<td></td>
<td>0.241</td>
<td></td>
<td>0.083</td>
<td>-0.211</td>
<td></td>
</tr>
<tr>
<td>VA in Worst Eye</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.987**</td>
<td>-0.256</td>
</tr>
<tr>
<td>Inter-ocular VA difference</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.228</td>
</tr>
</tbody>
</table>

The influence of amblyopia condition or treatment factors that may impact on social acceptance score was further investigated by testing for differences in self-esteem between treatment or condition sub-groups (Table 5.5). No significant difference was found between amblyopic children with a history of strabismus and those without, or between those who did or did not wear spectacles or between levels of refractive error. A significant difference in social acceptance score was found between those amblyopic children who had a history of treatment by patching (n=32) and those who did not (n=15) (t_{df=45} = -2.328; p=0.024)

Table 5.5: Influence of condition or treatment factors on social acceptance score

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Social Acceptance Score Mean (Std Deviation)</th>
<th>t^a_{(df=45)}</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strabismus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>31</td>
<td>2.92 (0.68)</td>
<td>-1.034 a</td>
<td>0.446</td>
</tr>
<tr>
<td>No</td>
<td>16</td>
<td>3.15 (0.73)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wears Glasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>39</td>
<td>3.00 (0.64)</td>
<td>0.087 a</td>
<td>0.931</td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>2.98 (0.98)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wore Patch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>32</td>
<td>2.85 (0.71)</td>
<td>-2.328 a</td>
<td>0.024</td>
</tr>
<tr>
<td>No</td>
<td>15</td>
<td>3.33 (0.55)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of refractive correction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nil</td>
<td>8</td>
<td>2.98 (0.98)</td>
<td>0.602 b</td>
<td>0.618</td>
</tr>
<tr>
<td>+0.25D to +2.75</td>
<td>16</td>
<td>3.11 (0.62)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+3.00D to +5.75D</td>
<td>16</td>
<td>3.03 (0.58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;+6.00D</td>
<td>7</td>
<td>2.69 (0.80)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Amongst the amblyopic children who were treated by patching (n=32), no significant difference was seen in social acceptance scores between those who were patched when of pre-school or school entry age (more than 5 years of age (n=23)) and those who were not (n=9). Thus being of school age when patched does not appear to be of significance. Further, no significant difference was seen in social acceptance scores between those whose patching treatment continued for more than 12 months (n=21) and those whose patching duration was less than 12 months (n=11) (p>0.05) (Table 5.6). Duration of patching seems to have no effect. Social acceptance score did not significantly differ between those who had been patched within the 12 months prior to participation in the study (n=5) and those whose patching was terminated more than 12 months previously.

| Table 5.6: Social acceptance score of amblyopic participants treated by patching |
|---------------------------------|-----------------|-----------------|
|                                | Social Acceptance | STATISTICAL      |
|                                | Score Mean (SD)  | SIGNIFICANCE    |
|                                |                 | t-test           |
|                                |                 | t(df=30)     | p    |
| **Age when patched**           |                 |                |
| Wore patch when of school age  | 2.92 (0.65)     | 0.971          | 0.339|
| (n= 23)                        |                 |                |
| Wore patch before of school    | 2.65 (0.86)     | -0.905         | 0.373|
| age (n=9)                      |                 |                |
| **Duration of patching**       |                 |                |
| More than 12 months (n=21)     | 2.76 (0.75)     | -0.832         | 0.342|
| Less than 12 months (n=11)     | 3.00 (0.64)     |                |      |
| **Period elapsed since**       |                 |                |
| patched completed              |                 |                |
| More than 12 months (n=5)      | 2.60 (0.56)     |                |      |
| Less than 12 months (n=27)     | 2.89 (0.74)     |                |      |
5.6 Discussion

The measurement of perceived self-esteem by use of a standardised age-appropriate questionnaire in this study revealed that children who had been treated for amblyopia had lower social acceptance scores than age-matched control children. Lower social acceptance scores were particularly found for subjects whose amblyopia was caused by acquired strabismus, all of whom wore glasses and two-thirds of whom had been treated with patching and for those with deprivation amblyopia who had the greatest amblyopic VA deficit. Lower social acceptance score was found to be correlated with a history of patching, but not with wearing glasses or with a history of strabismus.

In other areas related to self-esteem, including scholastic competence, physical appearance, athletic competence, behavioural conduct and global self worth, the amblyopic children gave scores similar to those of control children. While fine motor skills (Webber et al. 2008a) and on reaching and grasping have been recently reported to be reduced in amblyopia (Grant et al. 2007), our sample of amblyopia children perceived their athletic competence as highly as their peers.

Previous studies have suggested that the necessity to wear glasses or an eye patch can draw negative attention to a child (Horwood et al. 2005; Koklanis et al. 2006), with resultant victimisation or bullying and negative psychosocial effects. Our findings suggest that the negative attention drawn by wearing an eye patch impacts on the measure of self-esteem that relates to social acceptance. Studies of self-esteem in myopic children showed that whilst lower self-perception scores were associated more visual discomfort symptoms, they did not relate to magnitude of refractive error
(Dias et al. 2002), and did not vary with type of spectacle lens worn (Dias et al. 2005). Our findings support the conclusion that wearing glasses does not impact on a child’s self-esteem and does not vary with magnitude of refractive correction.

Together with the findings that wearing glasses does not significantly impact on self-esteem in myopic children (Dias et al. 2002; Dias et al. 2005), our results suggest that it is wearing an eye patch, rather than glasses, that creates the sense of being less well accepted and is potentially responsible for the stigma that has been reported to be associated with amblyopia therapy (Koklanis et al. 2006).

The findings of this study are important given the evidence from recent treatment trials which have specifically investigated the improvement in amblyopia that can be achieved through spectacle correction alone (Stewart et al. 2004a; The Pediatric Eye Disease Investigator Group 2006; Cotter et al. 2007). Evidence now exists that for some children with amblyopia, both strabismic (Cotter et al. 2007) and anisometropic (The Pediatric Eye Disease Investigator Group 2006), correction of refractive error alone can sufficiently improve visual acuity to the point that patching would no longer be considered necessary (Stewart et al. 2007). Our study indicates that spectacle wear does not contribute to reduced social acceptance in amblyopic children and emphasises the importance of exploring refractive correction as a first line of attack to treat amblyopia, with the hope that patching with its potential negative psychosocial effects may be minimised or avoided altogether. Indeed, it has now been established that reduced amounts of patching are as effective as full time patching (The Pediatric Eye Disease Investigator Group et al. 2003; The Pediatric Eye Disease Investigator Group 2003b; The Pediatric Eye Disease Investigator Group 2003d), and monitored occlusion trials have demonstrated
positive dose-response improvement in VA for up to 400 hours of patching with most improvement occurring in the first six weeks of patching (Stewart et al. 2004b; Stewart et al. 2007). Whilst not explored in this study, the use of atropine for penalisation rather than use of an occlusive patch has been suggested to have less social consequences and better acceptance by some amblyopic children (The Pediatric Eye Disease Investigator Group 2003a).

Clinicians are faced with the challenge of designing treatment regimens that are effective in restoring vision with minimal psychosocial side-effects. Our study provides evidence that amblyopia can impact on the self-esteem domain related to social interaction. There may be a psychosocial benefit to the child if patching is minimised and limited to times of day when the child has less interaction with social peers.

Acknowledgements

This work was supported by Queensland University of Technology (QUT) and the Institute of Health and Biomedical Innovation (IHBI). The authors thank all the participants for their co-operation; the staff of Dr Gole’s practice for their help in recruitment; and Philippe Lacherez, Diana Battisutta and Cameron Hurst of IHBI for assistance with biostatistics. This manuscript is based on data presented as a poster at the Association for Research in Vision and Ophthalmology meeting in May 2007, Fort Lauderdale, Florida.
Part B

The effect of amblyopia on self-esteem in preschool to grade 2 school level children.

5.7 Abstract

Aim: In an investigation of the psychosocial impact of amblyopia, the perceived self-esteem of amblyopic children from preschool to grade 2 school level was compared with that of age-matched controls.

Methods: Children with a history of treatment for amblyopia (n=29; age = 6.6 ± 0.6 years) and age-matched controls (n=20; age = 6.4 ± 0.5 years) completed a standardised age-appropriate pictorial questionnaire based evaluation of perceived self-esteem (The Pictorial Scale of Perceived Competence and Acceptance for Young Children).

Results: There were no significant differences in self perception scores of the amblyopic children compared to the controls in the domains of cognitive competence, physical competence and peer acceptance.

Conclusions: Amblyopic children from preschool to grade 2 school level are relatively robust in their perception of cognitive and physical ability and acceptance by their peers.
5.8 Introduction

Community funded screenings for amblyopia have questioned the age at which children should be screened. Contemporary studies have reported that visual outcomes are improved when amblyopia is detected and treated before six years of age (Eibschitz-Tsimhoni et al. 2000; Williams et al. 2003). In the previous chapter (Chapter 5 Part A) we reported data on the self-perception scores of children from Grade 3 school level (aged from approximately eight years) measured with the Harter Self Perception Profile for Children. Our data showed that self-perception of social acceptance was lower in children treated for amblyopia compared with age-matched controls and a reduction in these scores was associated with a history of patching treatment but not with a history of strabismus or spectacle wear.

Younger children may potentially be less affected by the social stigma associated with wearing an eye patch as part of amblyopia treatment, because it is only from middle to late childhood (from 8 to 11 years of age) that children begin to perceive their own competence or acceptance in comparison with others, particularly their peers (Harter 1988; Harter 1999). Younger children thus may lack the requisite skills (e.g. social comparison) to allow them to distinguish between ideal and real self-concepts (Harter 1999). In addition, young children, aged from three to eight years, have been reported not to be influenced by the presence of a cosmetically obvious strabismus when selecting a playmate (Johns et al. 2005).

In Chapter 5 Part A we suggested that there may be a psychosocial benefit to the child if patching is minimised and limited to times of the day when the child has less interaction with social peers. Of interest is whether children who are younger than eight years of age are more robust in their perception of peer acceptance. If so, there
may be a psychosocial benefit to identifying and treating children before they are of an age that peer comparison begins to form a basis for these aspects of self-esteem.

In this section we report data on the self-perception scores of children less than eight years of age who have been treated for amblyopia and compare their results with those of an age-matched control group. To test children from kindergarten to second grade the Pictorial Scale of Perceived Competence and Social Acceptance for Young Children (PSPCSA) was designed as an extension of the Perceived Competence Scale for Children use with younger age groups. As with the older child’s version, a domain-specific approach was taken (Harter and Pike 1984). In the PSPCSA the domains assessed were cognitive competence, physical competence and peer acceptance. Separate versions of the pictorial instrument are necessary for two age groupings, one suitable for Preschool/Kindergarten (approximately five to six years of age) and a second appropriate for First and Second grades (approximately seven to eight years of age) with separate books for assessment of girls and boys.

5.9 Methods

5.9.1 Participants

Forty-nine children participated in this study, including 29 children who had been treated for amblyogenic conditions (age = 6.6 ± 0.6 years) and 20 age-matched control subjects (age = 6.4 ± 0.5 years). The amblyopic sample had children from a range of aetiologies: infantile esotropia (n=8); acquired strabismus (n=11); anisometropia (n=5); mixed (n=4); deprivation (n=1). The amblyopic children and nine of the control children also participated in the study of fine motor skills reported in Chapter 4. The amblyopic children were recruited from the files of a private
paediatric ophthalmology practice as previously described in section 3.2.1 of the General Methods chapter. Eleven extra control subjects were recruited for this section of the study from a local primary (elementary) school via an email that outlined the purpose of the study to parents of children in Grades one and two.

All amblyopic children had received ophthalmological treatment for the underlying amblygenic condition (surgery or refractive correction) so did not have cosmetically obvious strabismus at the time of the study. All subjects were carried in full-term pregnancies and had no known neurological or ocular disorder (other than refractive error or their amblygenic conditions).

### 5.9.2 Self-Perception Assessment

Children younger than eight years of age (pre-school to grade 2) were tested with a pictorial questionnaire of 18 situations, and asked to identify which child in that situation they are most like. The activities depicted in each item were identical for girls and boys, however, the gender of the target child was different so that subjects could be asked to respond to a same-gender child. Administration of the pictorial questionnaire was according to test instructions. The child was given a sample item at the beginning of the questionnaire and was instructed to choose which child in the pictorial situation they were most like. The choice was refined further by asking if they were “very like” the child in the situation chosen or “a little like” the child in the situation. The questionnaire tapped into three domains: cognitive competence, physical competence and peer acceptance. Figure 5.2 shows an example from the Grade 1 to Grade 2 booklet for boys.
Chapter 5

Figure 5.2.: Example from Grade 1 to Grade 2 booklet for Boys

Items were scored from 1 to 4, where 4 indicated the most adequate self-judgment and 1 represented the least adequate self judgment. Items with each subscale were counter-balanced such that three items were worded with the most adequate statement on the left and three items were worded with the most adequate statement on the right. Scores from the child’s protocol were transferred onto a data coding sheet where all items for a given subscale were grouped together to facilitate calculation of the mean for each subscale. Scoring results in a total of six subscale means that defined a given child’s profile.

Means and standard deviations of subscale means for control samples are provided in the manual that accompanies the test booklets (Harter and Pike 1984). The outcome is a score between 1 and 4 on subscales.

5.10 Results

The self-perception scores of the amblyopic children were not significantly different from those of their age-matched peers for the three domain specific judgments of cognitive competence, physical competence and peer acceptance and were also comparable with published normative data. Table 5.7 presents the mean and standard deviations of self-perception domain scores for the amblyopic and control
children together with those of a normative sample tested by the authors of the PSPCSA (Harter and Pike 1984) (n=109; age = 6.9 years). While the cognitive competence score of the amblyopic group was found to be lower than that of the control group, a difference that approached statistical significance, the scores of the amblyopic children were comparable to the published normal values for their age group.

**Table 5.7: Self-perception subscale scores Estimated Marginal Means (standard error) for younger children.**

<table>
<thead>
<tr>
<th></th>
<th>AMBLYOPIA N=29</th>
<th>CONTROL N=20</th>
<th>ANOVA SIGNIFICANCE</th>
<th>Harter Normative data(Harter and Pike 1984) N=109</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Competence</td>
<td>3.44 (0.51)</td>
<td>3.69 (0.36)</td>
<td>3.388 0.072</td>
<td>3.4 (0.35)</td>
</tr>
<tr>
<td>Physical Competence</td>
<td>3.39 (0.50)</td>
<td>3.54 (0.43)</td>
<td>1.217 0.276</td>
<td>3.4 (0.39)</td>
</tr>
<tr>
<td>Peer Acceptance</td>
<td>3.02 (0.58)</td>
<td>3.20 (0.57)</td>
<td>1.257 0.268</td>
<td>3.1 (0.55)</td>
</tr>
</tbody>
</table>

**5.11 Discussion**

Children with a history of amblyopia who were from preschool to grade 2 school level gave self-perception scores in the domains of cognitive competence, physical competence and peer acceptance that were similar to those of age-matched control children. This finding concurs with that of a recently published study of gross motor abilities and self perception in amblyopic children aged from four to seven years that also employed the PSPCSA (Engel-Yeger 2008).
We have previously reported that older children, from grade 3 school level, have lower scores on the social acceptance domain “feels accepted by peers” or “feels popular” and that the lower social acceptance score was found to be correlated with a history of patching, but not with wearing glasses or with a history of strabismus. In the equivalent domain in the Pictorial scale, peer acceptance, the younger amblyopic children did not show a reduction in self-perception scores compared to the controls.

Self-perceptions of competence are belief systems that become more clearly differentiated with age (Byrne 1996; Marsh and Hattie 1996). As a child progresses through the developmental stages of childhood the nature of self-representations alters and can be identified at sequential stages of childhood. Self-representation of very young children, aged 3 to 4 years, generally reflects descriptions of behaviours, ability, emotions, possessions and preferences that are potentially observable by others (Harter 1999). They generally lack the requisite skills (e.g. social comparison) to allow them to distinguish between ideal and real self-concepts, so self-representations are likely to be unrealistically positive and generally demonstrate all-or-nothing thinking in which usually their descriptions are all positive (Harter 1999). This continues in children aged 5 to 7 years with typically very positive self-representations as the child continues to overestimate his or her own abilities (Harter 1999). In middle to late childhood (from 8 to 11 years of age) the child rates themselves based on comparison with others, particularly their peers (Harter 1988; Harter 1999).

Williams and Harrod (2006) report that in those children who had a vision screening at 3 years and 1 month (who therefore would be classified as receiving early intervention for amblyopia) almost 50% fewer reported having been bullied,
compared with children screened by the school nurse in the first year of school (aged between 4 and 5 years). They also reported that there was no bullying in children who wore glasses, supporting our previous conclusion that patching, rather than wearing of glasses, has negative psychosocial consequences for children (Williams and Harrad 2006).

While the causes of reduced social-acceptance scores, like bullying, in older children can be multifactorial, our finding that peer-acceptance in younger amblyopic children is comparable to age-matched peers supports the suggestion that the timing of intervention may influence the psychosocial implications for a child who is treated with patching.

In the previous chapter (Chapter 5 Part A) we suggested that if a child was of school age there may be a psychosocial benefit to the child if patching is minimised and limited to times of day when the child has less interaction with social peers. Our finding that the peer acceptance score of younger amblyopes is relatively robust further supports the suggestion that identification of amblyopia and treatment prior to the age when peer comparisons begin to emerge, that is, prior to approximately eight years of age, may be of psychosocial benefit to the child. Our findings indicate that there may be benefits in psychosocial as well as visual outcomes if children are identified and treated prior to entry into formalised schooling, when peer comparisons begin to emerge and awareness of differences created by amblyopia treatment, especially patching, can occur.
Chapter 6 RESULTS

CLINICAL MEASURES OF EYE MOVEMENTS

Part A


6.1 Abstract

Aim: To investigate the functional impact of amblyopia in children, the performance on a clinical test of eye movements was compared between groups of amblyopic and age-matched control children. The influence of visual factors on test outcome measures was explored.

Methods: Eye movements were assessed with the Developmental Eye Movement (DEM) test, in a group of children with amblyopia (n=39; age 9.1 ± 0.9 years) of different causes (infantile esotropia n=7; acquired strabismus n=10; anisometropia n=8; mixed n=8; deprivation n= 6) and in an aged matched control group (n = 42; age = 9.3 ± 0.38 years). LogMAR visual acuity (VA), Randot stereopsis and refractive correction were also recorded in both groups.

Results: No significant difference was found between the amblyopic and age-matched control groups in outcome measures of the DEM (Vertical time, Horizontal
time, number of errors and Ratio (Horizontal time/Vertical time). Outcome measures of the DEM did not significantly relate to measures of VA in either eye, level of binocular function, history of strabismus or refractive error.

**Conclusions:** The performance of amblyopic children on the DEM, a commonly used, clinical measure of eye movements, has not previously been reported. Amblyopia has no effect on eye movements when assessed with the DEM, despite significant impairment of binocular vision, and reduced VA in both the better and amblyopic eye in our sample of amblyopic children.
6.2 Introduction

Approximately three percent of the population develop amblyopia (Attebo et al. 1998; Brown et al. 2000), poor vision that results from abnormal visual experience during early childhood. Children with amblyopia may have poorer visual acuity in both the affected and fellow eye, little or no stereopsis or binocular fusion and poorer efficiency in their accommodation and oculo-motor control (McKee et al. 2003).

While much has been reported of the visual characteristics of amblyopia and the neurological adaptations that underlie these effects (McKee et al. 2003; Anderson and Swettenham 2006; Levi 2006), there is little published evidence of the disability associated with amblyopia (Snowden and Stewart-Brown 1997a) particularly with regard to the ability to complete activities of daily living that impact on career opportunities or career choices for amblyopes (Hartmann et al. 2000), or on tasks pertinent to the activities of amblyopic children and their educational achievement. People with a history of amblyopia are reported to feel it has affected their school and career choices (Campbell and Charney 1991; Satterfield et al. 1993; Packwood et al. 1999), however a recent birth cohort study involving 8861 participants reported that amblyopia did not significantly impact educational, health or social outcomes (Rahi et al. 2006).

In addition to reduced visual acuity, contrast sensitivity and position acuity (McKee et al. 2003), amblyopes have poorer control of fixation in both the amblyopic and non-amblyopic eye (Kandel et al. 1980) and binocular coordination of saccades is impaired in strabismics, particularly those with large angle strabismus (Kapoula et al. 1997). Although a causal relationship between “poor” eye movements and reading has not been confirmed (Starr and Rayner 2001), assessment of eye movements in
poor readers is routine in clinical paediatric optometry practice (Scheiman and Wick 1994), and is recommended in optometric clinical guidelines for the evaluation of learning-related vision problems (Garzia et al. 2006). While the visual anomalies known to be associated with amblyopia, such as reduced visual acuity (VA) in both affected and fellow eye, reduced or absent stereopsis, and poor fixation control may be expected to impact the fluency of eye movements under habitual binocular viewing conditions, the performance of amblyopic children on clinical tests of eye movements has not previously been reported.

The most common assessment of eye movements in optometric practice is observation of fixation ability, saccadic eye movements and pursuit eye movements and grading of these eye movements for smoothness and accuracy on a 1 to 4 scale (Scheiman and Wick 1994; Ciuffreda and Tannen 1995b). While the grading scales are simple to administer, the reliability and repeatability and quantification of clinical observation have been questioned (Scheiman and Wick 1994). Although less common in clinical practice, objective infrared recording of eye movements during reading for comprehension can be provided by the Visagraph II Eye-Movement recording system (Scheiman and Wick 1994). While the highly detailed description of eye movements provided by Visagraph is comprehensive, the relatively high equipment costs, significantly longer time required for testing and relatively high degree of technical knowledge required to obtain a valid recording have limited its use in clinical practice.

An alternative clinical test of saccadic eye movements is the Developmental Eye Movement Test (DEM) (Garzia 1990) which gives a measure of visual-verbal oculomotor skills and rapid automatized naming (RAN) (Tassinari and De Land
The effect of amblyopia on the DEM test in children

Chapter 6

2005). The DEM is a standardised clinical test of saccadic eye movements and is recommended for use in optometric practice for the evaluation of learning-related vision problems in children (Garzia et al. 2006).

We have previously reported that amblyopia impacts on outcomes of fine motor skills tests of visual motor control and upper-limb speed and dexterity, and that poorer fine motor skill performance was associated with a history of strabismus (Webber et al. 2008a). The deficits in motor performance were greatest on timed manual dexterity tasks reflecting both speed and accuracy. We speculated that the outcomes on the DEM test, which are also judged on speed and accuracy, may be similarly affected in a group of amblyopes.

In addition to a history of strabismus, the visual anomalies associated with amblyopia that we hypothesise may influence DEM test outcomes include the level of VA in the better eye, as this predicts VA under binocular conditions (Rubin et al. 2000), level of stereopsis as a measure of binocular fusion and inter-ocular VA difference as a measure of depth of amblyopia. Hyperopia will also be considered as it has been linked with poor performance compared with controls on several spatial cognitive and motor tests (Atkinson et al. 2005; Atkinson et al. 2007), and hyperopic children demonstrate poor reading performances compared with emmetropic and myopic children (Shankar et al. 2007).

In this study, performed under habitual binocular viewing conditions, we used the DEM to obtain a quantitative assessment of saccadic eye movements in a sample of children with amblyopia of differing aetiologies and compared outcome measures with that of an age-matched group of children. The influence of amblyopia aetiology
and measured visual characteristics were examined by testing whether these factors were associated with outcome measures of the DEM.

6.3 Methods

6.3.1 Participants

Thirty-nine children (aged 9.1 ± 0.9 years) who had been diagnosed and treated for amblyopia or amblyogenic conditions and forty-two control children (aged 9.3 ± 0.4 years) participated in this study. Potential amblyopic subjects were recruited from the private practice of a paediatric ophthalmologist (GG) and control subjects were recruited from a local primary (elementary) school. Details of their recruitment and clinical characteristics have been previously reported (Webber et al. 2008a; Webber et al. 2008b). Amblyopia in our subjects resulted from a range of causes; seven had a history of infantile esotropia, ten had history of acquired strabismus, eight had history of anisometropia, eight had history of both strabismus and anisometropia and six had a history of disturbance of monocular image clarity such as congenital cataract (deprivation). All had received ophthalmological treatment for the underlying amblyogenic condition (surgery or refractive correction) and had concluded occlusion or penalisation treatment. The group included both children with successful treatment outcome and children who still had clinically significant amblyopia (greater than 0.2 logMAR difference in VA between eyes). Refractive correction (typically less than one year old) was worn for all tests.

6.3.2 Vision Assessment

Visual acuity was measured in each eye using a 3 metre logMAR chart while the child wore their refractive correction based on cycloplegic refraction within the
previous twelve months. The resultant VA for each eye was scored on a letter by letter basis. The level of binocular function was assessed with the Randot Preschool Stereoacuity test (Birch et al. 1997; Birch et al. 2008), chosen for its established validity and normative data. Suppression was confirmed by the Mirror-Pola technique (Siderov 2001) if no stereoscopic response was obtained on the Randot test.

6.3.3 Developmental Eye Movement Test

Saccadic eye movements were assessed with the Developmental Eye Movement (DEM) test (Garzia 1990), in which the time taken for a series of numbers (single digits) to be seen, recognised and spoken with accuracy is measured. The test consists of two subtests with 40 numbers arranged in vertical columns (Tests A and B), and a subtest with 80 irregularly spaced numbers arranged in 16 horizontal rows (Test C). The child is asked to name aloud the single digit numbers as quickly and accurately as possible and the times taken to read aloud the 80 numbers in both the four vertical columns (vertical time) and the sixteen line horizontal array (horizontal time) are recorded. The number of omission and addition errors is recorded and test times are adjusted for errors made. Upon completion of the test, a ratio was calculated by dividing the time taken to read the 80 numbers in the horizontal array by the total time for reading the 80 numbers in vertical subsets. The outcomes from the DEM test are Vertical time, Horizontal time, Number of Errors and Ratio_{horizontal time/vertical time}. Results can be converted to standard scores and percentile ranks based on published age-normative data for this test (Richman and Garzia 1987).

Both amblyopic and control subjects also completed a self-esteem questionnaire and tests of fine motor skills performance during the test session; the findings of these
tests have been published elsewhere (Webber et al. 2008a; Webber et al. 2008b).

Complete assessment of vision, fine motor skills, perceived self esteem and DEM took about 45 minutes per subject and were completed within one test session by all subjects.

All participants were given a full explanation of the experimental procedures and the option to withdraw from the study at any time was explained to both parent and child. Written informed consent was obtained from the parent prior to participation in the study. The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee and all protocols concurred with the guidelines of the Declaration of Helsinki.

**6.3.4 Statistical Analysis**

All data were tested for normality using the Kolmogorov-Smirnov test. Where the data were normally distributed, the results from the amblyopes were compared with those of the control group using independent samples t-test and results between amblyopic subgroups were compared with a one-way ANOVA (Statistical Package for the Social Sciences – SPSS V14), using a significance level of 0.05. When statistically significant differences were found between means, Bonferroni post-hoc tests were used. Non-parametric tests were used where the data were not normally distributed. Pearson’s correlation co-efficients were calculated to explore the relationships between DEM measures and subject vision characteristics; to account for multiple comparisons, a significance level of 0.01 was used (Curtin and Schulz 1998).
6.4 Results

No significant differences in age or gender were found between the amblyopic and control groups. On average the subjects with amblyopia had 0.06 logMAR VA in the better eye and 0.44 logMAR in the worst eye. In the control group there was very little difference between eyes (-0.03 logMAR in the better eye; -0.01 logMAR in the worst eye). Twenty-nine of the amblyopic subjects (73%) and three control subjects (7%) wore a hyperopic refractive correction.

When compared with age-matched control children, the amblyopic children had a greater inter-ocular difference in VA, poorer VA in both their better and worse eyes and were less likely to have normal stereopsis (40 sec of arc) (p<0.05). Table 1 summarises the mean and standard errors for the age, gender, refractive and vision characteristics of the amblyopic and control groups and presents the results of statistical analysis for differences between groups.

Subjects were grouped according to their stereopsis level; “nil” if no stereoscopic response could be measured, “reduced” if response indicated stereopsis between 800 and 60 seconds of arc and “normal” if response indicated stereopsis better than or equal to 40 seconds of arc. The level of stereopsis varied significantly both between the amblyopic and control groups ($\chi^2_{(df=2)} = 66.08; p<0.001$) and between subgroups ($\chi^2_{(df=8)} = 18.87; p<0.001$)(Table 1). The majority of control group subjects (98%) had normal stereopsis ($\leq 40$ sec of arc) (Fielder and Moseley 1996) compared with only eight percent of the amblyopic group. All subjects with infantile esotropia had no measurable stereopsis, whilst 75% of anisometropic amblyopes had reduced levels of stereopsis; 25% of the anisometropes had normal stereopsis.
In addition to significant differences between the amblyopia and control groups, significant differences were measured between amblyopic aetiology subgroups in VA worst eye, intra-ocular VA difference, level of stereopsis and average refractive error (Table 6.1). *Post hoc* testing indicated that those with aetiology of deprivation had significantly poorer VA in worst eye and greater inter-ocular VA difference than the other subgroups and the difference in refractive error was significant between the deprivation and mixed aetiology sub-groups.

Mean and standard deviation of DEM outcome measures Vertical time, Horizontal time, Number of Errors and Ratio (horizontal time/vertical time) are shown for the amblyopic and control groups in Table 6.2. No significant differences in outcome measures of the DEM were found between the amblyopic and age-matched control groups, and the data for each group was comparable with published DEM normative data for children aged between 9 and 10 years of age (Richman and Garzia 1987). In addition, outcome measures of the DEM did not significantly differ between amblyopic subgroups (Table 6.2).
Table 6.1: Age, gender, refractive and vision characteristics of samples. Mean (standard deviation) of data is presented.

<table>
<thead>
<tr>
<th>STATISTICAL SIGNIFICANCE Between Amblyopia and Control Group</th>
<th>Amblyopic Sub-groups</th>
<th>STATISTICAL SIGNIFICANCE One-Way ANOVA Between Amblyopic aetiology groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>N=42 N = 39 t (df=79) p</td>
<td>N=7 N=10 N=8 N=8 N=6 F or χ² p</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.34 (0.38) 9.12 (0.96) -1.214 0.228 9.51 (1.26) 8.90 (0.83) 9.64 (0.79) 8.56 (0.82) 9.26 (0.86) 1.888 a 0.135</td>
<td></td>
</tr>
<tr>
<td>Gender (% Female)</td>
<td>20 (48%) 17 (43%) χ² (df=2) 0.664 29% 50% 38% 38% 50% 1.564 (χ² df=4) 0.815</td>
<td></td>
</tr>
<tr>
<td>Stereopsis</td>
<td>Nil 0 (0%) 23 (59%) χ² (df=2) ω0&lt;0.001 7 (100%) 7 (70%) 0 (0%) 5 (63%) 4 (67%) 18.87 (χ² df=8) 0.016</td>
<td></td>
</tr>
<tr>
<td>800° – 60°</td>
<td>1 (2%) 13 (33.3%) 66.08 &lt;0.001 0 (0%) 2 (20%) 6 (75%) 3 (38%) 2 (29%)</td>
<td></td>
</tr>
<tr>
<td>≤ 40°</td>
<td>41 (98%) 3 (7.7%) 0 (0%) 1 (10%) 2 (25%) 0 (0%) 0 (0%) 6.254a 0.001</td>
<td></td>
</tr>
<tr>
<td>Inter Ocular Difference in VA (logMAR)</td>
<td>0.02 (0.03) 0.38 (0.52) 4.475 &lt;0.001 0.51 (0.72) 0.11 (0.10) 0.22 (0.18) 0.21 (0.16) 1.09 (0.69) 6.254a 0.001</td>
<td></td>
</tr>
<tr>
<td>VA in Best Eye (logMAR)</td>
<td>-0.03 (0.05) 0.06 (0.11) 4.726 &lt;0.001 0.06 (0.12) 0.09 (0.10) 0.05 (0.10) 0.08 (0.13) 0.00 (0.10) 0.748 a 0.566</td>
<td></td>
</tr>
<tr>
<td>VA in Worst Eye (logMAR)</td>
<td>-0.01 (0.05) 0.44 (0.50) 5.710 &lt;0.001 0.57 (0.68) 0.21 (0.13) 0.27 (0.12) 0.28 (0.21) 1.09 (0.73) 5.180 a 0.002</td>
<td></td>
</tr>
<tr>
<td>Refractive error (dioptres)</td>
<td>0.16 (0.63) 2.92 (2.49) 6.941 &lt;0.001 1.17 (1.21) 4.23 (3.20) 2.75 (1.66) 4.59 (1.56) 0.79 (1.50) 5.044 a 0.003</td>
<td></td>
</tr>
</tbody>
</table>

a one-way ANOVA F(4,39)  ‡ Post hoc Bonferroni indicates differences between sub-groups
Table 6.2: Developmental Eye Movement test outcomes – mean (standard deviation)

<table>
<thead>
<tr>
<th>OUTCOME MEASURE</th>
<th>Control</th>
<th>Total Amblyopia Group (age 9.0-9.99)</th>
<th>Normative data</th>
<th>STATISTICAL SIGNIFICANCE Between Amblyopia and Control Group</th>
<th>Amblyopic Sub-groups</th>
<th>STATISTICAL SIGNIFICANCE Between Amblyopic aetiology groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 42</td>
<td>N=39</td>
<td>N=84</td>
<td></td>
<td>N=7</td>
<td>N=10</td>
</tr>
<tr>
<td>Vertical Adjusted Time (seconds)</td>
<td>41.12 (6.79)</td>
<td>42.13 (9.05)</td>
<td>42.33 (8.20)</td>
<td>0.050</td>
<td>0.070</td>
<td>39.29 (6.85)</td>
</tr>
<tr>
<td>Horizontal Adjusted Time (seconds)</td>
<td>52.71 (11.54)</td>
<td>53.18 (16.96)</td>
<td>51.13 (13.30)</td>
<td>0.145</td>
<td>0.885</td>
<td>47.29 (8.75)</td>
</tr>
<tr>
<td>Number of Errors</td>
<td>0.98 (2.42)</td>
<td>1.62 (3.60)</td>
<td>2.17 (4.10)</td>
<td>0.944</td>
<td>0.348</td>
<td>2.71 (5.62)</td>
</tr>
<tr>
<td>Ratio (Horizontal Time/Vertical Time)</td>
<td>1.27 (0.19)</td>
<td>1.25 (0.20)</td>
<td>1.21 (0.19)</td>
<td>-0.551</td>
<td>0.583</td>
<td>1.21 (0.17)</td>
</tr>
</tbody>
</table>

*Post hoc tests indicate significant differences between sub-groups*
An indication of the clinical significance of the DEM outcomes was derived by referring to published normative data (Richman and Garzia 1987). As well as presenting mean and standard deviation for normative groups, the DEM handbook provides calculation of a standard score and indication of percentile rank of performance against the normative data. Results were determined to be abnormal if the subject scored in the 15th percentile or below, considered outside the normal range by standardised and validated testing of the DEM (Scheiman et al. 1996). The number of subjects in either group whose outcome result was outside the range of published normative data (Richman and Garzia 1987) is shown in Table 6.3. No significant difference was seen between amblyopic and control groups in the number of subjects who meet this clinical criterion for poor outcome.

Table 6.3: Number of subjects with DEM scores below 15th percentile

<table>
<thead>
<tr>
<th>Total N (% of subjects)</th>
<th>Amblyopic Group</th>
<th>Control Group</th>
<th>Chi-square (df=1)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Time ≥ 53 seconds</td>
<td>6 (7%)</td>
<td>4 (10%)</td>
<td>2 (5%)</td>
<td>0.890</td>
</tr>
<tr>
<td>Vertical Time ≥ 64 seconds</td>
<td>12 (15%)</td>
<td>6 (15%)</td>
<td>6 (14%)</td>
<td>0.032</td>
</tr>
<tr>
<td>Number of Errors ≥ 4</td>
<td>11 (14%)</td>
<td>6 (15%)</td>
<td>5 (12%)</td>
<td>0.209</td>
</tr>
<tr>
<td>Ratio ≥ 1.40</td>
<td>15 (19%)</td>
<td>7 (18%)</td>
<td>8 (19%)</td>
<td>0.016</td>
</tr>
</tbody>
</table>

6.4.1 Visual determinants of DEM outcome measures.

Pearson correlation coefficients were calculated between DEM outcome measures and the characteristics of the subjects that we considered might influence oculo-motor control (history of strabismus, VA in better eye, VA in worse eye, intra-ocular VA difference, average refractive error and level of stereopsis). As expected, there were a number of significant intercorrelations between the subject visual
characteristics, and between the outcome measures of the DEM (p<0.05). However, no significant correlations were found between the DEM outcome measures and subject visual characteristics.

### 6.4.2 Impact of treatment success

Within the amblyopic group no significant differences were found in DEM outcomes between those children who would be clinically described as having successful versus unsuccessful treatment outcome (0.2 logMAR difference in VA between eyes) (Table 6.4).

**Table 6.4: Difference in DEM results between Amblyopic VA groups**

<table>
<thead>
<tr>
<th>DEM Outcome Measure</th>
<th>VA in worse eye ≤ 2.0 logMAR N = 19</th>
<th>VA in worse eye &gt;2.0 logMAR N = 20</th>
<th>t(df=37)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Time (seconds)</td>
<td>41.26 (6.69)</td>
<td>42.95 (10.95)</td>
<td>-0.5777</td>
<td>0.568</td>
</tr>
<tr>
<td>Horizontal Time (seconds)</td>
<td>53.37 (14.26)</td>
<td>53.00 (19.63)</td>
<td>0.067</td>
<td>0.947</td>
</tr>
<tr>
<td>Number of Errors</td>
<td>1.89 (4.04)</td>
<td>1.35 (3.20)</td>
<td>0.468</td>
<td>0.642</td>
</tr>
<tr>
<td>Ratio(Horizontal Time/Vertical Time)</td>
<td>1.29 (0.23)</td>
<td>1.21 (0.15)</td>
<td>1.314</td>
<td>0.197</td>
</tr>
</tbody>
</table>

The influence of binocular function was explored by testing for differences in DEM outcomes between stereopsis groups. Whilst those with no measurable stereopsis recorded the highest mean number of errors, the differences between stereopsis groups were not statistically significant for any of the DEM outcome measures as shown in Table 6.5.

**Table 6.5: Difference in DEM results between Binocular function groups**

<table>
<thead>
<tr>
<th>DEM Outcome Measure</th>
<th>Nil stereopsis N = 23</th>
<th>Reduced stereopsis N=14</th>
<th>Normal stereopsis N =44</th>
<th>F(2,78)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Time (seconds)</td>
<td>43.52 (10.60)</td>
<td>40.29 (6.56)</td>
<td>41.02 (6.59)</td>
<td>0.985</td>
<td>0.378</td>
</tr>
<tr>
<td>Horizontal Time (seconds)</td>
<td>55.78 (20.73)</td>
<td>49.29 (9.46)</td>
<td>52.61 (11.21)</td>
<td>0.919</td>
<td>0.403</td>
</tr>
<tr>
<td>Number of Errors</td>
<td>2.43 (4.04)</td>
<td>0.50 (0.76)</td>
<td>0.93 (2.38)</td>
<td>2.495</td>
<td>0.089</td>
</tr>
<tr>
<td>Ratio(Horizontal Time/Vertical Time)</td>
<td>1.26 (0.24)</td>
<td>1.22 (0.13)</td>
<td>1.27 (0.16)</td>
<td>0.416</td>
<td>0.661</td>
</tr>
</tbody>
</table>
6.5 Discussion

This is the first study to report the performance of amblyopic children on a clinical measure of saccadic eye movements and to compare that performance with normally sighted control children. Our findings indicate that, despite significantly reduced VA in both the fellow and affected eyes, reduced or absent stereopsis and significantly greater hyperopic refractive error, amblyopic children gave scores similar to those of control children for the outcome measures of the Developmental Eye Movement (DEM) test, including Vertical time, Horizontal time, Number of Errors and Ratio(horizontal time/vertical time).

In addition to determining that the ability of amblyopic children to quickly execute saccades to fixate, identify and name single digits was equal to that of age-matched peers, we found that the outcome measures of the DEM did not significantly relate to measures of VA in either eye, levels of binocular function or magnitude of refractive correction.

The prevalence of clinically unacceptable performance on the DEM was equivalent in the amblyopic and control groups and agreed with published normative data for the DEM test, suggesting that under habitual binocular viewing conditions amblyopia does not carry with it a functionally relevant reduction in saccadic eye movement speed and accuracy.

The DEM provides an indirect, quantitative evaluation of saccadic eye movements based on the speed by which a series of numbers can be seen, recognised and verbalised with accuracy (Tassinari and De Land 2005). It is thus purported to detect oculomotor dysfunction and is recommended in optometric clinical practice guidelines for the quantitative evaluation of saccadic eye movements in children for
learning-related vision problems (Garzia et al. 2006). The Horizontal sub-test mimics the eye movements made during reading, with saccades of variable length required to fixate on the irregularly spaced single digits (N10 font size) along horizontal rows, while the Vertical subtests give a base measure of how quickly the child can name 80 numbers without having to make the saccadic eye movements along rows. The time to complete the task and the number of errors are the clinical outcomes, with significantly slower and/or error prone performance on the Horizontal task than the Vertical task, that is higher Ratio score, indicating poor saccadic eye movement control. Poor performance on both the Vertical and Horizontal subtests would indicate slow automatic naming ability.

Despite recognition of reading as an important vision dependent ability that contributes to an individual’s quality of life (Uusitalo et al. 1999), few studies have evaluated the impact of amblyopia on reading under habitual binocular viewing conditions. Specific reading disability was found to be relatively rare in a small sample of children with amblyopia (n=20) (Koklanis et al. 2006) and not more prevalent than reported in the general population. Likewise, we found that the proportion of amblyopic children whose DEM results were determined to be abnormal was not greater in the amblyopic group than in either the control group or published normative data.

Stifter et. al. (2005) have recently reported a functionally relevant reading impairment (reduced maximum reading speed under binocular viewing conditions) in micro-strabismic children (n=20, age 11.5 ± 1.1 years). A sustained and prevalent controversy in reading eye movement research is whether fluent reading is controlled by low-level eye movement efficiency or whether it is influenced by the more
moment-to-moment cognitive processes (Starr and Rayner 2001). In children without amblyopia, poor performance on outcome measures of the DEM has been associated with parental observation of signs of poor reading fluency in children (n=84, age 10.0 ± 2.2 years) such as losing place or omitting words when reading or copying and re-reading lines unknowingly (Tassinari and De Land 2005), and has been found to predict students with below average reading performance (Larter et al. 2004). We wished to establish whether amblyopic children had poorer saccadic eye movement efficiency, as measured by the DEM, to determine if poorer eye movement control during reading explained the slower reading speed reported by Stifter et. al.(2005). Our finding that amblyopia has no effect on eye movements when assessed with the DEM indicates that the deficit in binocular reading speed reported in amblyopic children (Stifter et al. 2005) is not due to poor saccadic eye movement control. Stifter et. al. also report that better binocular reading speed in the amblyopic group was associated with more central and steady fixation and better sensory binocular function, but did not relate to age, VA, accommodative impairment, strabismic angle or refractive error (Stifter et al. 2005). In the present study, timed outcome measures on the DEM were not associated with history of strabismus, VA in either eye, level of binocular function or magnitude of refractive error.

It has been reported that the reading speed of well-corrected fluent observers reading ordinary text with adequate light under adequate lighting conditions is limited by letter spacing (crowding), not size (acuity) (Pelli et al. 2007). This is independent of text size, contrast, and luminance given that text contrast is at least four times the threshold contrast for an isolated letter (Pelli et al. 2007). Levi et al have recently demonstrated that crowding rather than acuity limits reading in amblyopic observers, as well as normal observers, in both central and peripheral vision (Levi et al. 2007).
Crowding should not influence the DEM task that consists of 3mm tall, high contrast single digits (approximately N10) with 5mm between rows of numbers and spacing of 10 to 25 mm between numbers. However, the extent to which crowding may explain the reduction in reading speed under binocular conditions reported by Stifter et.al. (2005) remain unclear, even though crowding would not be anticipated to contribute to resolution under the binocular viewing conditions that the difference between micro-strabismic and control children was measured.

Neurophysiological evidence indicates dysfunction in amblyopes in both primary and secondary visual area and regions within the parieto-occipital cortex and ventral temporal cortex (Anderson and Swettenham 2006). The poorer performance of amblyopes compared with controls on timed manual dexterity tasks (Grant et al. 2007; Webber et al. 2008a), may reflect dysfunction in higher order cortical process inherent in amblyopia and its sensory motor integration. While the correlation between upper limb speed and dexterity scores and the DEM Ratio suggests a trend, the DEM task is not impaired to the same extent as the fine motor skills tasks. The saccadic eye movements and the visual-verbalisation required to perform the DEM are not degraded to the same extent as fine motor skills by amblyopia.

This indicates that the oculomotor control required for the DEM is a lower order task, not influenced to the same degree by the neurophysiological changes inherent in amblyopia.

Amblyopia remains the most common cause of reduced vision in children and young people, with significant costs to both the individual and community for screening and treatment. While a number of functionally relevant deficits in tasks that contribute to quality of life have now been reported (Grant et al. 2007), the educational, health and social life outcomes of amblyopes does not appear to be impeded (Rahi et al. 2006).
In addition to determining the extent of functionally relevant deficits in performance that may accompany amblyopia, it is important to have an understanding of how children with amblyopia perform on clinical tests commonly used in paediatric practice. Such understanding is important for clinicians interpreting test results and for providing advice to parents and carers of the consequences of amblyopia. Clinical treatment plans for amblyopia aim to improve visual acuity and binocular function outcomes, however, the relationship between degraded vision and performance both on clinical tests of visual efficiency and on tasks relevant to children is yet to be fully established.
Part B

Relationship between DEM and Visagraph III recorded eye movements in children

6.6 Abstract

Aim: To investigate the relationship between indirect measures of eye movements commonly used in clinical practice and direct eye movement recordings made during reading for comprehension in children.

Methods: Participants with normal vision (n=59; age = 9.7 ± 0.6) were recruited from elementary (primary) school grades 4 and 5. Eye movements were assessed with the Developmental Eye Movement (DEM) test and Visagraph III infra-red recordings of eye movements were made during both reading for comprehension and naming numbers.

Results: Children with slower Visagraph recorded reading rates tended to have slower DEM Horizontal Times ($r = -0.547$) and slower DEM Vertical Times ($r = -0.414$). Similarly, children with slower Visagraph recorded number calling rates tended to have slower DEM Horizontal Times ($r = -0.716$) and slower DEM Vertical Times ($r = -0.665$). The Number of Errors recorded during the DEM test did not significantly relate to Visagraph recorded measures of reading fluency. Children with higher DEM Ratios had slower Visagraph recorded reading rates during reading for comprehension ($r = 0.368$).
Conclusions: A number of the outcome measures of the DEM are strongly associated with objective infra-red eye movement recordings of reading rates indicating the clinical usefulness of the DEM for the identification of children with slower rates of reading.
6.7 Introduction

Clinical assessment of the oculomotor system is recommended in the optometric management of learning-related vision problems (Garzia et al. 2006). Methods of evaluating oculomotor performance range from gross observation, to use of quantitative rating scales, to indirect measures of eye movements and finally to direct measure of eye movements with infra-red recording systems.

In optometric practice the most common assessment of eye movements is observation of fixation stability, saccadic eye movements and pursuit eye movements and grading of these eye movements for smoothness and accuracy on a rating scale from 1 to 4 (Scheiman and Wick 1994). Grading scales that have normative data include the Northeastern State University College of Optometry Oculomotor Test (NSUCO) and the Southern California College of Optometry (SCCO) rating system (Scheiman and Rouse 2006). However, while the grading scales are simple to administer and require no special equipment, the reliability, repeatability and quantification of clinical observation has been questioned (Scheiman and Wick 1994; Scheiman and Rouse 2006).

Indirect measures of eye movements provide a more quantitative method of evaluating saccadic eye movements during tasks that simulate reading. Some of these tests include the Pierce Saccadic Test, the King-Devick Saccadic Test and the Developmental Eye Movement (DEM) Test (Scheiman and Rouse 2006). These three tests are designed on the same principle; the patient is asked to call out a series of numbers arranged in horizontal rows as quickly as possible without using a finger or pointer as a guide. The time taken to call out all numbers and the amount of errors
made are compared to normative tables. To account for poor automaticity in number
naming skills, the DEM also measures the time to call out the same amount of
numbers arranged in vertical columns. The DEM is considered the best clinical
indirect method of evaluating saccadic eye movements because the test design
accounts for automaticity in number-naming skills (Scheiman and Rouse 2006) and it
is used clinically by optometrists to assess oculomotor skills and rapid automatized
naming (RAN) (Tassinari and De Land 2005).

Poor performance on the DEM test has been reported to correlate with parental
observation of reading errors, such as losing place or omitting words when reading or
re-reading lines unknowingly (Tassinari and De Land 2005). The timed outcomes of
the DEM have been found to predict performance on a test of academic achievement,
the English Language Arts section of the Test of New York State Standards (Lack
2005). High correlation with the reading subtest of the Wide Range Achievement
Test (WRAT) was reported in the initial validation study of the DEM (n=58; mean
age 8.9 years) (Richman and Garzia 1987).

Although less common in clinical practice, the Visagraph III Eye Movement
recording system has been identified as the best clinical method for direct eye
movement recording (Scheiman and Wick 1994; Scheiman and Rouse 2006). The
pattern of eye movements recorded during reading can be described by several
features. These include fixations, regressions, return-sweep saccades, span of
recognition, fixation duration and reading rate (Ciuffreda and Tannen 1995a).

Fixations refer to the total number of times the eyes move during reading. The eyes
move from one fixation point to another by left-to-right progressive saccades of 1 to
2 degrees. Regressions refer to fixations that are directed from right-to-left by
“backward” movements during reading. In established readers, regressions make up about 10% to 15% of saccades during reading. Children learning to read and poor readers make a greater number of regressions (Ciuffreda and Tannen 1995a).

Return-sweep saccades refers to the large right-to-left slightly oblique saccadic eye movement that shifts the eyes from near the end of one line to near the beginning of the next line of text. The return-sweep saccades are typically 12 to 20 degrees in angular extent, with saccadic durations of 40 to 54 msec (Ciuffreda and Tannen 1995a).

While the highly detailed record of eye movements provided by the Visagraph is comprehensive, the relatively high equipment costs, significantly longer time required for testing and relatively high degree of technical knowledge required to obtain a valid recording may have limited its use in clinical practice (Scheiman and Rouse 2006). The Visagraph is reported to produce data that is reliable, however, the relationship between Visagraph data and measures of reading comprehension have yet to be conclusively established (Colby et al. 1998).

In our study of the impact of amblyopia in children, performance on the DEM was compared between groups of amblyopic and age-matched control children. To gain a more detailed description of the eye movements made during reading we also tried to obtain Visagraph infra-red recording whilst reading for comprehension in the amblyopic children. However, we found such recordings were unreliable through the spectacle corrections worn by the majority of the amblyopic group of children. We therefore focused on how the outcome measures of the DEM would relate to the pattern of eye movements recorded during reading for comprehension with the Visagraph and particularly whether the DEM would identify children with slow
reading rates measured objectively. While correlations have been reported in normal children between DEM Horizontal time and the number of fixations ($r=0.350$), duration of fixation ($r=0.496$) and numbers per minute reading rate ($r=-0.259$) recorded with the Visagrap during a comparable number naming task (Lack 2005), the relationship between the Visagrap recordings of eye movement characteristics during reading for comprehension and outcomes of the DEM has not previously been described. To investigate the relationship between these two clinical oculomotor measures we recorded eye movements in a group of children from primary (elementary) school grades 4 and 5 both during reading for comprehension and number-naming, a task similar to that employed in the DEM. The strength and direction of relationships between the Visagrap measures and outcome scores on the DEM test were explored.

### 6.8 Methods

#### 6.8.1 Participants

Subjects (n=59; age = 9.7 ± 0.6) were recruited from a local primary (elementary) school (Bulimba SS). Recruitment was as previously described in the Methodology chapter, section 3.2.2. Only children in grades 4 and 5 participated in this evaluation of eye movements. Children in earlier grades were not included due to the greater variability of reading fluency parameters in younger ages, as children are still developing reading skills (Kulp and Schmidt 1997).

Subjects completed tests of visual acuity and stereoacuity, fine motor skills and a self-esteem questionnaire as described in sections 3.5, 3.6 and 3.8 of the Methodology chapter. Complete assessment of vision, fine motor skills, perceived self-esteem and DEM took about 45 minutes per subject and were completed within
one test session by all subjects. Infra-red recording of eye movements during both reading for comprehension and naming aloud numbers were made with the Visagraph III at a second session and took about 20 minutes per subject to complete.

6.8.2 Eye Movements

Two measures of eye movements were made in this group of children.

6.8.2.1 Developmental Eye Movement Test

Firstly, saccadic eye movements were assessed with the DEM test (Garzia 1990), in which the time taken for a series of numbers (single digits) to be seen, recognised and spoken with accuracy was measured.

The test consisted of two subtests with 40 numbers arranged in vertical columns (Tests A and B), and a subtest with 80 irregularly spaced numbers arranged in 16 horizontal rows (Test C) (Figure 3.5). The child was asked to name aloud the single digit numbers as quickly and accurately as possible and the time taken to read aloud the 80 numbers in both the four vertical columns (vertical time) and the sixteen line horizontal array (horizontal time) were recorded. The number of omission and addition errors was recorded and test times were adjusted for errors made.

Upon completion of the test, a ratio was calculated by dividing the time taken to read the 80 numbers in the horizontal array by the total time for reading the 80 numbers in vertical subsets. The outcomes from the DEM test are Vertical time, Horizontal time, Number of Errors and Ratio_{horizontal time/vertical time}. Results were converted to standard scores and percentile ranks based on published age-normative data for this test (Richman and Garzia 1987).
6.8.2.2 Visagraph

Secondly, reading eye movements were recorded with the Visagraph III eye-movement recording system that uses goggles containing infra-red sensors to capture eye position information during reading (as shown in Figure 6.1)

![Visagraph III recording goggles](image)

**Figure 6.1: Visagraph III recording goggles. (From Taylor Associates/Communications Inc 2008)**

Two types of clinical recording tests were made with the Visagraph III: a reading recording where the eye movements made when reading a short age-appropriate paragraph text are captured and a number recording where the test card consists of a series of numbers between 1 and 5. Comprehension tests were administered following the reading evaluation to confirm that the child was reading for comprehension, rather than merely giving the appearance of reading. From the Visagraph recordings a number of measures of eye movements made during the reading task are summarised in a Reading Report. Figure 6.2 shows an example of a plot of the trace produced by the Visagraph. Traces for both right (red) and left (blue) eye are shown. The right tracing of each pair are the original data and the left of each pair are the computed traces from which the measures in the Reading Report are derived.
Figure 6.2 Graph of original tracing for left eye (red) and right eye (blue) from which Visagraph measures are derived.

Recordings where the comprehension score was less than 70% should be discarded, however, all subjects scored greater than 70% correct on the multiple choice comprehension test. The comprehension test was administered immediately after the reading was complete. Ten questions with “yes” or “no” optional responses were read aloud to the subject. The subject’s responses were recorded by the examiner.
Outcome measures used for analysis were the number of fixations per 100 words, number of regressions per 100 words, span of recognition, average duration of fixations and reading rates. Average span of recognition effectively refers to the amount of print that is perceived and processed with each fixation. The span of recognition was specified in units of “words” and was calculated by dividing the number of fixations into the number of words in the specified paragraph. Fixation duration refers to the length of time that the eye pauses or remains fixated on a word. Reading rate refers to the number of words read per unit time and was specified in words per minute. For the numbers task the measures reported included: fixations per 100 numbers, regressions per 100 numbers, average duration of fixation and reading rate both with and without re-reads (numbers per minute). As the data obtained for each eye separately differed by less than five percent, findings for the right and left eye were averaged for analysis of Visagraph outcomes for both the reading and number naming tasks.

From the Visagraph recordings a number of measures of eye movements made during the reading task are summarised in a Reading Report (An example is shown in Figure 6.3).
Figure 6.3: Reporting report generated by Visagraph. Results highlighted in red are considered clinically poor performance for age or grade.

### 6.8.3 Statistical Analysis

Pearson’s correlation co-efficients ($r$) were calculated to test for associations between DEM measures and the eye movement parameters derived from the Visagraph reports; to account for multiple comparisons, a significance level of 0.01 was used (Curtin and Schulz 1998).
6.9 Results

The mean, standard deviation and range of DEM test outcomes and Visagraph outcome measures of number of fixations, number of regressions, duration of fixation, span of recognition and reading rates for both silent reading for comprehension and naming aloud numbers are presented in Table 6.6.

Table 6.6: DEM and Visagraph outcome measures in control children (n=59)

<table>
<thead>
<tr>
<th>Test (DEM)</th>
<th>Vertical adjusted time (seconds)</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developmental Eye Movement Test</td>
<td>40.4</td>
<td>7.0</td>
<td>29</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Horizontal adjusted time (seconds)</td>
<td>51.2</td>
<td>11.1</td>
<td>30</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Number of Errors</td>
<td>1.3</td>
<td>2.9</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Ratio Horizontal Time/Vertical Time</td>
<td>1.26</td>
<td>0.17</td>
<td>1.0</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Visagraph Recording during silent reading for comprehension</td>
<td>Average number of Fixations per 100 words</td>
<td>168</td>
<td>37.3</td>
<td>101.5</td>
<td>257</td>
</tr>
<tr>
<td>Visagraph Recording while naming numbers aloud</td>
<td>Average number of Regressions per 100 words</td>
<td>29</td>
<td>14</td>
<td>5</td>
<td>74</td>
</tr>
<tr>
<td>Average span of recognition</td>
<td>0.62</td>
<td>0.14</td>
<td>0.39</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>Average duration of fixation (seconds)</td>
<td>0.29</td>
<td>0.05</td>
<td>0.22</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Average reading rate (words per minute)</td>
<td>130</td>
<td>34</td>
<td>70</td>
<td>231</td>
<td></td>
</tr>
</tbody>
</table>

There were a number of significant correlations between some of the DEM and Visagraph outcomes measured in this study (p<0.01) as can be seen in Table 6.7.
Table 6.7: Pearson correlation co-efficients calculated between DEM and Visagraph findings. **Bold indicates statistically significant correlation (p<0.01)

<table>
<thead>
<tr>
<th>DEM Test</th>
<th>Visagraph Silent reading for comprehension</th>
<th>Visagraph Oral digit reading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number Fixations</td>
<td>Number Regression</td>
</tr>
<tr>
<td>Vertical Adjusted Time</td>
<td>.277</td>
<td>.301</td>
</tr>
<tr>
<td>Horizontal Adjusted Time</td>
<td>.407**</td>
<td>.263*</td>
</tr>
<tr>
<td>Number of Errors</td>
<td>-.042</td>
<td>-.087</td>
</tr>
<tr>
<td>Ratio (Vertical Time / Horz Time)</td>
<td>.317</td>
<td>.048</td>
</tr>
</tbody>
</table>

Children with slower reading rates measured with the Visagraph tended to have slower DEM Horizontal Times ($r=-0.547$) and slower DEM Vertical Times ($r=-0.414$). Similarly, children with a slower number naming rate tended to have slower DEM Horizontal Times ($r=-0.716$) and slower DEM Vertical Times ($r=-0.665$).

Figure 6.4 shows the bivariate correlation between Visagraph silent reading rate and DEM Horizontal Time; approximately thirty percent of the variation in reading rate could be predicted from the DEM Horizontal Time.

Stronger relationships were seen between DEM measures and Visagraph parameters recorded during number naming (a task similar to DEM) than those recorded during the silent reading for comprehension task. Figure 6.5 shows the variation in numbers naming rate with DEM Horizontal Time, where the Horizontal Time predicted approximately half of the variance seen in numbers naming per minute rate.
Figure 6.4: Variation in Visagraph Reading Rate with DEM Horizontal Time

Figure 6.5: Variation in Visagraph Numbers Reading Rate with DEM Horizontal Time
The number of errors recorded during the DEM test was not significantly associated with any of the measures of reading fluency recorded by Visagraph. Children with a higher DEM Ratio had slower reading rates recorded during reading for comprehension ($r = 0.368$); however, as shown in Figure 6.6, only 13 percent of the variation in Visagraph reading rate could be predicted from the DEM Ratio outcome.

![Figure 6.6: Variation in Visagraph Reading Rate with DEM Ratio](image)

6.10 Discussion

The DEM is a clinical measure commonly used by optometrists to assess saccadic eye movements and is recommended for use in the evaluation of children for learning-related vision problems. However, the relationship between the outcome measures of the DEM and infra-red recorded eye movements during reading for
comprehension has not previously been reported in children. The DEM outcome measure of Horizontal adjusted time, the time taken to name aloud numbers irregularly spaced in a horizontal array that mimics the reading task, showed the strongest associations with Visagraph outcome measures. Children with a longer DEM Horizontal time tended to have an increased number of fixations, reduced span of recognition, increased duration of fixation and ultimately slower reading rate as measured by the Visagraph during reading for comprehension. As would be expected, the strength of the relationship between the DEM and Visagraph recorded measures was even greater when the task was naming numbers, a task similar to that used in the DEM test.

The number of errors made during the DEM test, which mainly resulted from skipping a row of numbers on the Horizontal task, did not significantly correlate with infra-red recording of reading rates. Recording of the number and type of errors is important in the DEM so that both the Vertical time and Horizontal time can be adjusted to account for the number of digits actually named by the child. That is, if a child skips a line of digits in the horizontal test and therefore calls out five fewer digits than required the Horizontal time will be lower than the test design expects. One second is added to the recorded time for each digit skipped; similarly one second is deducted for each digit called twice. The DEM examiner’s booklet advises that Error scores are not taken into account in their clinical response categories and that clinicians should consider Error scores independently. Similarly, our data suggests that Error scores alone are not useful for the identification of children with lower recorded reading rates.
Clinically, a high DEM Ratio score (proportionally greater time to name numbers in the horizontal array relative to the vertical) is considered to indicate an ocular motor deficiency. High Ratio scores suggest greater difficulty in number calling when horizontal eye movements are required than the baseline number calling performance recorded during the vertical task. Poor ocular motor control has been suggested to contribute to poor reading fluency, however, in our data only thirteen percent of the variation in reading rate when reading for comprehension could be accounted for by the DEM ratio. Similarly, the DEM Ratio did not correlate with the number of fixations or regressions made during either the reading for comprehension or number reading tasks. These findings are in agreement with those reported by Lack (2005) in his comparison of the DEM with the Visagraph Numbers test and in Richman and Garzia’s (1987) study of validity of the DEM, where the test authors determined the correlation between DEM measures and scores on the reading subtest of the Wide Range Achievement Test (WRAT) in 58 children (mean age 8.9 years). In accord with our findings, reading scores were more highly correlated with DEM Horizontal time ($r=-0.78$) than with DEM Ratio ($r=-0.55$) (Richman and Garzia 1987).

The associations between DEM outcomes measures and the objective recordings obtained from the Visagraph, particularly those between horizontal time and reading rate, where thirty percent of the variance in recorded reading rate was associated with the DEM Horizontal time (Figure 6.4), suggest that the timed outcomes of the DEM may be useful clinically for the identification of children who have slower reading rates. The data suggest that it is the Horizontal adjusted time, rather than the Ratio, that is the most useful measure. The DEM is recommended in optometric clinical guidelines for the assessment of ocular motor efficiency in children being evaluated for learning-related vision problems (Garzia et al. 2006), however, how the DEM
outcomes relate to learning has not been fully established. Our data supports the clinical use of the DEM for the identification of children who may have slower reading rates, however, the relationship between reading rate and learning or between DEM outcomes and learning have not been fully established.

The Visagraph provides highly detailed quantification of the eye movement pattern during reading tasks. Its clinical use in optometric practice is, however, limited by the relatively high equipment costs, significantly longer time required for testing and relatively high degree of technical knowledge required to obtain valid recordings. Future studies that address the technical shortcomings of the Visagraph to provide reliable measures through the habitual correction of amblyopic children would provide useful information regarding objectively measured patterns of eye movements made by amblyopic children during reading tasks.
Chapter 7 RESULTS
ACADEMIC SCORES

Relationship between fine motor skills and academic scores in children.

7.1 Abstract

Aim: In order to investigate the functional implications of fine motor skill proficiency, the relationships between measures of fine motor skills and educational outcomes were explored in children with normal vision.

Methods: Participants with normal vision (n=57; age = 9.7 ± 0.6 years) recruited from elementary (primary) school grades 4 and 5, were assessed on a battery of vision tests including Bailey-Lovie logMAR VA and Randot Preschool Stereoacuity test. Fine motor skills were assessed using Visual Motor Control and Upper Limb Speed and Dexterity subtests of the Brunicks-Oseretsky Test of Motor Proficiency. Results from standardised tests of literacy and numeracy were obtained from school records and, for a subset of children, from independent State-wide testing (n=29). The relationships between educational outcomes and vision and fine motor skills were explored with bivariate correlation analyses.

Results: In the younger cohort (grade 4; n=29; age 9.3 ± 0.4 years), children with better Upper Limb Speed and Dexterity scores were likely to have higher mathematics scores ($r= 0.472$), however, none of the educational test results were significantly correlated with Visual Motor Control scores. In the grade 5 cohort
(n=28; age 10.2 ± 0.3 years) children with higher Upper Limb Speed and Dexterity scores tended to have higher education scores in both spelling ($r= 0.471$) and reading ($r= 0.371$) and those with higher Visual Motor Control scores tended to have higher spelling scores ($r= 0.354$).

**Conclusions:** Proficiency on clinical measures of fine motor skills was associated with better outcomes on standardised measures of educational performance, particularly in children in grade 5. Educational performance was most highly correlated with outcome measures that reflect speed and accuracy.
7.2 Introduction

Education, occupation and employment are recognised as key outcomes across a life course and have been evaluated at a population level in the investigation of the functional impact of amblyopia (Rahi et al. 2006). We reported in Chapter 4 that amblyopic children performed worse than age-matched controls on nine of sixteen fine motor skills sub-items and for the overall age-standardised scores for both visual motor control and upper limb speed and dexterity items.

Poor fine motor skills have been implicated in poor academic performance due to the need for more time to copy material or complete work, which in turn can negatively influence self-esteem (McHale and Cermak 1992). Fine motor skills are believed to influence the quality and quantity of the child’s learning and achievement in the classroom and the development of the child’s self-esteem and motivation (McHale and Cermak 1992). The types of tasks that involve fine motor skills in the classroom include writing, drawing, using an eraser, ruling lines, steadying paper, taking books from the desk, turning pages, using scissors and undertaking craft activities. There is variation in the amount of time spent on fine motor activities in a classroom, reflective of teaching styles rather than variation in grade level; that is, in some classrooms the primary learning modality is fine motor activity, whereas in other classrooms group discussion or oral instruction predominates (McHale and Cermak 1992).

In the preceding chapters, the effect of amblyopia on a range of motor skills, as well as self-esteem, was described, however, the question of relevance to a child’s quality of life remains. The children with amblyopia had worse performance than the age-matched control children on a range of standardised, age-appropriate tasks designed
to assess the motor skills needed in practical, everyday tasks. While the impact of amblyopia was greatest on manual dexterity tasks that required speed and accuracy, visual motor control scores were also reduced in the amblyopic group. As children in elementary (primary) school are reported to spend thirty to sixty percent of their day performing hand writing and other fine motor tasks (McHale and Cermak 1992), we sought to explore the relationships between fine motor skills scores and standardised measures of educational achievement.

In this chapter we determined the relationship between outcome measures on fine motor skills tasks and scores on standardised tests of educational attainment in children with normal vision. This allowed us to indirectly consider the implications of the deficits found in these skills in amblyopic children. This indirect approach to interpreting the educational implication of the decrements in fine motor skills in amblyopic children was taken because, while it was relatively easy to gain approval from the relevant school authority to obtain the educational outcomes of the control children who attended Bulimba State School, this was not the case for the amblyopic children who attended different schools and school districts across South East Queensland.

In this chapter we explored the relationships between outcome scores of the Brunicks-Oseretsky Test of Motor Proficiency (BOTMP) and results of standardised tests of mathematics, spelling and reading in children with normal vision. Understanding the relationships between fine motor skills proficiency and educational outcomes may provide insight into the implications of the decrements in fine motor skills found in children with amblyopia.
7.3 Methods

7.3.1 Participants

The children included in this component of the study (n=57; age = 9.7 ± 0.6 years) were recruited from grades 4 and 5 of a local primary (elementary) school (Bulimba State School) (BSS) via a letter sent home to parents outlining the purpose of the study; 60% of invited students were granted parental consent to participate. These children participated as part of the group of children with normal vision from which age-matched control groups were drawn for the previously reported investigations.

Subjects completed tests of visual acuity and stereopsis, fine motor skills and eye movements, and a self-esteem questionnaire as described in sections 3.5 to 3.8 of Chapter 3. Complete assessment of vision, fine motor skills, perceived self esteem and DEM took about 45 minutes per subject and was completed within one test session by all subjects.

Standardised measures of educational achievement were obtained for the control children from Bulimba State School with approval granted by Education Queensland, the Department responsible for state schools in Queensland, and permission of the school principal.

7.3.2 Assessment of Educational achievement

Two sets of standardised educational outcomes were made available by the school with parental consent. Firstly, educational data on standardised measures of literacy and numeracy measured internally by the school at the start of the school year (February 2005) were collected on 57 of the 59 BSS children who were in grade 4 and 5 who participated as control subjects in the previously reported investigations.
(two students were absent from school on the day of testing). Mathematics, reading and spelling were tested with standardised assessment tools by the usual classroom teacher in class time at the beginning of the school year (February 2005).

Mathematics was assessed with the Progressive Achievement Test in Mathematics Revised (PATMaths Revised) (Australian Council for Educational Research 2005), spelling was assessed using the Single Word Spelling Test (SWST) (Sacre and Masterson 2001) and reading was assessed with the Reading Progress Test (RPT) (Vincent et al. 1997).

The PATMaths Revised tests are used in Australian schools to provide information to teachers about the level of achievement attained by their students in the skills and understanding of mathematics. There are six tests which cover grade year levels from 4 to 9 in Queensland and require 45 minutes testing time. Raw scores on a test can be converted to a norm-referenced percentile rank using 1997 norms.

Preparation of the tests involved extensive review and revision to confirm high reliability and validity over a large cohort of children (Australian Council for Educational Research 2005).

The Single Word Spelling Test (SWST) is a series of tests designed to assess the spelling attainment of 5 to 14 year olds. The tests are intended for group administration and take approximately 30 minutes each to administer. Test D was administered to grade 4 students and Test E to grade 5 students. The SWST series was standardised in June 2000 using a sample of schools in the UK. High measures of reliability, repeatability and content validity were reported (Sacre and Masterson 2001).
The Reading Progress Tests are a series of seven tests for children aged 5 to 11 years. Each test has cross-sectional normal values which give standardised scores and reading ages, as well as ability scores and has high repeatability and validity. The tests are made up of three main types of comprehension question: (1) identifying the meaning of individual words, (2) selecting the right answer from a number of choices after reading a short story, non-fiction passage or poem, and (3) choosing, or supplying, missing words in a short story or non-fiction passage. The children work through the tests at their own pace after an initial explanation by the teacher, generally requiring 45-50 minutes to complete the tests (Vincent et al. 1997).

The second set of standardised test outcomes, results on the Queensland Studies Authority (QSA) Years 3, 5 and 7 tests in Aspects of Literacy and Numeracy, were also obtained from the school on a subset of 29 of the 57 children (those children in Grade 5 who sat the tests in August 2005), allowing validation of the achievement scores obtained by the classroom teachers. The QSA 3,5,7 tests, developed specifically for Queensland students and managed by the Queensland Studies Authority on behalf of the Queensland Government (Queensland Studies Authority 2004), are based on Queensland syllabuses and are designed to cover a wide range of children's abilities across the state. Results are reported as scaled scores. As for the internal tests of educational ability, the children completed the tests in their classroom with their regular classroom teacher, and answer booklets were marked by the Queensland Studies Authority external to the school. Aspects of Measurement and Data, Number, and Space are assessed in the Numeracy Test. Aspects of Reading and Viewing, Spelling, and Writing, are assessed in the Literacy Test.
7.3.3 Statistical Analysis

Pearson’s correlation co-efficients ($r$) were calculated to test the correlation between the two sets of educational achievement data and to explore the relationships between fine motor skills scores and measures of literacy and numeracy; to account for multiple comparisons, a significance level of 0.01 was used (Curtin and Schulz 1998).

7.4 Results

Table 7.1 shows that the children included in this study had on average -0.03 logMAR VA in their better eye and -0.02 logMAR VA in their poorer eye, with an average of 0.013 logMAR difference in acuity between eyes. The majority (56/57) of the group scored 18 out of 18 on the Randot stereopsis test, indicating at least 40 seconds of arc stereoacuity. One subject scored 16 out of 18, identifying all items up to 60 seconds of arc disparity and one out of three 40 seconds of arc items. Two subjects wore glasses to correct hyperopic refractive error.

Fine motor skills scores were derived from the sum of scores on eight tasks within both the visual motor control and upper limb speed and dexterity domains of the Brunicks-Oseretksy Test of Motor Proficiency. The item sum scores were converted to subtest age-standardised scaled scores of performance relative to published normative values (Bruininks 1978) as per section 3.6. An estimate of the level of clinical performance on an overall item was derived from the age-standardised scaled score by referring to published normative data (Bruininks 1978). The clinical performance was graded to be at, or above, average for age in all of the children for the Visual Motor Control domain and in 95% of the children for the Upper Limb Speed and Dexterity domain.
Table 7.1: Summary of vision and fine motor skills results in BSS group (n=59)

<table>
<thead>
<tr>
<th>Vision</th>
<th>Mean (Std. Deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA Best Eye (logMAR)</td>
<td>-0.029 (0.044)</td>
</tr>
<tr>
<td>VA Worst (logMAR)</td>
<td>-0.016 (0.044)</td>
</tr>
<tr>
<td>Intra-ocular VA Difference</td>
<td>0.013 (0.019)</td>
</tr>
<tr>
<td>Stereopsis (number correct out of 18)</td>
<td>17.95 (0.294)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fine Motor Skills</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Motor Control</td>
<td></td>
</tr>
<tr>
<td>Sum of sub-items</td>
<td>22.7 (1.3)</td>
</tr>
<tr>
<td>Standard Score</td>
<td>20.6 (2.5)</td>
</tr>
<tr>
<td>Upper Limb Speed and Dexterity</td>
<td></td>
</tr>
<tr>
<td>Sum of sub-items</td>
<td>45.6 (4.3)</td>
</tr>
<tr>
<td>Standard Score</td>
<td>18.3 (3.7)</td>
</tr>
</tbody>
</table>

7.4.1 Validation of Internal BSS tests with External QSA standardised tests

Outcome scores on the QSA state wide standardised tests were highly associated with scores achieved on internal BSS tests. Table 7.2 presents the Pearson correlation coefficients between the BSS results and the QSA results (n=29).

Table 7.2: Correlation analysis between BSS measures and QSA measures of mathematics, reading, spelling N=29.

<table>
<thead>
<tr>
<th>QSA standardised test results – Grade 5 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numeracy</td>
</tr>
<tr>
<td>Literacy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BSS Internal tests</th>
<th>NUMBER</th>
<th>NUMERACY</th>
<th>MEASUREMENT AND DATA</th>
<th>SPACE</th>
<th>READING AND VIEWING</th>
<th>WRITING</th>
<th>SPELLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics Standard Score</td>
<td>.655**</td>
<td>.645**</td>
<td>.393*</td>
<td>.552**</td>
<td>.685**</td>
<td>.106</td>
<td>.272</td>
</tr>
<tr>
<td>Spelling Standard Score</td>
<td>.380</td>
<td>.487*</td>
<td>.312</td>
<td>.581</td>
<td>.652**</td>
<td>.099</td>
<td>.763**</td>
</tr>
<tr>
<td>Reading Standard Score</td>
<td>.402*</td>
<td>.563*</td>
<td>.402*</td>
<td>.642**</td>
<td>.801**</td>
<td>.359</td>
<td>.557**</td>
</tr>
</tbody>
</table>
The strongest correlations were noted between those components of educational ability that tested similar educational tasks across the two tests; that is, the BSS Reading score and the QSA Reading and Viewing score ($r=0.801$), BSS spelling score and QSA Spelling ($r=0.763$) and BSS Math score and QSA Number ($r=0.655$).

The finding of a strong association between the two educational measures, even though the internal tests were taken at the start of the school year while the QSA tests were taken more than mid-way through the school year, suggests that the relationship between the two approaches is likely to be robust, given that some children may have made relative gains during this time. The strength of the association between the two measures provides support for the use of the internal school tests (BSS) as a measure of educational outcomes. As the BSS educational scores were available for the larger cohort of fifty seven children, they were used as the measure of educational outcome for the subsequent analyses.

### 7.4.2 Vision and BSS educational outcomes

The BSS Mathematics, Reading and Spelling outcome scores were not associated with measures of vision (VA in either eye, VA difference or stereoacuity). Table 7.3 presents Pearson correlation coefficients calculated between the vision and education measures.

The outcome spelling score was, however, significantly related to age ($r = -0.400$). To account for confounding influence of age in subsequent analysis, the tests for correlation between motor skills and educational outcome were conducted separately for the grade 4 and grade 5 cohorts.
Table 7.3: Relationship between age, vision and educational scores
**  Correlation is significant at the 0.01 level.

<table>
<thead>
<tr>
<th></th>
<th>MATH STANDARD SCORE</th>
<th>SPELLING STANDARD SCORE</th>
<th>READING STANDARD SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (decimal)</td>
<td>-.139</td>
<td><strong>-.400</strong></td>
<td>-.228</td>
</tr>
<tr>
<td>VA RE (logMAR)</td>
<td>-.212</td>
<td>-.095</td>
<td>-.253</td>
</tr>
<tr>
<td>VA LE (logMAR)</td>
<td>-.173</td>
<td>-.086</td>
<td>-.147</td>
</tr>
<tr>
<td>Intra-ocular VA Difference</td>
<td>-.118</td>
<td>-.038</td>
<td>-.251</td>
</tr>
<tr>
<td>Stereoacuity (number correct out of 18)</td>
<td>.102</td>
<td>.070</td>
<td>.080</td>
</tr>
</tbody>
</table>

7.4.3 Motor Skills and educational outcomes

Grade 4 students

Table 7.4 presents Pearson correlation coefficients calculated between the fine motor and DEM outcomes and educational scores in the grade 4 cohort (n=29; age 9.3 ± 0.4 years). The children with better ULSD scores achieved higher mathematics scores ($r = 0.472$), however, the VMC scores were not correlated with any of the educational test results.

Table 7.4: Grade 4 cohort – Relationship between Motor skills and Educational Achievement Scores. ** Correlation is significant at the 0.01 level.

<table>
<thead>
<tr>
<th>BOTMP Fine Motor Skills</th>
<th>Mathematics Standard Score</th>
<th>Spelling Standard Score</th>
<th>Reading Standard Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual-Motor Control Standard Score</td>
<td>.074</td>
<td>.156</td>
<td>-.103</td>
</tr>
<tr>
<td>Upper Limb Speed and Dexterity Standard Score</td>
<td><strong>.472</strong></td>
<td>.175</td>
<td>.302</td>
</tr>
</tbody>
</table>
Figure 7.1 is a plot of the bivariate distribution of mathematics score and USLD standard score. While the spread in the data is apparent in the graph, a positive correlation is seen, with a tendency for higher mathematics scores in those children with higher ULSD scores. Approximately 22 percent of the variation in mathematics score can be accounted for by ULSD score.

![Figure 7.1: Bivariate distribution of Mathematics standard score and ULSD standard score in Grade 4 cohort](image)

**Figure 7.1: Bivariate distribution of Mathematics standard score and ULSD standard score in Grade 4 cohort**

**Grade 5 students**

Table 7.5 presents Pearson correlation coefficients calculated between the fine motor skills and DEM outcomes and educational scores in the grade 5 cohort (n=28; age 10.2 ± 0.3 years). Significant correlations (p<0.01) were found between ULSD and both Spelling (r= 0.471) and Reading scores (r= 0.371) and between VMC and Spelling (r= 0.354). The fine motor skills scores accounted for 12 to 22 percent of the variation in these educational scores.
Table 7.5: Grade 5 cohort – Relationship between Motor skills and Educational Achievement Scores. ** Correlation is significant at the 0.01 level.

<table>
<thead>
<tr>
<th>BOTMP Fine Motor Skills</th>
<th>Mathematics Standard Score</th>
<th>Spelling Standard Score</th>
<th>Reading Standard Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual-Motor Control Standard Score</td>
<td>.172</td>
<td>.354**</td>
<td>-.031</td>
</tr>
<tr>
<td>Upper Limb Speed and Dexterity Standard Score</td>
<td>.224</td>
<td>.471**</td>
<td>.371**</td>
</tr>
</tbody>
</table>

Figure 7.2 plots the bivariate distribution of spelling score and USLD standard score. Again, while the spread of the data is apparent in the graph, a positive correlation is seen, with a tendency of higher spelling scores in those children with higher ULSD scores. Approximately 22 percent of the variation in spelling score can be accounted for by ULSD score.
7.5 Discussion

Proficiency on clinical measures of fine motor skills was associated with better outcomes on standardised measures of educational performance, particularly in children in grade 5. Educational performance was most highly correlated with fine motor skills measures that reflect speed and accuracy. Significant associations were found between measures of fine motor skill proficiency and educational achievement scores, with performance on the upper limb speed and dexterity (ULSD) item (timed manual dexterity tasks) showing the strongest association with education outcomes. The fine motor skills scores accounted for 12 to 22 percent of the variation in these educational scores.

This sample of children with normal vision had few examples of below average clinical performance on the tests of fine motor skill. The clinical performance was graded to be at, or above average for age for all of the children in the VMC domain and for ninety-five percent of the children in the ULSD domain. Nevertheless, there were some reasonably strong relationships between ULSD and mathematics scores in the grade 4 group and between ULSD and spelling and reading in the grade 5 cohort.

The finding that VMC had relatively little association with educational outcomes was somewhat surprising as this was the item that involved more pencil-to-paper activities. However, unlike the ULSD tasks, the scoring of the VMC does not reflect the time required to complete the task. The timing element may be an important factor, in that children slow to complete a task may not finish all the work required in a test situation and thus achieve a lower score.

While our results are not evidence for a causative relationship between fine motor skills and educational outcomes, they do suggest a tendency for children with lower
proficiency scores on standardised tests of fine motor skills to achieve lower scores on education tests than those children with higher scores. Poor fine motor skills have been suggested to contribute to poor academic performance, due to need for more time to copy material or complete work (McHale and Cermak 1992). Another theory would be that whatever factor is influencing proficiency for timed manual dexterity tasks may similarly influence learning in other domains which would be reflected in the education scores.

This pilot study of a small group of children with normal vision provides an indirect measure of how proficiency in fine motor skills might influence educational outcomes of children with a history of amblyopia. This approach was taken because standardised measures of educational achievement were readily obtainable for the control children from Bulimba State School, with permission granted by Education Queensland and the school principal. The sample of amblyopic children who participated in the study reported in the previous chapters were drawn from the private practice of a paediatric ophthalmologist and attended either state schools, independent schools or catholic schools from a broad geographic region of south-east Queensland. Access to educational data of the amblyopic children would therefore have required additional approval from Independent Schools Queensland and from Queensland Catholic Education Commission as well as permission from each amblyopic child’s school principal which was outside the scope of the present study.

We sought to explore the implications of fine motor skill proficiency by determining the relationships between fine motor skills scores and educational measures. Our results suggest that deficits in fine motor proficiency may be expected to have negative educational consequences for amblyopic children, although this question
requires a prospective study to further clarify the relationship. Future studies are planned to more directly measure the impact of amblyopia on educational outcomes, an important quality of life measure in children; such studies would involve gaining access to standardised educational measures in children with amblyopia.
Chapter 8  GENERAL DISCUSSION

8.1 Introduction

A Health Technology Assessment report published in 1997 concluded that the evidence for the value of childhood vision screening for amblyopia or its aetiological conditions did not support any expansion of current screening programmes; indeed, it recommended that the National Screening Committee should consider halting the existing programme (Snowden and Stewart-Brown 1997a). The authors specifically highlighted the lack of evidence on the long-term impact of amblyopia, the extent of disability that amblyopia and strabismus have and their impact on quality of life. The review conclusions were much debated in the literature, with criticism that its recommendations were not objective and that a lack of adequate data regarding the effectiveness of amblyopia treatment might result in a premature disassembly of pre-school vision screening programs (Rahi and Dezateux 1997; Stewart-Brown and Snowden 1998; Williams et al. 1998).

The study presented in this thesis sought to address the identified deficit in the literature by determining the impact of amblyopia on functional outcomes, including motor and psychosocial skills in children, and hence considered the extent of possible disability that accompanies amblyopia in the paediatric population. Specifically, the performance of amblyopic children was measured and compared with that of age-matched controls on standardised clinical tests of fine motor skills and saccadic eye movements. The relative influence of the cause and extent of amblyopia on outcome scores was investigated to determine which factors were most likely to contribute to motor skills performance. The psychosocial impact of
amblyopia and its treatment was explored by comparing self-esteem scores between amblyopic and control children, using a clinical measure of self-perception that tested across a number of domains of importance to children’s lives as well as global self-worth.

Performance of amblyopic children on standardised developmental tests of fine motor skills was poorer than that of controls, particularly in those amblyopes with a history of strabismus. The deficits in fine motor skills scores were greatest on manual dexterity tasks involving speed and accuracy. However, there were no significant differences in outcome scores between amblyopic children and controls on the Developmental Eye Movement test (DEM), an indirect measure of saccades.

We found that amblyopia can negatively impact on the self-esteem domain related to social interaction in children aged from approximately eight years of age. However, self-esteem scores in global self-worth and other domains considered of importance in children’s lives, including athletic ability and physical appearance, were not affected by amblyopia. Self-esteem scores in younger amblyopic children (aged five to eight years) were not different to those of controls.

We explored the relationship between fine motor skills scores and standardised test scores in reading, spelling and mathematics in a subgroup of control children. Our analysis found that outcomes on standardised measures of educational performance are associated with clinical measures of fine motor skills. Scores on timed manual dexterity tasks had the strongest association with educational performance.

Collectively, the results of this study indicate that, in addition to the reduction in visual acuity and binocular function that define the condition, amblyopes demonstrate functional impairment in those childhood development skills that
underlie proficiency in everyday activities. The study provides support for strategies aimed at early identification and remediation of amblyopia and the co-morbidities that may arise from abnormal visual neurodevelopment.

The specific research questions of the study were:

(1) Do children with amblyopia have poorer fine motor skills than age-matched control children? Can a decrement in fine motor skills score be predicted from vision characteristics?

Amblyopic children performed worse than age-matched control children on nine of sixteen fine motor skills tasks. The deficits in motor performance were greatest on manual dexterity tasks requiring speed and accuracy. Importantly, comparison of the distributions of overall scores indicated that the consistent decrement in the amblyopic group was not a consequence of a few individuals showing large deficits, but rather a global reduction in performance. When the fine motor skill performance scores were compared to published normative data, a range of motor skills ability was seen in both groups, however, a larger proportion of the amblyopic group had scores which fell in the “below average” performance range and a smaller proportion performed in the “above average” range for both fine motor skills domains. The difference between amblyopic and control groups was greater in the battery of tasks that required speed and dexterity (ULSD) rather than tasks that required accuracy and control (VMC). Both amblyopia aetiology and level of binocular vision were related to fine motor skills scores. However, when the inter-relationships between various factors was taken into account, performance on the fine motor skills tasks was associated with a history of strabismus, but not with level of stereopsis or inter-
ocular difference in VA. We concluded that fine motor skills were reduced in our sample of amblyopic children, particularly those with strabismus, compared to controls. The deficits in motor performance were greatest on manual dexterity tasks requiring speed and accuracy.

(2) Do children with amblyopia have poorer self-esteem than age-matched children with normal vision development? Can self-esteem scores be predicted from condition or treatment information?

Self-perception of social acceptance was lower in amblyopic children aged from grade three school level (approximately eight years of age) compared with age-matched controls. Lower social acceptance scores were found for subjects whose amblyopia was caused by acquired strabismus, all of whom wore glasses and two-thirds of whom had been treated with patching, and for those with deprivation amblyopia who had the greatest amblyopic VA deficit. In other areas related to self-esteem, including scholastic competence, physical appearance, athletic competence, behavioural conduct and global self worth, amblyopic children had scores similar to those of control children. A reduction in social-acceptance scores was associated with a history of patching treatment but not with a history of strabismus or spectacle wear.

Self-esteem scores of amblyopic children from preschool to grade two school level (aged from five to eight years) were similar to those of age-matched children with normal visual development, including the domain that related to peer-acceptance. Compared with older children, children less than eight years are thought to be less influenced by the responses of their peers and may therefore be less conscious of
the stigma associated with wearing an eye patch during treatment. Our study
indicates that spectacle wear does not contribute to reduced social acceptance in
amblyopic children and emphasises the importance of exploring refractive
correction as the first step in treatment of amblyopia, with the hope that patching,
with its potential negative psychosocial effects, may be minimised or avoided
altogether.

(3) Do children with amblyopia have poorer outcomes on clinical measures of eye
movements than children with normal vision development? Can performance on
clinical tests of eye movements be predicted from measured vision
characteristics?

In our sample of amblyopic children, the outcomes measures on the DEM test were
equivalent to those of age-matched children with normal vision, indicating that the
ability of amblyopic children to quickly execute the saccades required to fixate,
identify and name single digits was not significantly different to that of their age-
matched peers. In addition, we found that the outcome measures of the DEM did not
significantly relate to VA in either eye, or to inter-ocular VA difference, levels of
stereoacuity, or magnitude of refractive correction.

The DEM test is an indirect measure of saccades and is commonly employed by
optometrists for the clinical assessment of oculomotor efficiency. The Visagraph III
Eye-Movement recording system uses goggles containing infrared sensors to capture
eye position during reading. We investigated the relationship between the outcome
measures of the DEM and objective recordings of eye movement characteristics
during reading for comprehension in children with normal vision. We found that those children with slow DEM outcomes (particularly Horizontal time) tended to have slower words per minute reading rate calculated from Visagraph recording. Our findings support the clinical use of the timed outcomes of the DEM to aid identification of children who are likely to have slower reading rate. However, the relationships between DEM outcomes, Visagraph recorded eye movement characteristics and measures of reading or learning are yet to be established.

(4) How do measures of fine motor skill relate to measures of educational performance in children with normal visual development?

To investigate the functional implications of fine motor skill performance, the relationships between measures of fine motor skills and educational outcomes were explored in children with normal vision. The amblyopic children attended a variety of schools and districts throughout South-East Queensland which made access to their standardised test results logistically outside the scope of this study. Proficiency on clinical measures of fine motor skill was associated with better outcomes on standardised measures of educational performance for the control children. Educational performance was most highly correlated with those fine motor skill measures that reflect speed and accuracy.

While our results are not evidence for a causative relationship between fine motor skills and educational outcomes, they do suggest a tendency for children with lower scores on standardised tests of fine motor skills to achieve lower scores on education tests than those children with higher scores. Alternatively, a factor that influences
proficiency on timed manual dexterity tasks may similarly influence learning in other domains which would be reflected in the education scores.

8.2 Implications for theory

It is important to consider the findings of this study in the context of current knowledge of the neurophysiological changes underlying amblyopia. Abnormal visual experience early in life interferes with the neuro-development of the visual pathway and results in loss of visual function. Neurophysiological evidence indicates dysfunction in amblyopes in both primary and secondary visual areas, regions within the parieto-occipital cortex and the ventral temporal cortex (Anderson and Swettenham 2006). The most profound and consistent changes in the visual pathways are at the striate cortex (Ciuffreda et al. 1991), however, amblyopia is also believed to impact on the extra-striate pathways, predominantly those which process motion information (Simmers et al. 2003), although the extent of these changes is less well known.

We hypothesized that the aetiology of amblyopia would influence performance on fine motor skills tasks, given the differences in results of electrophysiological studies of neurophysiology and psychophysical studies of visual function of amblyopes with a history of blur (anisometropia and form deprivation) and those with a history of ocular misalignment (strabismus). Indeed, in addition to significant differences in fine motor skill scores between amblyopic and control children, we found significant differences in scores between amblyopia subgroups, where not all of the amblyopic groups displayed a deficit in fine motor skills. Our results suggest that the cause of amblyopia, rather than the extent of the clinical visual deficit, determines the impact of amblyopia on fine motor skill development. Our finding that strabismus has the
greatest negative influence on fine motor skills performance may indicate that neurological changes associated with strabismus have a detrimental influence on the development of hand-eye co-ordination skills.

McKee et al. (2003) suggest that individuals with amblyopia should be classified based on two distinct developmental anomalies that account for the differential pattern of vision losses in amblyopia found between aetiological groups. These are the developmental anomaly arising from blurred or obscured vision during early development, as is the case in anisometropic and deprivation amblyopia; and that resulting from disruption to the development of binocular vision in the central visual field, as occurs with strabismus (McKee et al. 2003). Our finding that strabismic amblyopes had poorer fine motor skills scores than those whose amblyopia resulted from blurred or obscured vision suggests that neurophysiological change beyond the primary visual cortex may be more profound in the developmental anomaly arising from ocular misalignment. Whether this neurological consequence is subsequent to the relative pattern of the visual losses described by McKee et al. (2003) or a co-existing consequence of the primary condition is not known.

Previous studies have attempted to correlate performance on fine motor skills with a deficit in VA or reduction in stereopsis (Rogers et al. 1982; Hrisos et al. 2006; Caputo et al. 2007; Grant et al. 2007; Mazyn et al. 2007). We determined the relative contributions of these to fine motor skill performance in a multiple regression analysis that took into account the inter-relationship between factors. This analysis indicated that it was the cause of amblyopia, rather than the extent of VA or stereoacuity loss, that correlated with fine motor skill performance. This implies that performance on this test of fine motor skills was not limited due to blur or loss of
depth perception making the task more difficult, but rather genuinely reflects poorer fine motor proficiency in those children whose amblyopia is a consequence of ocular misalignment.

Our investigation involved the evaluation of two domains of fine motor skills: VMC and ULSD. While the scores of the amblyopic children were poorer than those of control children in both domains, the greatest decrement in performance was in ULSD tasks, whose scores were based on the number of times the manual dexterity task was successfully completed within a set time frame. The amblyopic children may have adopted a compensatory strategy of slowing down their responses, in order to provide the opportunity for visual feedback during the task, allowing accurate completion of the drawing and cutting tasks, hence achieving better scores in this domain. However, during the timed ULSD tasks there was less opportunity for visual feedback to influence the outcome score and no opportunity for compensatory slowing of response times. This speed-accuracy trade-off was proposed by Grant et al. (2007) when quantifying the reaching and grasping behaviour of amblyopic subjects. Relative to controls, amblyopes showed a range of deficits in their approach to an object and when closing and applying grasp, including prolonged execution times and more errors (Grant et al. 2007). That is, on the timed manual dexterity tasks amblyopes may have slowed their motor response in order to accurately complete the tasks because they could not see the tasks clearly, or loss of stereoacuity limited judgement of position of the tasks. Their findings were suggested to be compatible with altered processing in amblyopia at both the primary visual cortex and beyond, although they reported no significant difference in the movement kinematics or error rates between strabismic and non-strabismic amblyopes. (Grant et al. 2007).
Our multiple regression analysis lends greater support to the hypothesis that amblyopia arising subsequent to strabismus influences the neural development of fine motor skill dexterity, rather than the residual loss of visual clarity and depth perception making the fine motor skills tasks more difficult to perform. Amblyopes have been reported to have deficits in visual processing of global-orientation and global-motion whose cortical locus is likely to be beyond the striate cortex, particularly affecting the dorsal extrastriate processing stream (Simmers et al. 2003; Simmers et al. 2005). Our finding is compatible with neurophysiological changes beyond the primary visual cortex, with the suggestion that this change may be more profound in strabismic amblyopia. Neurophysiological studies that further explore differences between amblyopic developmental groups in abnormal neurodevelopment beyond the striate cortex may provide further insight into the underlying mechanisms.

Our exploratory study in a small group of children with normal vision tested the relationships between fine motor skill scores and outcomes on standardised tests of reading, spelling and mathematics. While our results are not evidence for a causative relationship between fine motor skills and educational outcomes, they do suggest a tendency for children with lower proficiency scores on standardised tests of fine motor skills to achieve lower scores on education tests than those children with higher scores. Poor fine motor skills have been suggested to contribute to poor academic performance due to the need for more time to copy material or complete work (McHale and Cermak 1992). An alternative hypothesis is that whatever factor is influencing proficiency for timed manual dexterity tasks may similarly influence learning in other domains which are reflected in the education scores. Inclusion of
measures of educational outcomes in future studies of functional effects of amblyopia is warranted.

We hypothesised that amblyopic children would not perform as well as control children on a clinical test of saccadic eye movements. While we recognise that the DEM is an indirect measure of saccades, the task does require rapid eye movements to change fixation between numbers for accurate identification and naming of digits. Like the ULSD items of the fine motor skills test, the DEM outcomes are scored based upon the time taken to complete the tasks. However, unlike the fine motor skills test outcomes, the amblyopic children performed as well as age-matched controls on the DEM test and the outcome measures on the DEM were not associated with a history of strabismus, VA in either eye, level of binocular function or magnitude of refractive error.

Our results thus demonstrate that the saccadic eye movements and visual-verbalisation skills required to perform the DEM are not degraded by amblyopia to the same extent as visual-motor control and visually-directed manual dexterity required for the fine motor skills tasks. This indicates the involvement of different neural pathways that are not altered to the same extent by amblyopic neurodevelopment. Functional neuro-imaging studies in humans have contributed to the identification and localization of regions comprising a network involved in saccade generation (McDowell et al. 2008). At the sub-cortical level, this network includes the striatum, thalamus, and superior colliculus; cortically, the network includes primary visual cortex and extrastriate cortex, regions of posterior parietal cortex, and the frontal eye field and supplementary eye field in frontal cortex. Our findings may suggest that saccadic execution is a lower order neurological task than that of motor
planning and is not influenced to the same degree by the neurophysiological changes inherent in amblyopia.

Alternatively, the DEM may not have been a sensitive enough test of saccadic eye movements to reveal differences between amblyopes and controls. Further study of binocular eye movement characteristics in amblyopia is warranted, particularly those eye movements that may relate to the performance of functional tasks such as reading. Employment of direct measures of eye movements using oculomotor recording techniques may provide a more sensitive measure than the clinical test used in this study.

In our study of the impact of amblyopia on self-esteem we showed that children with a history of amblyopia who were at preschool to grade 2 school level had similar self-perception scores in the domains of cognitive competence, physical competence and peer acceptance to those of age-matched control children. However, older amblyopic children, from grade 3 school level and above, had lower scores on the social acceptance domain “feels accepted by peers” or “feels popular” than their age-matched peers. Our finding that children less than eight years of age are robust in their self-evaluation is consistent with current knowledge of the development of a child’s self-perception. Highly positive self-concept is believed to persist throughout the early childhood years, with typically very positive self-representations as the child continues to overestimate his or her own abilities (Harter 1999). It is only during middle to late childhood (from 8 to 11 years of age) that the child’s rating of themselves becomes increasing based on comparison with others, particularly their peers (Harter 1988; Harter 1999).
Our study provides further support for concerns raised by others that patching can have negative psychosocial consequences for children, particularly if the patching is conducted when the child is old enough to be aware of the differences between themselves and their peers, or when the child starts school when the potential for bullying arises (Koklanis and Georgievski 2007) (Williams and Harrad 2006).

8.3 Implications for public health policy

During the decade since the Snowden and Stewart-Brown (1997a) first questioned whether vision screening to detect amblyopia, refractive error and strabismus should continue, evidence supporting continued childhood vision screening has emerged. From a population perspective, studies have now described the association between amblyopia and lifetime risk of vision impairment (Rahi et al. 2002; van Leeuwen et al. 2007). Debate has continued regarding the benefits of community funded vision preschool screenings to detect the conditions that may cause amblyopia, with the cost-effectiveness of screening found to be dependant on the long-term utility effects of loss of vision in one eye (Carlton et al. 2008). The lifetime risk of bilateral vision impairment is much higher for amblyopes than for controls; being as high as eighteen percent for those with amblyopia compared with ten percent in non-amblyopes (van Leeuwen et al. 2007). While data for the natural history of untreated amblyopia are still scarce, randomised controlled treatment trials (Clarke et al. 2003), and reviews of patients who have not been compliant with treatment (Simons and Preslan 1999), indicate that amblyopia does not recover without intervention. Our study provides evidence that amblyopia results in poorer outcomes on tests of those skills required for proficiency in daily living tasks and which relate to childhood academic performance. A higher proportion of our amblyopic sample than our controls had
outcome scores that were clinically rated as being “below average”; seventeen percent of the amblyopic children had “below average” scores in ULSD compared with three percent of the control children.

The optimal time for visual screening has also been the subject of debate (Dutton and Cleary 2003). Preschool vision screening, at age 3 to 4 years, has been advocated rather than screening at school entry when children are generally 4 to 5 years of age. This is supported by findings that early screening for amblyopia risk factors lowers the later prevalence and severity of amblyopic deficits (Eibschitz-Tsimhoni et al. 2000; Williams et al. 2002). However, Clarke et al.’s finding that treatment efficacy is not reduced if treatment is deferred, suggests that screening and treatment is not critical at 4 years of age and could be delayed until during the first year of school (Clarke et al. 2003). In our study we demonstrated that amblyopic children from preschool to grade 2 school level had similar peer-acceptance scores to those of children with normal vision, however, differences were evident in older amblyopic children. Our findings thus suggest a psychosocial benefit if patching is completed before the age that children begin to make peer-comparisons in their formation of self-perception (that is before approximately eight years of age). Indeed, recent amblyopia treatment studies have found that part-time patching is effective in restoring VA and that the course of patching treatment need not extend beyond six months (Stewart et al. 2007). Collectively this evidence suggests that early screening for amblyopic risk factors, allowing completion of patching therapy before the start of formal schooling, may carry psychosocial benefits for the child by avoiding the negative attention of patching at school.
8.4 Implications for Clinical Practice

Fine motor skills are believed to underlie thirty to sixty percent of primary (elementary) school classroom activities, such as cutting and colouring, and especially writing tasks (McHale and Cermak 1992). Early evaluation and treatment of fine motor skills is recommended due to the negative effects of handwriting difficulties on a child’s academic performance and self-esteem (Ratzon et al. 2007). Visual-motor control problems may interfere with a child’s ability to acquire writing skills and fully participate in student activities (Ratzon et al. 2007), and performance on a visual analysis and visual motor integration task was found to relate to academic performance in 7, 8 and 9 year olds (Kulp 1999).

Deficits in fine motor skills in pre-school to primary (elementary) school aged amblyopic children were found in both VMC and ULSD domains. Clinicians should be made aware of the potential for reduced fine motor skills in children with strabismic amblyopia, so that they can prompt early referral for evaluation of these skills and early remediation if appropriate. Alternatively, changes to classroom activities may be appropriate for those disadvantaged by reduced skills, such as allowance of more time to complete tasks, or incorporation of programs to practice these skills to better proficiency, either during school or homework time. Planned studies of the educational outcomes of amblyopic children are needed to more directly determine how they relate to vision and fine motor skill deficits.

Clinicians are also faced with the challenge of designing treatment regimens that are effective in restoring vision with minimal psychosocial side-effects. Our study provides evidence that amblyopia can impact on social interactions, particularly in amblyopes with acquired strabismus, and suggests psychosocial benefits if patching
is minimised and limited to times of day when the child has less interaction with social peers. These findings regarding self-esteem are important given the evidence from recent treatment trials which have specifically investigated the improvement in amblyopia that can be achieved through spectacle correction alone. Importantly, our study indicates that spectacle wear does not contribute to reduced social acceptance in amblyopic children and emphasises the importance of exploring refractive correction as the first step in treating amblyopia, with the hope that patching with its potential negative psychosocial effects may be minimised or avoided altogether. Our finding that the peer-acceptance score of amblyopic children in preschool to grade 2 school level is similar to that of controls supports the suggestion that identification and treatment prior to the age when peer comparisons begin to emerge may be of psychosocial benefit to the child.

The DEM test is employed by optometrists to diagnose oculomotor dysfunction, with a high Ratio(Horizontal Time/Vertical Time) believed to be indicative of poor saccadic eye movement control. Given the endorsement of the DEM for ocular motor evaluation in the optometric assessment of learning-related vision problems in children (Scheiman and Rouse 2006), studies are needed that describe how its outcomes specifically relate to eye movements, particularly during reading. In our pilot study conducted in a sub-group of the control children we found a number of significant relationships between DEM outcome measures and the objective recordings obtained from the Visagraph. In particular, DEM Horizontal time accounted for thirty percent of the variance in words per minute reading rate calculated from Visagraph recording. This suggests that the timed outcomes of the DEM may be useful clinically for the identification of children who are likely to be slower readers. Our findings also suggest that the most useful DEM measure for identifying children with
a slower reading rate is Horizontal Time, rather than Ratio. While our findings support the clinical use of the DEM for the identification of children who may have slower reading rates, the relationship between Visagraph calculated reading rates, DEM outcomes and more extensive measures of reading or learning have not been fully explored.

8.5 Limitations and Further Research

The study presented in this thesis aimed to investigate the functional outcomes of amblyopia in children and to ascertain the impact of the condition and its treatment in the childhood population targeted by vision screening programs. Our findings demonstrate that amblyopia has a functional impact that goes beyond the monocular VA deficit and loss of binocular function that define the condition. We have shown that children with amblyopia perform more poorly on a range of standardised, age-appropriate tasks designed to assess the motor skills needed in practical, everyday tasks. This particularly applies to amblyopic children with strabismus, and the impact of amblyopia was greatest on manual dexterity tasks that require speed and accuracy. Importantly, our results represent the first time that the relative contribution of various vision characteristics on fine motor skills performance has been determined in a large sample of amblyopic subjects from a range of aetiologies.

However, as with any study there were some limitations to our experimental approach, often driven by practical considerations, and which form the basis of suggestions for future work and these are considered below.

As Nilsson (2007) suggested, evaluation of the benefits of screening and treating visual anomalies, should ideally include three groups: (1) normal controls, (2) untreated amblyopes and (3) amblyopes after successful treatment (Nilsson 2007).
While our study did not include an untreated amblyopic group, there was a range of VA in the amblyopic eye after treatment from 0.0 logMAR to 2.0 logMAR, an indicator of relative treatment success. Correlation analysis indicated that the fine motor skill deficit found in the amblyopic group was not related to amblyopic VA, which suggests that successful treatment does not necessarily restore normal motor function.

Future studies that examine changes in fine motor skill performance before and after treatment for strabismic versus anisometropic amblyopes, would allow determination of whether improvement in fine motor skills correlates with either improvements in stereoacuity or VA and whether differences exist between developmental anomaly groups. This type of study would need to control for the expected improvement in developmental skills with age, so tests would need to have established good quality age-matched normative data, or comparisons would need to be made with untreated controls that were longitudinally tested at the same time intervals.

Our study employed a clinical measure of stereoacuity, the Randot stereoacuity test. While this test has established reliability and is suitable for use in the children (Birch et al. 2008), it does not test to threshold levels of stereoacuity. This resulted in stereopsis scores that were not normally distributed, instead many subjects had stereoacuity equal to or better than the highest level tested (40 seconds of arc) and many could not pass the test at any level. Future studies that explore the relationship between task performance and stereoacuity should include stereoacuity measures that test to threshold.

We suggested that the reduction in performance of the amblyopic group was not a function of greater difficulty seeing the task, but rather reflected an effect of
amblyopia on neural pathways beyond the primary visual cortex. This hypothesis could be further explored by removing all visual cues for both the amblyopic and control groups in tests of motor performance, such as timed manual dexterity.

In our study of the impact of amblyopia in children, the performance on the DEM was compared between groups of amblyopic and age-matched control children. To gain a more detailed description of the eye movements made during reading we also attempted Visagraph infra-red recording whilst reading for comprehension in the amblyopic children. However, we found such recordings were unreliable when made through the spectacle correction worn by the majority of the amblyopic children. Future studies should address the technical shortcomings of the Visagraph, or use alternative objective recording techniques to gain reliable measures. This would provide useful information regarding the pattern of eye movements made by amblyopic children during reading tasks. Amblyopia is reported to affect accommodation and fixation stability, ocular measures that were not assessed in this study. Future studies that measure accommodation characteristics and fixation stability and how they relate to recorded eye movements may provide insight into the deficits in reading performance reported in amblyopes (Stifter, Burggasser et al. 2005).

We sought to explore the implications of fine motor skill proficiency by determining the relationships between fine motor skill scores and educational measures. An inference that may be drawn from our study is that deficits in fine motor proficiency may be expected to have negative educational consequences for amblyopic children. Future studies that have access to standardised educational measures in children with
amblyopia will allow a more direct measure of the impact of amblyopia on educational outcomes, an important quality of life measure in children.

In this study a single, unmasked examiner (the PhD candidate) tested and scored all subjects. While it is acknowledged that ideally the examiner should have been masked to participant grouping, this was not possible in this study as the candidate was responsible for recruitment of participants as well as conducting all testing. To monitor for bias a sub-sample of score sheets (n=20) were re-scored by an independent researcher masked to the participant group. Paired-samples t-tests indicated no significant difference in scoring between examiners on 15 of 16 subtests. Masking of the examiner to participant grouping would be desirable in future studies that examine functional skills in amblyopic children.

8.6 Summary

In addition to the visual deficits of reduced VA and stereoacuity that define amblyopia, we demonstrated that amblyopic children have reduced performance on standardised measures of fine motor skills involved in practical, everyday tasks. This particularly applies to amblyopic children with a history of strabismus, with the impact of amblyopia being greatest on manual dexterity tasks that require speed and accuracy. As well as differences between amblyopes and controls in mean scores, we found that relatively more amblyopic children had scores that were classified as “below average” and fewer amblyopic children scored “above average”.

Importantly, this is the first study to report the relative contribution of various vision characteristics to motor performance in a large sample of amblyopes, with amblyopia resulting from a range of causes.
The psychosocial impact of amblyopia was evident in our study of self-esteem. Self-perception of social acceptance was lower in amblyopic children in grade 3 or above compared with that of with age-matched controls, with lowest scores found in children whose amblyopia was caused by acquired strabismus. The self-perception scores of younger amblyopic children, including peer acceptance, were not different from those of controls.

We found no evidence of a deficit in ocular motor skills in our sample of amblyopic children, where the outcomes scores of the DEM, a clinical measure of eye movements, were similar between the amblyopes and controls. The outcome scores of the DEM were also found to be associated with reading rates measured using objective infrared recording of eye movements in children with normal vision.

In children with normal vision, those with higher fine motor skills scores (particularly in timed manual dexterity tasks) tended to have higher outcome scores on standardised education tests. While not evidence of a causative relationship between fine motor skills and academic achievement, the implied effect of fine motor skills deficits warrants further investigation.

In summary, this study provides evidence that, in addition to the reduced VA and binocular function that define the condition, amblyopes have functional impairments in childhood development skills that underlie proficiency in everyday activities. The study provides support for strategies aimed at early identification and treatment of amblyopia and the identification of co-existing deficits in the development of visually directed skills that may arise from abnormal visual neurodevelopment.
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