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Webber, Ann, Wood, Joanne, Gole, Glen, & Brown, Brian
(2008)
The effect of amblyopia on fine motor skills in children.
Investigative Ophthalmology and Visual Science, *49*(2), pp. 594-603.

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https://doi.org/10.1167/iovs.07-0869

The effect of amblyopia on fine motor skills in children.

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Word Count: 4250

ABSTRACT

Purpose 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 ± 0.2 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 ± 0.2 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 visual acuity in either eye.

Conclusions Fine motor skills were reduced in amblyopic children. Of the visual factors examined in this study, only the presence of strabismus was significantly associated with poorer fine motor skills performance.

Keywords:

Amblyopia, fine motor skills, stereopsis, binocular vision

INTRODUCTION

Amblyopia, affects approximately three percent of the population[1,2] 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 7 years of age)[3] 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.[4]

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.[5] 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.[5,6] Disruption of binocular function with resultant reduction in stereopsis is common, particularly in amblyopes with a history of strabismus.[5,6] 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.[5] 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.[5]

While much is known about the visual characteristics of amblyopia, the natural history of the condition and appropriate detection and treatment strategies,[6] the functional disadvantage of amblyopia has not been fully explored.[7] 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.[8] 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.[9] Most studies that have investigated this issue have compared performance under monocular and binocular conditions,[10,11] generally concluding that binocular vision facilitates control of manipulation, reaching and balance,[11] and that people who lack stereopsis have difficulty performing tasks which rely on three dimensional visual cues.[12] There are, however, many individuals who perform well on tests of manual dexterity even though their stereopsis is poor,[12] 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.[13]

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.[14] 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,[15,16] 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.

METHODS

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 ± 0.2 years) and 37 age-matched control subjects (age 8.3 ± 0.2 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 pediatric 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[17] 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).
- Anisometropic - ≥1.00 dioptre difference in mean spherical refractive error and/or ≥ 1.50 D between the eyes in astigmatism (n=15)
- Mixed - history of both strabismus and anisometropia (n=13)
- Deprivation – history of disturbance of monocular image clarity e.g. monocular cataract (n=9)

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.[19] 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,[20] 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[21] if no stereoscopic response was obtained on the Randot test.

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).[22] 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 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.[22]

TABLE 1 about here

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.[22] Results are converted to subtest age-standardised scaled scores of performance relative to published normative values.[22]

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.

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.[23] 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);[24] multi-collinearity (unacceptably high degree of correlation between investigated factors) was defined as a VIF value of 3 or more.[24]

RESULTS

The amblyopic children had a greater interocular 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 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=0.00) 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 interocular difference in VA (0.13 logMAR), whilst those with deprivation amblyopia had the greatest mean difference in interocular 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 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 (≤ 40”)[9] compared with only six percent of the amblyopic group. Most subjects with infantile esotropia (88%) had no measurable stereopsis, whilst, 73% of anisometropic amblyopes 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 ($\chi2_{(df=2)} = 82.47$; $p<0.000$) and between subgroups ($\chi2_{(df=10)} = 111.22$; $p<0.000$)(Table 2).

Table 2 about here

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 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 3 about here

Age-standardised scaled scores, calculated from the sub-item sum,[22] 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).

Table 4 about here

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.[22] 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 $\chi2 = 6.5$; $p=0.040$; ULSD $\chi2 = 9.35$; $p=0.009$) (Figure 1). Differences were also evident between subgroups (VMC $\chi2 = 19.13$; $p=0.039$; ULSD $\chi2 = 20.18$; $p=0.028$) (Table 5).

Table 5 about here

Figure 1 about here

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 and Figures 1 and 2). *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.

Figs 2 & 3 about here

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 6).

Figure 4 and Table 6 about here

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 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 7 about here

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 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 8).

Table 8 about here

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 for 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 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,[13] 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.[13] A speed-accuracy trade-off has been proposed when quantifying the reaching and grasping behaviour in amblyopic subjects.[25] 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 deficits in adults with amblyopia, Grant et. al.[25] 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. [25] that amblyopes have the greatest difficulties with motor performance tasks when they are timed. Grant et. al. 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.[25] 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.[5] 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.[25] 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,[5] 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.[26,27] 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. [26] Lack of stereopsis has been suggested to account for delayed neuro-developmental performance of infants with strabismus,[28] and in non-strabismic amblyopes, stereopsis, independent of visual acuity, was found to influence performance on visual motor integration (design copying).[27] 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.[13] 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,[5,25] 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.

ACKNOWLEDGMENTS

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

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Table 1: Sub-items comprising Visual-motor control and Upper-limb speed and dexterity items of BTOMP[22]

VMC - all tasks are done with preferred hand		
Sub item	Description	Record
1: Cutting circle	Cuts out a bold circle embedded within six concentric circles.	Number of errors
2: Drawing through crooked path	Draws a pencil line through a crooked path.	
3: Drawing through straight path	Draws a pencil line through a straight path.	
4: Drawing through curved path	Draws a pencil line through a curved path.	
5: Copying circle	Copies a geometric shape.	Accuracy of shape reproduction following specific scoring guidelines
6: Copying triangle		
7: Copying diamond		
8: Copying overlapping shapes		
ULSD – all tasks are done with preferred hand except for item 2 (which requires both hands). A practice trial precedes each test run.		
1: Placing pennies in a box	Places pennies one at a time into an open box.	The number of pennies placed into the box correctly in 15 seconds
2: Placing pennies in two boxes with both hands	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.	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.
3: Sorting shape cards	Sorts a mixed deck of red and blue cards into two piles, separating them by colour.	The number of cards correctly sorted in 15 seconds.
4: Stringing beads	Strings beads onto a shoelace.	The number of beads placed correctly in 15 seconds.
5: Displacing pegs	Displaces pegs with 2 mm base diameter on a pegboard, moving each peg to the hole directly above it.	The number of pegs displaced correctly in 15 seconds.
6: Drawing vertical lines	Draws straight lines between pairs of horizontal lines.	The number of vertical lines drawn correctly in 15 seconds. Accuracy following specific test guidelines.
7: Making dots in circles	Makes a pencil dot inside each of a series of circles	The number of circles dotted correctly in 15 seconds.
8: Making dots	Makes pencil dots on a blank page	The number of separate dots made in 15 seconds.

Table 2: Age, gender and vision characteristics of test and age matched control groups.

		Control	Total Amblyopia Group	STATISTICAL SIGNIFICANCE **Between Amblyopia and Control Group**		Infantile Esotropia	Acquired Strabismus	Anisometropia	Mixed	Deprivation	STATISTICAL SIGNIFICANCE One-Way ANOVA **Between Amblyopic aetiology groups and control group**	
		N=37	N = 82		p	N=17	N=28	N=15	N=13	N=9		p
Age (years)		8.28 (.21)	8.21 (.18)	0.06[a]	0.807	7.79 (.44)	8.11 (.30)	8.47 (.38)	8.33 (.58)	8.64 (.40)	0.51[a]	0.770
Gender (% Female)		48.6%	54.9%	0.26[b]	0.613	52.9%	67.9%	26.7%	53.8%	66.7%	7.81[b]	0.167
Stereopsis	Nil	50 (61%)	0 (0.0%)	***82.47*** (df=2)	***<0.000***	15 (88%)	18 (64%)	1 (7%)	9 (69%)	7 (78%)	***111.22*** (df=10)	***<0.000***
	800" – 60"	27 (33%)	4 (11%)			2 (12%)	8 (29%)	11 (73%)	4 (31%)	2 (22%)		
	≤ 40"	5 (6%)	33 (89%)			0 (0 %)	2 (7%)	3 (20%)	0 (0%)	0 (0%)		
Inter Ocular Difference in VA (logMAR)		0.02 (0.00)	0.31 (0.06)	***10.97***[a]	***0.001***	0.26 (0.12)	0.13 .(0.03)	0.22 (0.03)	0.22 (0.04)	1.27 (0.37)	***17.95***[a]	***<0.000***
VA in Best Eye (logMAR)		-0.01 (0.01)	0.10 (0.01)	***21.59***[a]	***<0.000***	0.10 (0.03)	0.12 (0.03)	0.08 (0.03)	0.09 (0.03)	0.02 (0.04)	***5.58***[a]	***<0.000***
VA in Worst Eye (logMAR)		0.00 (0.01)	0.38 (0.05)	***29.55***[a]	***<0.000***	0.36 (0.11)	0.25 (0.04)	0.30 (0.42)	0.31 (0.05)	1.08 (0.24)	***20.37***[a]	***<0.000***
Refractive error (dioptres)		0.08 (0.08)	2.30 (0.25)	***49.47***[a]	***<0.000***	1.21 (0.42)	3.72 (0.48)	3.00 (0.40)	4.03 (0.39)	0.53 (0.43)	***23.75***[a]	***<0.000***

[a] one-way ANOVA F$_{(5,113)}$ [b] Chi-Square df = 5 for AGE; df = 1 for Binocular for amblyopic v control and df = 5 for aetiology subgroup analysis

Table 3: Median (Range) for fine motor skills sub-tests for amblyopic and age matched control subjects

	Control N=37	All Amblyopes N=82	χ2 p	Infantile Esotropia N=17	Acquired Strabismus N=28	Anisometropia N=15	Mixed N=13	Deprivation N=9	Kruskal Wallis p
VISUAL MOTOR CONTROL									
7-1 CUTTING CIRCLE	4 (0 - 4)	4 (0 – 4)	0.065	4 (0 - 4)	4 (0 - 4)	4 (2 - 4)	4 (3 - 4)	4 (3 - 4)	.138
7-2 DRAWING CROOKED PATH	4 (2 - 4)	4 (0 – 4)	0.053	4 (1 - 4)	4 (0 - 4)	4 (2 - 4)	4 (2 - 4)	4 (2 - 4)	.157
7-3 DRAWING STRAIGHT PATH	4 (2 - 4)	4 (0 – 4)	***0.017***	3 (2 - 4)	4 (2 - 4)	4 (1 - 4)	3 (0 - 4)	4 (4 - 4)	***.001***
7-4 DRAWING CURVED PATH	3 (0 - 4)	3 (0 – 4)	0.352	2 (0 - 4)	3 (2 - 4)	4 (0 - 4)	2 (0 - 4)	4 (2 - 4)	.063
7-5 COPYING CIRCLE	2 (1 - 2)	2 (0 – 2)	0.147	2 (1 – 2)	2 (0 – 2)	4 (2 - 4)	2 (2 – 2)	2 (2 – 2)	***.024***
7-6 COPYING TRIANGLE	2 (2 - 2)	2 (0 – 2)	***0.027***	2 (1 – 2)	2 (0 – 2)	2 (1 – 2)	2 (1 – 2)	2 (2 – 2)	.064
7-7 COPYING DIAMOND	2 (1 - 2)	1 (0 – 2)	***0.004***	1 (0 – 2)	1 (0 – 2)	2 (0 – 2)	1 (0 – 2)	2 (1 – 2)	***.021***
7-8 COPYING PENCILS	2 (0 - 2)	2 (0 – 2)	0.861	2 (0 – 2)	1 (0 – 2)	2 (0 – 2)	2 (0 – 2)	2 (1 – 2)	.167
SUM ITEM 7	22 (10 - 24)	21 (6 - 24)	***0.014***	19 (6 - 24)	20.50 (8 - 24)	22 (12 - 24)	20 (8 - 23)	23 (22 - 24)	***.002***
UPPER LIMB SPEED AND DEXTERITY									
8-1 PENNIES IN BOX	5 (1 - 6)	4 (1 - 6)	***0.003***	4 (1 - 6)	3.5 (1 - 5)	4 (2 - 6)	4 (3 - 5)	5 (3 - 6)	***.012***
8-2 PENNY PAIRS IN BOX	10 (6 – 10)	9 (1 - 10)	0.088	9 (1 – 10)	9 (4 - 10)	10 (7 - 10)	9 (7 -10)	10 (9 -10)	***.014***
8-3 SORTING CARDS	4 (1 – 7)	3 (1 -7)	***0.036***	3 (1 - 7)	3 (1 - 5)	3 (2 - 6)	3 (2 - 7)	4 (3 - 6)	***.045***
8-4 STRINGING BEADS	2 (1 – 5)	2 (1 – 4)	***0.023***	2 (1 - 4)	1.5 (1 - 3)	2 (1 - 3)	2 (1 - 3)	2 (1 - 3)	.097
8-5 DISPLACING PEGS	4 (3 – 7)	4 (2 – 7)	***0.046***	4 (2 - 5)	4 (2 -5)	4 (3 - 6)	4 (3 - 6)	5 (4 - 7)	***.043***
8-6 DRAWING VERT LINES	6 (3 – 8)	5 (0 - 8)	***0.000***	5 (1 - 8)	4 (0 - 6)	5 (2 - 7)	5 (2 - 7)	5 (4 - 6)	***.003***
8-7 DOTS IN CIRCLES	5 (2 – 7)	4 (1 – 8)	0.062	5 (2 - 7)	4 (1 - 6)	5 (2 - 7)	4 (3 -7)	6 (4 - 8)	***.001***
8-8 MAKING DOTS	6 (3 – 7)	5 (1 – 9)	***0.048***	6 (1 - 9)	4.5 (2 - 8)	6 (2 -8)	6 (1 - 8)	6 (5 - 8)	***.022***
SUM ITEM 8	42 (24 - 53)	37 (11 - 50)	***0.000***	39 (11 - 49)	35 (17 - 42)	40 (23 - 48)	37 (26 - 46)	41 (35 - 50)	***.000***

Table 4: Mean (standard error) for age standardised fine motor skills scores for amblyopic and age matched control subjects

** Post hoc Bonferroni indicates sig diff

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

Table 5: Proportion of sub-groups scoring in above average or higher ranges on fine motor skills tasks

		AMBLYOPIC SUBGROUPS					All Amblyopes N=82	Control N=37	STATISTICAL DIFFERENCE BETWEEN SUBGROUPS		STATISTICAL DIFFERENCE BETWEEN AMBLYOPIC AND CONTROL GROUPS	
		Infantile Esotropia N=17	Acquired Strabismus N=28	Anisometropia N=15	Mixed N=13	Deprivation N=9			$\chi2$ (df=10)	Asymp. Sig. (2-sided) p	$\chi2$ (df=2)	Asymp. Sig. (2-sided) p
Visual Motor Control	Above Average	8 (47%)	14 (50%)	9 (60%)	5 (38%)	9 (100%)	45 (55%)	29 (78%)	19.13	0.039	6.46	0.040
	Average	9 (53%)	13 (46%)	5 (33%)	7 (54%)	0 (0%)	34 (41%)	8 (22%)				
	Below Average	0 (0%)	1 (4%)	1 (7%)	1 (8%)	0 (0%)	3 (4%)	0 (0%)				
Upper Limb Speed and Dexterity	Above Average	6 (35%)	7 (25%)	3 (20%)	5 (39%)	6 (67%)	27 (33%)	22 (59%)	20.18	0.028	9.35	0.009
	Average	9 (53%)	13 (46%)	10 (67%)	6 (46%)	3 (33%)	41 (50%)	14 (38%)				
	Below Average	2 (12%)	8 (29%)	2 (13%)	2 (15%)	0 (0%)	14 (17%)	1 (3%)				

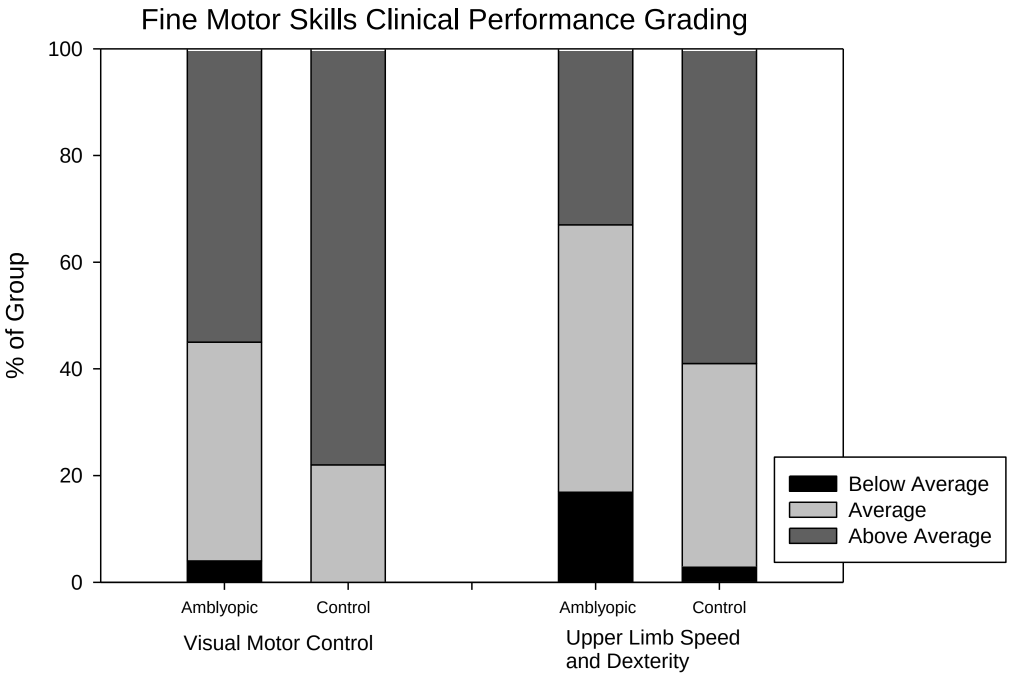

Figure 1: Proportion of amblyopic and control groups in clinical performance bands

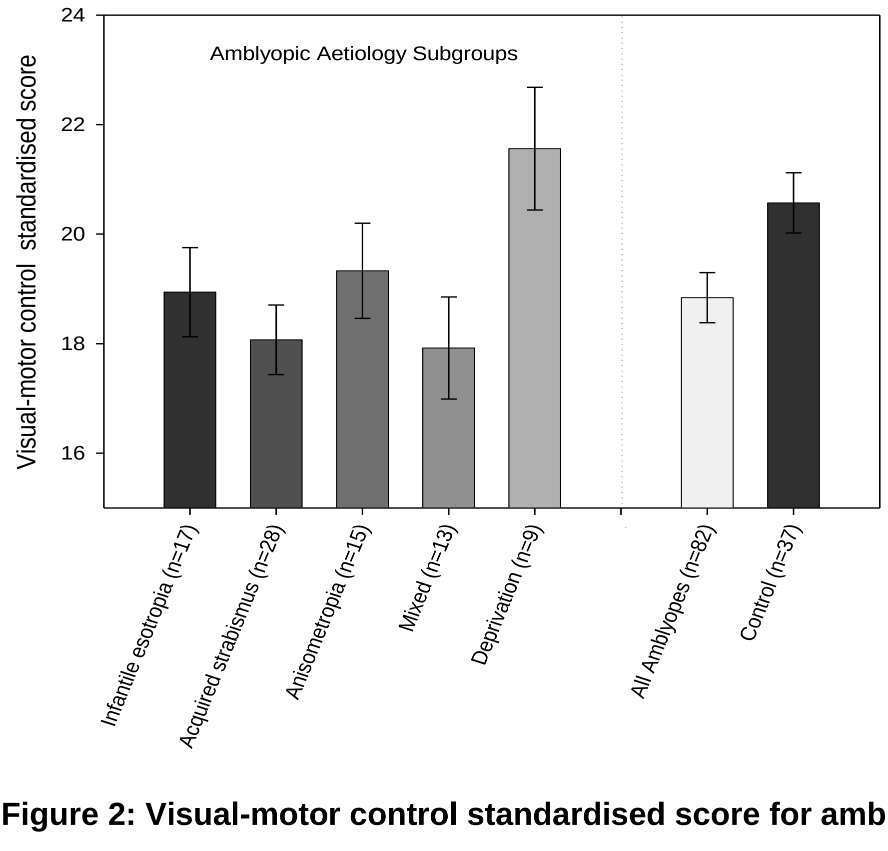

Figure 2: Visual-motor control standardised score for amblyopia groups and control

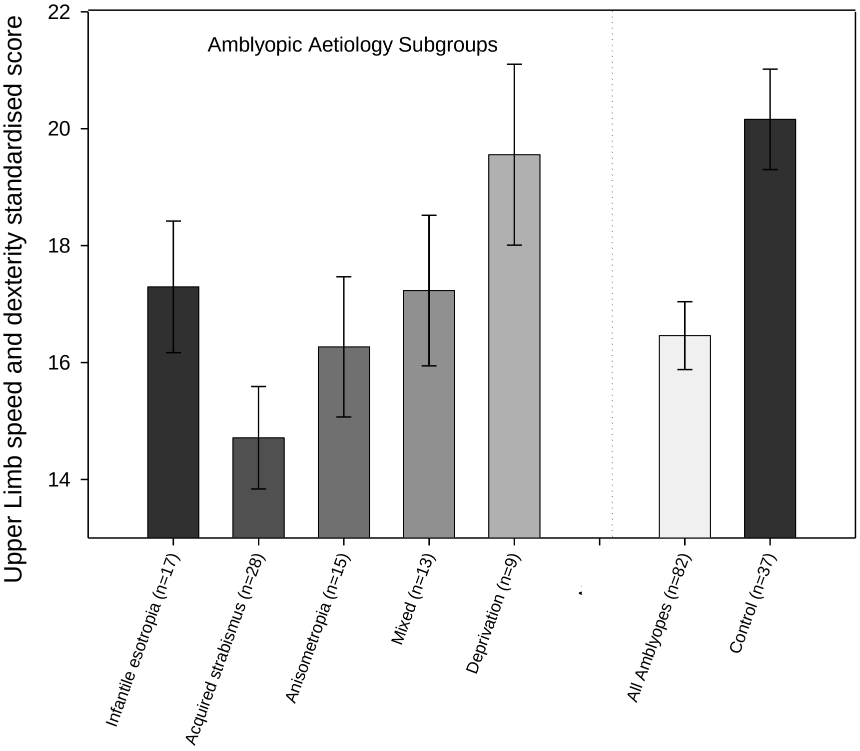

Figure 3: Upper-limb speed and dexterity standardised score for amblyopia groups and control

Table 6: Fine motor skills scores for stereoscopic groups

	No stereopsis N=50	Reduced stereopsis N=31	Normal Stereopsis N=38	ANOVA	
				$F_{(2,116)}$	p
Visual Motor Control (VMC) Standard score	19.02 (0.58)	18.03 (0.77)	20.84 (0.53)	***4.712***	***0.011***
Upper Limb Speed and Dexterity (ULSD) Standard Score	16.62 (0.74)	16.45 (0.90)	19.47 (0.83)	***4.178***	***0.018***
Fine Motor Skills Total Score	35.82 (1.02)	34.81 (1.39)	40.32 (1.00)	***6.405***	***0.002***

Table 7: Intercorrelations between vision parameters examination and fine motor skills performance

	VISION CHARACTERISTICS				FINE MOTOR SKILLS RESULT		
	BINOCULAR	AVERAGE REFRACTIVE RROR	VA WORST EYE	VA BEST EYE	STANDARD-SCORE VMC	STANDARD-SCORE ULSD	TOTAL FINE MOTOR SKILLS SCORE
STRABISMUS	***.601(**)***	***-.484(**)***	-.080	***-.392(**)***	***.267(**)***	***.281(**)***	***.354(**)***
BINOCULAR		***-.304(**)***	***-.388(**)***	***-.270(**)***	.060	.139	.136
AVERAGE REFRACTIVE ERROR			.195	***.324(**)***	-.182	***-.285(**)***	***-.311(**)***
VA WORSE EYE				***.243(**)***	.013	-.074	-.048
VA BEST EYE					-.147	-.018	-.093

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

Table 8: Multiple linear regression model of fine motor skills performance in total group.

		N	Mean	Std error	Regression coefficient (B)	Std. Error	F	significance	Partial Eta ^{2}
Strabismus	Yes	58	34.43	1.27	36.109	2.218	***5.428***	***.022***	***.046***
	No	61	39.04	1.09	40.715	1.119			
Stereopsis	Nil	50	37.64	1.26	-.063	2.385	1.862	.160	.032
	Reduced	31	34.86	1.25	-2.836	1.968			
	Normal	38	37.70	1.55	0(a)	.			
Average Refractive Error					-.517	.329	2.470	.119	.022
VA in Worst Eye					-.162	1.977	.007	.935	.000
VA in Best Eye					4.630	5.237	.781	.379	.007

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