The effect of amblyopia on the Developmental Eye Movement test in children

ABSTRACT

AIM: To investigate the functional impact of amblyopia in children, the performance of amblyopic and age matched control children on a clinical test of eye movements was compared. 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), stereoacuity and refractive error were also recorded in both groups.

RESULTS: No significant difference was found between the amblyopic and age-matched control group for any of the outcome measures of the DEM (Vertical time, Horizontal time, number of errors and Ratio (Horizontal time/Vertical time)). The DEM measures were not significantly related to VA in either eye, level of binocular function (stereopsis), 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. Under habitual binocular viewing conditions, amblyopia has no effect on eye movements as assessed with DEM, despite significant impairment of binocular vision and decreased VA in both the better and worse eye.

INTRODUCTION

Approximately three percent of the population develop amblyopia,[1,2] which is generally defined as poor vision resulting from abnormal visual experience during early childhood. Children with amblyopia may have poorer visual acuity (VA) in both the affected and fellow eye, little or no stereopsis or binocular fusion and poorer efficiency in their accommodation and oculo-motor control.[3] While much has been reported regarding the visual characteristics of amblyopia and the neurological adaptations that underlie these effects,[3-5] there is little published evidence of the disability associated with amblyopia.[6] In particular, there has been only limited research on the impact of amblyopia on the ability to complete activities of daily living that impact on career opportunities or career choices for amblyopes,[6] or on tasks pertinent to the activities of amblyopic children and their educational achievement.[7] Persons with a history of amblyopia are reported to feel that it has affected their school and career choices,[8-10] however, a recent birth cohort study involving 8861 participants reported that amblyopia did not significantly impact on educational, health or social outcomes.[11]

In addition to having reduced VA, contrast sensitivity and hyper-acuity[3], amblyopes have poorer control of fixation in both the amblyopic and non-amblyopic eye[12] and binocular coordination of saccades is impaired in strabismic amblyopes, particularly those with large angle strabismus.[13] Although a causal relationship between 'poor' eye movements and reading has not been confirmed,[14] assessment of eye movements in poor readers is routine in clinical paediatric optometry practice,[15] and recommended in optometric clinical guidelines for the evaluation of learning-related vision problems.[16] 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 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 direct 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.[15] While the grading scales are simple to administer, the inter-rater reliability of direct observation tests has been questioned.[15] 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 (Taylor Associates NY).[15] While the highly detailed description 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.

An alternative clinical test of saccadic eye movements is the Developmental Eye Movement Test (DEM)[17] which provides a measure of visual-verbal oculomotor skills and rapid automatized naming (RAN).[18] 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.[16] While the test-retest reliability of the DEM has been questioned,[19] in a more controlled setting test-retest reliability has been shown to be relatively high.[18]

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.[20] The deficits in motor performance were greatest on timed manual dexterity tasks reflecting both speed

and accuracy. The outcomes of the DEM test are also judged on speed and accuracy, hence, we examined whether they may be similarly affected in a group of amblyopic children.

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,[21] level of stereopsis as a measure of binocular fusion and inter-ocular VA difference as a measure of depth of amblyopia. Hyperopia is also be considered as it has been linked with poor performance compared with controls on several spatial cognitive and motor tests,[22,23] and hyperopic children have poor reading performance compared with emmetropic and myopic children.[24]

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 those of an age-matched group of control children. The influences of aetiology and measured visual characteristics on the outcome measures of the DEM were also explored.

METHODS

Participants:

Thirty-nine children (aged 9.1 ± 0.9 years; range 8.0 to 11.2 years) who had been diagnosed and treated for amblyopia or amblyogenic conditions and forty-two control children (aged 9.3 ± 0.4 years; range 8.6 to 10.0 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 participant recruitment and clinical characteristics have

been previously reported.[20,25] 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 causing deprivation amblyopia (five from monocular cataract and one from persistent monocular primary vitreous requiring lensectomy and vitrectomy). 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 a successful treatment outcome and children who still had clinically significant amblyopia (greater than 0.2 logMAR difference in VA between eyes). The current refractive correction based on a cycloplegic refraction (1.0 percent cyclopentolate) within the previous twelve months was worn for all testing.

Vision Assessment

Visual acuity was measured in each eye using a three-metre Bailey-Lovie logMAR chart[26] while the child wore their current refractive correction. 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,[27] chosen for its established validity and normative data.[28] Suppression was confirmed by the Mirror-Pola technique[29] if no stereoscopic response was obtained on the Randot Preschool Stereoacuity Test.

Developmental Eye Movement Test

Saccadic eye movements were assessed with the Developmental Eye Movement test,[17] 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). Participants were 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) 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 were Vertical time, Horizontal time, Number of Errors and Ratio$_{(\text{horizontal time/vertical time})}$. Results were converted to standard scores and percentile ranks based on published age-normative data for this test.[30]

Amblyopic and control subjects also completed a self-esteem questionnaire and tests of fine motor skills performance during the experimental session; the findings of these tests have been published elsewhere.[20,25] 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 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.

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.

RESULTS

No significant differences in age or gender were found between the amblyopic and control groups. On average the subjects with amblyopia had a VA of 0.06 logMAR in the better eye (range -0.18 to 0.30 logMAR) and 0.44 logMAR in the worse eye (range 0.00 to 2.00 logMAR). Ten amblyopic subjects had corrected VA of logMAR 0.20 or better in their worse eye and nineteen amblyopic subjects children had a difference in acuity between eyes that was less than or equal to 0.20 logMAR. In the control group there was little difference between eyes (-0.03 logMAR in the better eye; -0.01 logMAR in the worse eye). All control subjects had VA better than 0.20 logMAR in their worse eye and all had less than 0.20 logMAR difference in VA between eyes.

A hyperopic refractive correction was worn by twenty-nine of the amblyopic subjects (73%) (range from +0.50D to +9.50D) and three control subjects (7%) (range +1.00D to +3.00D). Refractive correction was spherical in the three control subjects and in nineteen of the amblyopic group. Astigmatic correction varied between 1.00D and 2.25D in ten of the amblyopic subjects. In the amblyopic group, sixteen subjects had refractive corrections that were different between eyes by more than 1.00 D. The spherical equivalent of refractive correction, averaged between right and left eyes, is reported in Table 1.

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 the 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 the control subjects (98%) had normal stereopsis (≤ 40”)[31] compared with only eight percent of the amblyopic group. No subject with infantile esotropia had measurable stereopsis, 75% of anisometropic amblyopes had reduced levels of stereopsis and 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 in the worse eye, intra-ocular VA difference, level of stereopsis and average refractive error (Table 1). *Post hoc* testing indicated that those with an aetiology of deprivation had significantly poorer VA in the worse eye and a 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 $\text{Ratio}_{(\text{horizontal time/vertical time})}$ are shown for the amblyopic and control groups in Table 2. No significant differences in any of the outcome measures of the DEM were found between the amblyopic and age-matched control group, and the data for each group were comparable with published DEM normative data for children aged between 9 and 10 years of age (n=84).[30] Outcome measures of the DEM did not differ significantly between amblyopic subgroups (Table 2), however, the small sample sizes in the aetiological subgroups limit the statistical power of this analysis.

An indication of the clinical significance of the DEM outcomes was derived by referring to published normative data.[30] As well as presenting mean and standard deviation values for normative groups, the DEM handbook provides a calculation of a standard score and an indication of percentile rank of performance against the normative data. Where a subject scored in the 15th percentile or below, their results are considered abnormal and outside the normal range by standardised and validated testing of the DEM.[32] The number of subjects in either the amblyopia or the control group whose result was outside the range of published normative data[30] is shown in Table 3. No significant difference was seen between amblyopic and control groups in the number of subjects who met this clinical criterion for an abnormal result.

Visual determinants of DEM outcome measures

Pearson correlation coefficients were calculated for the total sample (n=81) between the DEM outcome measures and the visual characteristics of the subjects that we considered might influence oculo-motor control (history of strabismus, VA in better eye, VA in worse eye, inter-ocular VA difference, average refractive error and level of stereopsis). As expected, there were a number of significant intercorrelations between the visual characteristics of the participants ($p<0.05$) and also between the different DEM outcome measures ($p<0.05$). However, there were no significant correlations between the DEM outcome measures and participant visual characteristics.

Impact of treatment success

The amblyopic children were grouped for this analysis according to whether their treatment was considered to have been successful. Nineteen children (49%) had ≤ 0.20 logMAR difference in acuity between eyes and had 0.20 logMAR or better VA in their worse eye and were allocated to the successful outcome

group. No significant differences in DEM outcomes were found between those children who would be clinically described as having successful versus unsuccessful treatment outcomes (Table 4).

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, these differences did not reach significance as shown in Table 5.

DISCUSSION

This is the first study to report the performance of a group of amblyopic children on a clinical measure of saccadic eye movements and to compare that performance to an age-matched control group with normal vision. Our findings indicate that, despite significantly reduced VA in both the affected and fellow eyes, reduced or absent stereopsis and significantly greater hyperopic refractive error, the scores of the amblyopic children were similar to those of control children for the outcome measures of the Developmental Eye Movement (DEM) test: Vertical time, Horizontal time, number of Errors and Ratio$_{(\text{Horizontal time/Vertical time})}$.

In addition to determining that the ability of amblyopic children to quickly execute saccades to fixate, identify and name single digits was not significantly different from that of their 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 result in 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 with which a series of numbers can be seen, recognised and verbalised with accuracy.[18] 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.[33] 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 a higher Ratio score, indicating poor saccadic eye movement control. [17] Poor performance on both the Vertical and Horizontal subtests would indicate slow automatic naming ability. [17]

A clinical purpose of the DEM is to help practitioners determine whether poor saccadic tracking may contribute to poor reading behaviour.[17] Indeed, a sustained and prevalent controversy in reading eye movement research is whether fluent reading is controlled by low-level eye movement efficiency, as would be measured by the DEM, or whether it is influenced by the more moment-to-moment cognitive processes.[14] The DEM has been found to predict students with below average reading performance,[34] and to relate to parental observation of errors during reading, such as losing place or omitting words when reading or copying and re-reading lines unknowingly.[18] However, despite recognition of reading as an important vision dependent ability that contributes to an individual's quality of life,[35] few studies have evaluated the reading performance of amblyopes under habitual binocular viewing conditions. Specific reading disability was found to be relatively rare in a small sample of children with amblyopia (n=20)[36] and not more prevalent than reported in the general population. Conversely, Stifter et al. recently reported functionally relevant reading impairment (reduced maximum reading speed under binocular viewing conditions) in micro-strabismic children (n=20, age 11.5 ± 1.1 years).[37] Our finding that amblyopia had no effect on eye movements when assessed with the DEM indicates that the deficit in binocular reading speed reported in amblyopic children[37] is not explained by poor saccadic eye movement efficiency. Stifter

et al. also reported 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.[37] 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 under adequate lighting conditions is limited by letter spacing (crowding), and is independent of text size, contrast, and luminance, provided that text contrast is at least four times the threshold contrast for an isolated letter.[38] Levi et al. recently demonstrated that crowding rather than acuity limits reading in amblyopic observers, as well as in normal observers, in both central and peripheral vision.[39] Crowding should not influence performance on the DEM because the test targets consist of 3mm tall, high contrast single digits (approximately N10) with 5mm between rows of numbers and spacing of 10 to 25 mm between numbers. The extent to which crowding may explain the reduction in reading speed measured under binocular conditions as reported by Stifter et al.[37] remains unclear.

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. While a number of functionally relevant deficits in tasks that contribute to quality of life have now been reported,[40] the educational, health and social life outcomes of amblyopes do not appear to be affected.[11] 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. Our present findings demonstrate that

under habitual binocular viewing conditions, amblyopia does not impact on clinical measures of saccadic eye movement efficiency. While our finding suggests that reports of reduced reading speed in amblyopia are not due to poor eye movement control, further studies employing more direct and objective measures of eye movements during reading are required to further explore this relationship.

Understanding the influence of amblyopia on performance is important for clinicians when interpreting test results and for providing advice to parents of 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 both on clinical tests of visual efficiency and on visually directed tasks relevant to children is yet to be fully established and warrants further study.

REFERENCES

1. Attebo K, Mitchell P, Cumming R, Smith W, Jolly N, Sparkes R. Prevalence and causes of amblyopia in an adult population. *Ophthalmology* 1998;**105**(1)**:**154-159.
2. Brown SA, Weih LM, Fu CL, Dimitrov P, Taylor HR, McCarty CA. Prevalence of amblyopia and associated refractive errors in an adult population in Victoria, Australia. *Ophthal Epidemiol* 2000;**7**(4)**:**249-258.
3. McKee SP, Levi DM, Movshon JA. The pattern of visual deficits in amblyopia. *J Vis* 2003;**3**(5)**:**380-405.
4. Anderson SJ, Swettenham JB. Neuroimaging in human amblyopia. *Strabismus* 2006;**14**(1)**:**21-35.
5. Levi DM. Visual processing in amblyopia: human studies. *Strabismus* 2006;**14**(1)**:**11-19.

6. Snowden SK, Stewart-Brown SL. Preschool Vision Screening. Health Technology Assessment: NHS R&D HTA Program, 1997: 1-85.
7. Carlton J, Karnon J, Czoski-Murray C, Smith K, Marr J. The clinical effectiveness and cost-effectiveness of screening programmes for amblyopia and strabismus in children up to the age of 4-5 years: a systematic review and economic evaluation. *Health Technology Assessment* 2008;**12**(25)**:**1-230.
8. Packwood EA, Cruz OA, Rychwalski PJ, Keech RV. The psychosocial effects of amblyopia study. *Journal of AAPOS* 1999;**3**(1)**:**15-17.
9. Campbell LR, Charney E. Factors associated with delay in diagnosis of childhood amblyopia. *Pediatrics* 1991;**87**(2)**:**178-185.
10. Satterfield D, Keltner JL, Morrison TL. Psychosocial aspects of strabismus study. *Arch Ophthalmol* 1993;**111**(Aug)**:**1100-1105.
11. Rahi J, Cumberland PM, Peckham CS. Does amblyopia affect educational, health and social outcomes? Findings from 1958 British birth cohort. *Br J Ophthalmol* 2006;**332:**820-825.
12. Kandel GL, Grattan PE, Bedell HE. Are the dominant eyes of amblyopes normal? *American Journal of Optometry and Physiological Optics* 1980;**57:**1-6.
13. Kapoula Z, Bucci MP, Eggert T, Garraud L. Impairment of the binocular coordination of saccades in strabismus. *Vision Research* 1997;**37**(19)**:**2757-2766.
14. Starr MS, Rayner K. Eye movements during reading: some current controversies. *Trends in Cognitive Sciences* 2001;**5**(4)**:**156-163.
15. Scheiman M, Wick B. Clincial Management of Binocular Vision. Philadelphia: J.B. Lippincott Company, 1994.
16. Garzia R, Borsting E, Nicholson S, Press L, Scheiman M, Solan H. Optometric Clinical Practice Guideline: Care of the patient with learning related vision problems. St Louis, MO: American Optometric Association, 2006.

17. Garzia RP. A new visual-verbal saccade test: the developmental eye movement test (DEM). *Journal of the American Optometric Association* 1990;**61:**124-135.
18. Tassinari JT, De Land PN. Developmental Eye Movement Test: reliability and symptomatology. *Optometry* 2005;**76**(7)**:**387-399.
19. Rouse MW, Nestor EM, Parot CJ, DeLand PN. A reevaluation of the Developmental Eye Movement (DEM) Test's repeatability. *Optometry and Vision Science* 2004;**81**(12)**:**934-938.
20. Webber AL, Wood JM, Gole GA, Brown B. The effect of amblyopia on fine motor skills in children. *Invest Ophthalmol Vis Sci* 2008;**49**(2)**:**594-603.
21. Rubin GS, Munoz B, Bandeen-Roche K, West SK. Monocular versus Binocular Visual Acuity as Measures of Vision Impairment and Predictors of Visual Disability. *Invest Ophthalmol Vis Sci* 2000;**41**(11)**:**3327-3334.
22. Atkinson J, Braddick O, Nardini M, Anker S. Infant Hyperopia: detection, distribution, changes and correlates - outcomes from the Cambridge infant screening programs. *Optom Vis Sci* 2007;**84**(2)**:**84-96.
23. Atkinson J, Nardini M, Anker S, Braddick O, Hughes C, Rae S. Refractive errors in infancy predict reduced performance on the Movement Assessment Battery for Children at 3 1/2 and 5 1/2 years of age. *Dev Med Child Neurol* 2005;**47:**243-251.
24. Shankar S, Evans MA, Bobier W. Hyperopia and emergent literacy of young children: pilot study. *Optom Vis Sci* 2007;**84**(11)**:**1031-1038.
25. Webber AL, Wood JM, Gole GA, Brown B. The effect of amblyopia on self-esteem in children. *Optom & Vis Sci* 2008;**In Press**.
26. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. *American Journal Of Optometry And Physiological Optics* 1976;**53**(11)**:**740-745.
27. Birch EE, Williams C, Hunter J, Lapa MC, ALSPAC. Random Dot Stereoacuity of Preschool Children. *J Ped Ophthalmol Strab* 1997;**34**(217-222).
28. Birch EE, Williams C, Drover J, et al. Randot Preschool Stereoacuity Test: Normative data and validity. *J AAPOS* 2008;**12**(1)**:**23-26.

29. Siderov J. Suppression: clinical characteristics, assessment and treatment. Oxford: Butterworth Heinemann, 2001.
30. Richman M, Garzia R. Developmental Eye Movement Test, Version 1, Examiners Booklet, 1987.
31. Fielder AR, Moseley MJ. Does stereopsis matter in humans? *Eye* 1996;**10:**233-238.
32. Scheiman M, Gallaway M, Coulter R, et al. Prevalence of vision and ocular disease conditions in a clinical pediatric population. *J Am Optom Assoc* 1996;**67:**193-202.
33. Garzia R, Borsting E, Nicholson SB, Press LJ, Scheiman M, Solan HA. Optometric Clinical Practice Guideline: Care of the patient with learning related vision problems. In: Association AO, ed. St Louis, MO, 2000.
34. Larter S, Herse P, Naduvilath T, Dain S. Spatial load factor in prediction of reading performance. *Ophthal Physiol Opt* 2004;**24:**440-449.
35. Uusitalo RJ, Brans T, Pessi T, Tarkkanen A. Evaluating cataract surgery gains by assessing patients' quality of life using the VF-7. *Journal of Cataract & Refractive Surgery* 1999;**25**(7)**:**989-994.
36. Koklanis K, Georgievski Z, Brassington K, Bretherton L. The prevalence of specific reading disability in an amblyopic population. A preliminary report. *Binocular vision and strabismus quarterly* 2006;**21**(1)**:**27-32.
37. Stifter E, Burggasser G, Hirmann E, Thaler A, Radner W. Monocular and binocular reading performance in children with microstrabismic amblyopia. *Br J Ophthalmol* 2005;**89:**1324-1329.
38. Pelli DG, Tillman KA, Freeman J, Su M, Berger TD, Majaj NJ. Crowding and eccentricity determine reading rate. *Journal of Vision* 2007;**7**(2)**:**1-36.
39. Levi DM, Song S, Pelli DS. Amblyopic reading is crowded. *J Vis* 2007;**7 (2)**(21)**:**1-17.
40. Grant S, Melmoth D, Morgan M, Finlay A. Prehension deficits in amblyopia. *Invest. Ophthalmol. Vis. Sci.* 2007;**48**(3)**:**1139-1148.

Table 1: Age, gender, refractive and vision characteristics of samples. Mean (standard deviation) of data presented.

		Control	Total Amblyopia Group	STATISTICAL SIGNIFICANCE **Between Amblyopia and Control Group**		Amblyopic Sub-groups					STATISTICAL SIGNIFICANCE One-Way ANOVA **Between Amblyopic aetiology groups**	
						Infantile Esotropia	Acquired Strabismus	Anisometropia	Mixed	Deprivation		
		N=42	N = 39	t (df=79)	p	N=7	N=10	N=8	N=8	N=6	F or $\chi 2$	p
Age (years)		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
Gender (% Female)		20 (48%)	17 (43%)	$\chi 2$ (df=2) 0.664	0.404	29%	50%	38%	38%	50%	1.564 ($\chi 2$df=4)	0.815
Stereopsis	Nil	0 (0%)	23 (59%)	$\chi 2$ ***(df=2)*** ***66.08***	***<0.001***	7 (100%)	7 (70%)	0.0 (%)	5 (63%)	4 (67%)	***18.87*** ($\chi 2$df=8)	***0.016***
	800" – 60"	1 (2%)	13 (33%)			0 (0%)	2 (20%)	6 (75%)	3 (38%)	2 (29%)		
	≤ 40"	41 (98%)	3 (8%)			0 (0 %)	1 (10%)	2 (25%)	0 (0%)	0 (0%)		
Inter Ocular Difference in VA (logMAR)		0.02 (0.03)	0.38 (0.52)	***4.475***	***<0.001***	0.51 (0.72)	0.11 (0.10) ‡	0.22 (0.18) ‡	0.21 (0.16) ‡	1.09 (0.69) ‡	6.254[a]	***0.001***
VA in Better Eye (logMAR)		-0.03 (0.05)	0.06 (0.11)	***4.726***	***<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
VA in Worse Eye (logMAR)		-0.01 (0.05)	0.44 (0.50)	***5.710***	***<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***
Refractive error (dioptres)		0.16 (0.63)	2.92 (2.49)	***6.941***	***<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***

Table 2: DEM reading rate outcomes – mean (standard deviation)

OUTCOME MEASURE	Control	Total Amblyopia Group	Normative data (age 9.0-9.99)	STATISTICAL SIGNIFICANCE **Between Amblyopia and Control Group**		Amblyopic Sub-groups					STATISTICAL SIGNIFICANCE **Between Amblyopic aetiology groups**	
						Infantile Esotropia	Acquired Strabismus	Anisometropia	Mixed	Deprivation		
	N = 42	N=39	N=84	$T_{(df=79)}$	p	N=7	N=10	N=8	N=8	N=6	$F_{(4,39)}$	p
Vertical Adjusted Time (seconds)	41.12 (6.79)	42.13 (9.05)	42.33 (8.20)	0.570	0.570	39.29 (6.85)	42.90 (9.22)	37.38 (3.96)	42.50 (5.68)	50.00 (14.93)	2.098	0.103
Horizontal Adjusted Time (seconds)	52.71 (11.54)	53.18 (16.96)	51.13 (13.30)	0.145	0.885	47.29 (8.75)	52.80 (13.68)	46.63 (6.61)‡	56.38 (19.77)	65.17 (29.03)‡	1.386	0.260
Number of Errors	0.98 (2.42)	1.62 (3.60)	2.17 (4.10)	0.944	0.348	2.71 (5.62)	0.60 (1.35)	0.38 (0.52)	1.50 (3.51)	3.83 (5.23)	1.198	0.329
Ratio (Horizontal Time/Vertical T ime)	1.27 (0.19)	1.25 (0.20)	1.21 (0.19)	-0.551	0.583	1.21 (0.17)	1.23 (021)	1.25 (0.15)	1.31 (0.28)	1.26 (0.17)	0.264	0.899

[a] one-way ANOVA $F_{(4,39)}$ ‡ Post hoc tests indicate significant differences between sub-groups

‡ Post hoc tests indicate significant differences between sub-groups

Table 3: Number of subjects with DEM scores below 15th percentile

	Total N (% of subjects)	Amblyopic Group	Control Group	Chi-square (df=1)	p
Horizontal Time ≥ 53 seconds	6 (7%)	4 (10%)	2 (5%)	0.890	0.345
Vertical Time ≥ 64 seconds	12 (15%)	6 (15%)	6 (14%)	0.032	0.858
Number of Errors ≥ 4	11 (14%)	6 (15%)	5 (12%)	0.209	0.648
Ratio ≥ 1.40	15 (19%)	7 (18%)	8 (19%)	0.016	0.899

Table 4: Difference in DEM results between Amblyopic VA groups

DEM Outcome Measure	VA in worse eye ≤ 0.20 logMAR n = 19	VA in worse eye >0.20 logMAR n =20	$T_{(df=37)}$	p
Vertical Time (seconds)	41.26 (6.69)	42.95 (10.95)	-0.5777	0.568
Horizontal Time (seconds)	53.37 (14.26)	53.00 (19.63)	0.067	0.947
Number of Errors	1.89 (4.04)	1.35 (3.20)	0.468	0.642
$Ratio_{(Horizontal\ Time/Vertical\ Time)}$	1.29 (0.23)	1.21 (0.15)	1.314	0.197

Table 5: Difference in DEM results between Binocular function groups

DEM Outcome Measure	Nil stereopsis n = 23	Reduced stereopsis N=14	Normal stereopsis n =44	$F_{(2,78)}$	p
Vertical Time (seconds)	43.52 (10.60)	40.29 (6.56)	41.02 (6.59)	0.985	0.378
Horizontal Time (seconds)	55.78 (20.73)	49.29 (9.46)	52.61 (11.21)	0.919	0.403
Number of Errors	2.43 (4.04)	0.50 (0.76)	0.93 (2.38)	2.495	0.089
$Ratio_{(Horizontal\ Time/Vertical\ Time)}$	1.26 (0.24)	1.22 (0.13)	1.27 (0.16)	0.416	0.661