# The Effect of Amblyopia on Fine Motor Skills in Children

*Ann L. Webber,[1] Joanne M. Wood,[1] Glen A. Gole,[2] and Brian Brown[1]*

**Purpose.** In an investigation of the functional impact of amblyopia in children, the fine motor skills of amblyopes and age-matched control subjects 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 children ($n$ = 82; mean age, 8.2 ± 1.7 [SD] years) with amblyopia of different causes (infantile esotropia, $n$ = 17; acquired strabismus, $n$ = 28; anisometropia, $n$ = 15; mixed, $n$ = 13; and deprivation $n$ = 9), and age-matched control children ($n$ = 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 control subjects on 9 of 16 fine motor skills subitems and for the overall age-standardized scores for both VMC and ULSD items ($P < 0.05$). The effects were most evident on timed tasks. The etiology of amblyopia 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 intercorrelation 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 children with amblyopia, particularly those with strabismus, compared with control subjects. The deficits in motor performance were greatest on manual dexterity tasks requiring speed and accuracy. (*Invest Ophthalmol Vis Sci.* 2008;49:594–603) DOI:10.1167/iovs.07-0869

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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 predisposing amblyogenic condition, and in the absence of visible ocular or visual pathway disease. 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 etiologic conditions. If present during the critical period of visual development (up to ~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 nonamblyopic eye often displays small but measurable deficits, such as slightly poorer VA, compared with 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 etiologic 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 amblyopia, 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]

Although much is known about the visual characteristics of amblyopia, the natural history of the condition, and the 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 have amblyopia.[8] Few studies have been conducted to investigate the performance of amblyopes under habitual binocular viewing conditions and, even though amblyopia is the most common disorder treated in pediatric ophthalmic practice in industrialized 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 observation 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 that rely on three-dimensional visual cues.[12] There are, however, many individ-



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uals 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 postoperative improvements in motor performance that did not correlate with measured improvements in stereopsis.[13]

If the neurophysiological changes that occur in amblyopia are different under conditions of monocular blur versus oculomotor 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] The presence of hyperopic refractive error, a common finding in children with amblyopia, is associated with mild delays across many aspects of visuocognitive and visuomotor development[15,16]; therefore, the magnitude of hyperopic refractive error should be considered when investigating the determinants of fine motor skill performance.

In the present investigation, we compared the performance of a sample of children with amblyopia of different origins on standardized, age-appropriate tests of performance of fine motor skills under habitual binocular conditions with the performance of an age-matched group of children without amblyopia. The influence of etiology and measured visual characteristics was examined by testing whether these factors were associated with outcome measures of fine motor skills.

## Methods

### Participants

One hundred nineteen children participated in the study, including 82 who had diagnosed amblyopia or amblyogenic conditions for which they had been treated (mean age, 8.2 ± 1.7 [SD] years) and 37 age-matched control subjects (mean age, 8.3 ± 1.3 years). The amblyopia group included children who had been successfully treated and children who had a residual VA deficit (>0.2 logMAR difference in VA between eyes). Subjects with amblyopia 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 1 year old) was worn for all tests. From clinical diagnosis, confirmed by the treating ophthalmologist (GG), the subjects were grouped with respect to the etiologic cause of their amblyopia[17,18] as follows:

1. Infantile esotropia: history of esotropia before 12 months of age ($n$ = 17).

**Table 1.** Subitems Comprising Visual Motor Control and Upper Limb Speed and Dexterity Items of BTOMP[22]

| Subitem | Description | Record |
|---|---|---|
| **Visual Motor Control** | | |
| (All tasks are performed with the preferred hand.) | | |
| 1. Cutting circle | Cut out a bold circle embedded within six concentric circles | |
| 2. Drawing through a crooked path | Draw a pencil line through a crooked path | Number of errors (subitems 1–4) |
| 3. Drawing through a straight path | Draw a pencil line through a straight path | |
| 4. Drawing through a curved path | Draw a pencil line through a curved path | |
| 5. Copying a circle | | |
| 6. Copying a triangle | Copy a geometric shape (subitems 5–8) | Accuracy of shape reproduction according to specific scoring guidelines (subitems 5–8) |
| 7. Copying a diamond | | |
| 8. Copying overlapping shapes | | |
| **Upper Limb Speed and Dexterity** | | |
| (All tasks are performed with the preferred hand, except for item 2, which requires both hands. A practice trial precedes each test run.) | | |
| 1. Placing pennies in a box | Place 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 pick up a penny with each hand and place 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 | Sort a mixed deck of red and blue cards into two piles, separating them by color | The number of cards correctly sorted in 15 seconds |
| 4. Stringing beads | String beads onto a shoelace | The number of beads strung correctly in 15 seconds |
| 5. Displacing pegs | Displace 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 | Draw straight lines between pairs of horizontal lines | The number of vertical lines drawn correctly in 15 seconds. Accuracy is judged according to specific test guidelines. |
| 7. Making dots in circles | Make a pencil dot inside each of a series of circles | The number of circles dotted correctly in 15 seconds. |
| 8. Making dots | Make pencil dots on a blank page | The number of separate dots made in 15 seconds. |

2. Acquired strabismus: history of strabismus occurring after 12 months of age ($n = 28$).
3. Anisometropia: ≥1.00 D difference in mean spherical refractive error and/or ≥ 1.50 D between the eyes in astigmatism ($n = 15$).
4. Mixed: history of both strabismus and anisometropia ($n = 13$).
5. Deprivation: history of disturbance of monocular image clarity (e.g., monocular cataract; $n = 9$).

## Vision Assessment

Visual acuity was measured with 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. The 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 subitems to measure the ability to integrate visual responses with highly controlled motor responses. The ULSD item comprises eight timed subitems that measure hand and finger dexterity, hand speed, and arm speed. The subitems 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]

Performance on each subitem 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 subitem 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-standardized scaled scores of performance relative to published normative values.[22]

Subjects also completed a self-esteem questionnaire and the 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 approximately 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 parents and children. The option to withdraw from the study at any time was explained. All protocols were in accord with the guidelines of the Declaration of Helsinki.

## Statistical Analysis

All data were tested for normality by using the Kolmogorov-Smirnov test. When the data were normally distributed, the results from the amblyopes were compared with those of the control group by using one-way ANOVA (SPSS ver. 14, SPSS, Chicago, IL), with a significance level of 0.05. When statistically significant differences were found between means, Bonferroni post hoc tests were used. Nonparametric tests were used where the data were not normally distributed. Pearson's correlation coefficients were calculated to explore the relationships between vision characteristics and fine motor skills performance;

**Table 2.** Age, Gender, and Vision Characteristics of Test and Control Groups

| | Control ($n = 37$) | Total Amblyopia Group ($n = 82$) | Statistical Significance between Amblyopia and Control Group | | Amblyopic Subgroups | | | | | Statistical Significance between Amblyopic Etiology Groups and Control Group | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $F_{(1,117)}/\chi^2$ | $P$ | Infantile Esotropia ($n = 17$) | Acquired Strabismus ($n = 28$) | Anisometropia ($n = 15$) | Mixed ($n = 13$) | Deprivation ($n = 9$) | $F_{(5,113)}/\chi^2$ | $P$ |
| Age (y) | 8.28 (0.21) | 8.21 (0.18) | 0.06 | 0.807 | 7.79 (0.44) | 8.11 (0.30) | 8.47 (0.38) | 8.33 (0.58) | 8.64 (0.40) | 0.51 | 0.770 |
| Gender (% female) | 48.6 | 54.9 | 0.26 | 0.613 | 52.9 | 67.9 | 26.7 | 53.8 | 66.7 | 7.81 | 0.167 |
| Stereopsis, $n$ (%) | | | | | | | | | | | |
| Nil | 0 (0) | 50 (61) | **82.47** | **<0.000** | 15 (88) | 18 (64) | 1 (7) | 9 (69) | 7 (78) | **111.22** | **<0.000** |
| 800–60 sec arc | 4 (11) | 27 (33) | ($df = 2$) | | 2 (12) | 8 (29) | 11 (73) | 4 (31) | 2 (22) | ($df = 10$) | |
| ≤40 sec arc | 33 (89) | 5 (6) | | | 0 (0) | 2 (7) | 3 (20) | 0 (0) | 0 (0) | | |
| Interocular difference in VA (logMAR) | 0.02 (0.00) | 0.31 (0.06) | **10.97** | **0.001** | 0.26 (0.12) | 0.13 (0.03) | 0.22 (0.03) | 0.22 (0.04) | 1.27 (0.37) | **17.95** | **<0.000** |
| VA in better eye (logMAR) | −0.01 (0.01) | 0.10 (0.01) | **21.59** | **<0.000** | 0.10 (0.03) | 0.12 (0.03) | 0.08 (0.03) | 0.09 (0.03) | 0.02 (0.04) | **5.58** | **<0.000** |
| VA in worse Eye (logMAR) | 0.00 (0.01) | 0.38 (0.05) | **29.55** | **<0.000** | 0.36 (0.11) | 0.25 (0.04) | 0.30 (0.42) | 0.31 (0.05) | 1.08 (0.24) | **20.37** | **<0.000** |
| Refractive error (D) | 0.08 (0.08) | 2.30 (0.25) | **49.47** | **<0.000** | 1.21 (0.42) | 3.72 (0.48) | 3.00 (0.40) | 4.03 (0.39) | 0.53 (0.43) | **23.75** | **<0.000** |

Results shown in bold are significant.

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

## Results

The children with amblyopia had a greater interocular difference in VA than did the age-matched control children, had poorer VA in their better seeing eye, and were less likely to have normal stereopsis ($P < 0.05$). Sixty-five (80%) of the subjects with amblyopia and one control subject (3%) wore a hyperopic refractive correction. No significant differences in age or gender were found between the amblyopia and control groups. Table 2 summarizes 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 0.10 logMAR VA in the better eye and 0.38 logMAR in the worse eye. In the control group, there was very little difference between eyes (−0.006 logMAR in the better eye; 0.004 logMAR in the worse eye). In addition to significant differences between the amblyopia and control groups ($F_{(1,117)} = 21.59$; $P < 0.000$) and between subgroups ($F_{(5,113)} = 5.58$; $P < 0.000$), post hoc testing indicated significant differences in VA in the better eye between the control group and the infantile esotropia and acquired strabismus amblyopia subgroups.

Amblyopes with acquired strabismus had the least interocular difference in VA (0.13 logMAR), whereas those with deprivation amblyopia had the greatest mean difference in interocular VA (1.27 logMAR). These variations between subgroups 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 subgroups 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 with stereopsis that was equal to or better than the highest stereoacuity level tested (40 sec arc) 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 sec arc and "normal" if response indicated stereopsis better than or equal to 40 sec arc. The majority (89%) of control group subjects had normal stereopsis (≤40 sec arc)[9] compared with only six percent of the amblyopia group. Most subjects (88%) with infantile esotropia had no measurable stereopsis, whereas 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, between the amblyopia and control groups ($\chi^2_{(df=2)} = 82.47$; $P < 0.000$) and between the subgroups ($\chi^2_{(df=10)} = 111.22$; $P < 0.000$; Table 2).

Fine motor skills involving VMC tasks and ULSD tasks were poorer in amblyopes than in control subjects, in terms of both overall scores and subitem results. Significant differences in performance were found between the amblyopia and control groups on three of the eight subitems measured in the VMC subtest (drawing a straight path, copying a triangle, copying a diamond) and on six of the eight subitems measured in the

**Table 3.** Fine Motor Skills Subtest Scores for Amblyopia and Age-Matched Control Subjects

| | Control ($n$ = 37) | All Amblyopes ($n$ = 82) | $P$ ($\chi^2$) | Infantile Esotropia ($n$ = 17) | Acquired Strabismus ($n$ = 28) | Anisometropia ($n$ = 15) | Mixed ($n$ = 13) | Deprivation ($n$ = 9) | $P$ (Kruskal-Wallis) |
|---|---|---|---|---|---|---|---|---|---|
| **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) | 0.138 |
| 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) | 0.157 |
| 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) | **0.001*** |
| 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) | 0.063 |
| 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) | **0.024*** |
| 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) | 0.064 |
| 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) | **0.021*** |
| 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) | 0.167 |
| 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) | **0.002*** |
| **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) | **0.012*** |
| 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) | **0.014*** |
| 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) | **0.045*** |
| 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) | 0.097 |
| 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) | **0.043*** |
| 8-6 Drawing vertical lines | 6 (3–8) | 5 (0–8) | **0.000*** | 5 (1–8) | 4 (0–6) | 5 (2–7) | 5 (2–7) | 5 (4–6) | **0.003*** |
| 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) | **0.001*** |
| 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) | **0.022*** |
| 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) | **0.000*** |

Data are the median (range).
* Difference is significant $P < 0.05$ level.

**Table 4.** Age-Standardized Fine Motor Skills Scores for Amblyopic and Age-Matched Control Subjects

| | 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 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $F_{(1,117)}$ | $P$ | | | | | | $F_{(5,113)}$ | $P$ |
| Visual Motor Control (VMC) | | | | | | | | | | | |
| Standard Score | 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** |
| Upper Limb Speed and Dexterity (ULSD) | | | | | | | | | | | |
| Standard Score | 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 Fine Motor 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** |

Data are the mean (SE).
* Post hoc Bonferroni indicates significant difference.

**Table 5.** Proportion of Subgroups Scoring in Above-Average or Higher Ranges on Fine Motor Skills Tasks

| | Amblyopic Subgroups | | | | | | | 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) | All Amblyopes ($n$ = 82) | Control ($n$ = 37) | $\chi^2$ ($df$ = 10) | Asymp. Sig. (Two-Sided) $P$ | $\chi^2$ ($df$ = 2) | Asymp. Sig. (Two-Sided) $P$ |
| **Visual Motor Control** | | | | | | | | | | | |
| Above average | 8 (47) | 14 (50) | 9 (60) | 5 (38) | 9 (100) | 45 (55) | 29 (78) | | | | |
| Average | 9 (53) | 13 (46) | 5 (33) | 7 (54) | 0 (0) | 34 (41) | 8 (22) | **19.13** | **0.039** | **6.46** | **0.040** |
| 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) | | | | |
| Average | 9 (53) | 13 (46) | 10 (67) | 6 (46) | 3 (33) | 41 (50) | 14 (38) | **20.18** | **0.028** | **9.35** | **0.009** |
| Below average | 2 (12) | 8 (29) | 2 (13) | 2 (15) | 0 (0) | 14 (17) | 1 (3) | | | | |

Data are the number (%).

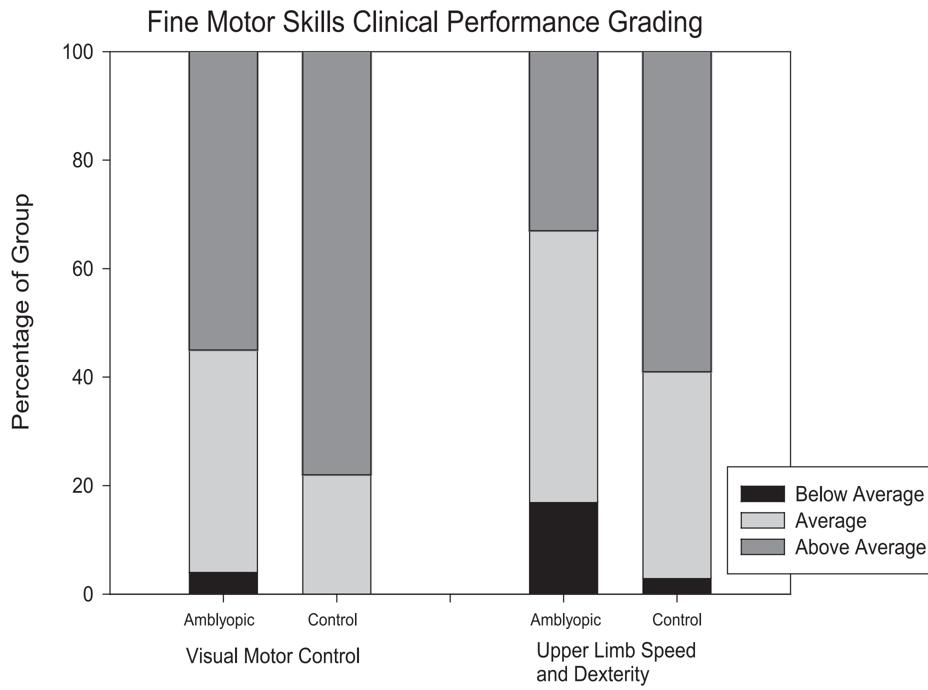


**FIGURE 1.** Proportion of amblyopia and control groups in clinical performance bands.

ULSD subtest (putting pennies in boxes, sorting cards, stringing beads, displacing pegs, drawing vertical lines, making dots). Median and range for subitem scores and subitem 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 nonparametric tests were used.

Age-standardized scaled scores, calculated from the subitem sum,[22] were significantly lower in the amblyopia group than in 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 3.43 standard points lower than control subjects in this item, whereas the difference between amblyopes and control subjects was 1.73 standard points for the VMC item (Table 4).

An estimate of the level of clinical performance on an overall item can be derived from the age-standardized scaled score by referring to published normative data.[22] For both fine motor skills domains, a greater proportion of the amblyopia

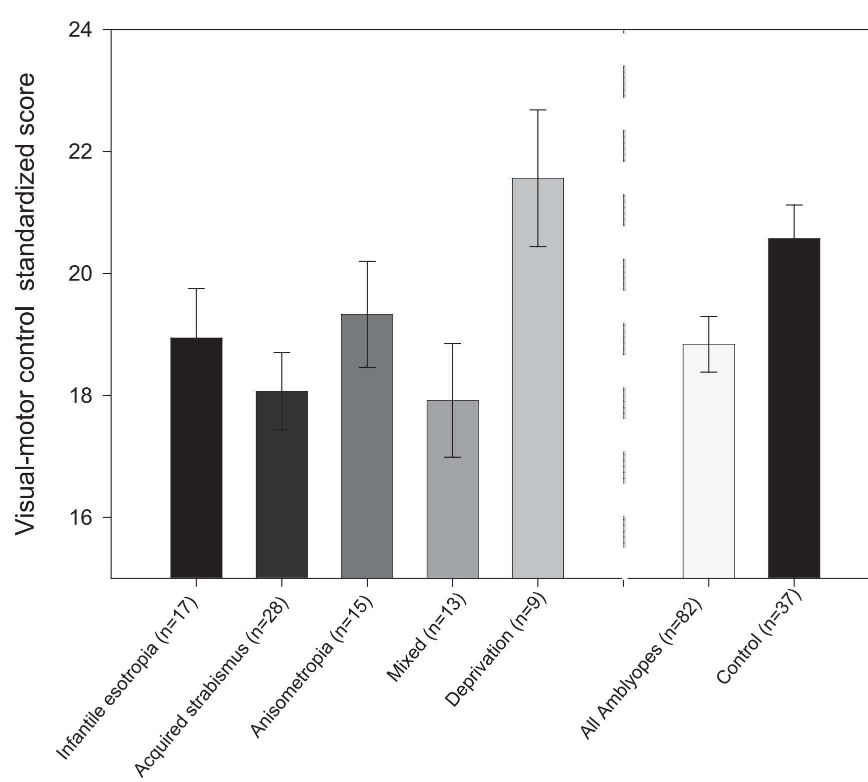


**FIGURE 2.** Visual-motor control standardized score for amblyopia groups and control.

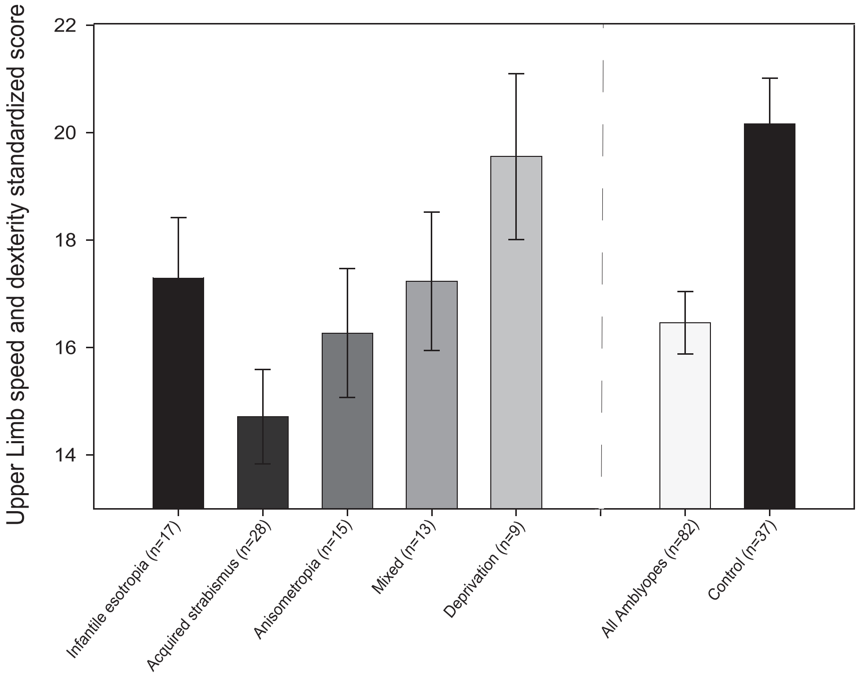


**FIGURE 3.** Upper limb speed and dexterity standardized score for amblyopia groups and control.

group than of the control group had below-average scores and fewer subjects in the amblyopia group achieved above-average scores (VMC $\chi^2 = 6.5$; $P = 0.040$; ULSD $\chi^2 = 9.35$; $P = 0.009$; Fig. 1). Differences were also evident between subgroups (VMC $\chi^2 = 19.13$; $P = 0.039$; ULSD $\chi^2 = 20.18$; $P = 0.028$; Table 5).

## Impact of Etiology

Subgroup etiology had a significant impact on the age-standardized scaled score for both VMC and ULSD items, and the overall fine motor skills score (ANOVA, $F_{(5,113);}$ $P < 0.05$; Table 4; Figs. 2, 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.

## Impact of Binocularity

The level of stereopsis had a significant effect on the score achieved for both the VMC item ($F_{2,116} = 4.712$; $P = 0.011$) and the ULSD item ($F_{2,116} = 4.178$; $P = 0.018$) as well as on the total fine motor skills score ($F_{2,116} = 6.405$; $P = 0.002$; Table 6). Post hoc analysis indicated that the subgroup with normal stereopsis performed significantly better than both the no-stereopsis and the reduced-stereopsis groups on both the ULSD item and overall fine motor skills score, and the same group performed better than the reduced stereopsis group on the VMC item.

## Determinants of Fine Motor Skills Performance

There were several 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 used to determine which visual characteristics could best predict any decrements in fine motor skills performance when the intercorrelation between the visual factors was taken into account.

The influence of VA (in either eye) and refractive error, together with the presence of a history of strabismus (which included a history of infantile esotropia, acquired strabismus, or amblyopia of mixed origin), and the 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 qualities on the overall fine motor skills score (sum of VMC and ULSD standardized scores). The general linear multiple regression model indicated that when the interrelationships between these subject characteristics were 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 with the level of binocular function, measures of refractive error, or VA in the better and worse eyes (Table 8).

**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** |

*† Post hoc Bonferroni indicates significant difference.

**TABLE 7.** Intercorrelations between Vision Parameters and Performance of Fine Motor Skills

| | Vision Characteristics | | | | Fine Motor Skills Result | | |
|---|---|---|---|---|---|---|---|
| | Binocular | Average Refractive Error | VA Worse Eye | VA Better Eye | Standard-Score VMC | Standard-Score ULSD | Total Fine Motor Skills Score |
| Strabismus | 0.601* | −0.484* | −0.080 | −0.392* | 0.267* | 0.281* | 0.354* |
| Binocular | | −0.304* | −0.388* | −0.270* | 0.060 | 0.139 | 0.136 |
| Average Refractive Error | | | .195 | 0.324* | −0.182 | −0.285* | −0.311* |
| VA Worse Eye | | | | 0.243* | 0.013 | −0.074 | −0.048 |
| VA Better Eye | | | | | −0.147 | −0.018 | −0.093 |

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

## 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 standardized test. Their performance was compared with that of an age-matched control group and the influence of etiology and binocularity on fine motor skills performance was examined in a multiple regression model that accounted for intercorrelation between possible explanatory measures.

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

When the fine motor skill performance scores were compared with published normative data, a range in motor skills ability is seen in both groups; however, a larger proportion of the amblyopia group had scores that fell in the below-average performance range and a smaller proportion performed in the above average range for both fine motor skills domains (Fig. 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 aged 4 to 6 years with congenital esotropia,[13] where it was found that, in addition to poorer total scores, the children with strabismus performed worse than age-matched control subjects on the subscale that assessed manual dexterity.[13] A speed-accuracy tradeoff has been proposed when quantifying the reaching and grasping behavior in amblyopic subjects.[25] During the timed ULSD tasks, in which for the majority of subitems, 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 amblyopes 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 amblyopes, under both binocular and nondominant eye viewing conditions, showed a range of deficits in the approach to an object and when closing and applying grasp. The differences between their amblyopes and control subjects included prolonged execution times and more errors, the extents of which covaried with the existing depth of amblyopia, although not its etiology. Our finding that ULSD tasks were affected 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 difficulty with timed motor performance tasks. They 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 intercorrelation between VA deficit and loss of

**TABLE 8.** Multiple Linear Regression Model of Fine Motor Skills Performance in Total Group

| | *n* | Mean | SE | Regression Coefficient (B) | SE | *F* | *P* | Partial Eta$^2$ |
|---|---|---|---|---|---|---|---|---|
| Strabismus | | | | | | | | |
| Yes | 58 | 34.43 | 1.27 | 36.109 | 2.218 | **5.428** | **0.022** | **0.046** |
| No | 61 | 39.04 | 1.09 | 40.715 | 1.119 | | | |
| Stereopsis | | | | | | | | |
| Nil | 50 | 37.64 | 1.26 | −0.063 | 2.385 | 1.862 | 0.160 | 0.032 |
| Reduced | 31 | 34.86 | 1.25 | −2.836 | 1.968 | | | |
| Normal | 38 | 37.70 | 1.55 | 0* | | | | |
| Average refractive error | | | | −0.517 | 0.329 | 2.470 | 0.119 | 0.022 |
| VA in worse eye | | | | −0.162 | 1.977 | 0.007 | 0.935 | 0.000 |
| VA in better eye | | | | 4.630 | 5.237 | 0.781 | 0.379 | 0.007 |

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

binocular function, while acknowledged, was not accounted for in their analysis.

We anticipated that the etiology of amblyopia could influence performance on fine motor skills tasks due to hypothesized 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 amblyopia groups displayed a deficit in fine motor skills. Although we recognize 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 at average or above-average performance levels, even though this group had the highest interocular VA deficit and few 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 interocular 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 etiologic groups.[5] Hand–eye coordination 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 the performance of fine motor skills may indicate that the neurological changes associated with strabismus have a detrimental influence on the development of hand–eye coordination skills.

The variation in the proportion of subjects in each etiological 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, whereas only approximately 10% of those with strabismus showed a binocular response. In our study, many of the subjects with strabismic amblyopia 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 the Mirror-Pola test).[21] However, when analyzed in the multiple regression model that takes into account the intercorrelation between strabismus and stereopsis, the influence of the level of stereopsis was not found to be significant.

In previous studies, investigators 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 neurodevelopmental performance of infants with strabismus,[28] and in nonstrabismic amblyopes, stereopsis, independent of VA, has been found to influence performance on visual motor integration (design copying).[27] However, researchers in a recent study reporting improvements in motor coordination in children who underwent late surgery for congenital esotropia (strabismus) could not relate the changes to postoperative 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 amblyopes 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 the 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 interrelationships by examining fine motor skills scores in a multiple regression model that took into account the intercorrelation 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 performance.

We explored the possible functional impact associated with amblyopia in a childhood population and the results 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 standardized, age-appropriate tasks designed to assess the motor skills needed in practical, everyday tasks. This particularly applies to child amblyopes with strabismus, and the impact of amblyopia was greatest on manual dexterity tasks that require speed and accuracy. 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 subjects with amblyopia from a range of origins. We did not separate the children with amblyopia 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 standardized measures of educational performance in a larger group of normal children. Clinicians may want to make parents and carers for children with a diagnosis of amblyopia aware of this more global impact when discussing the consequences of the condition.

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