Refractive errors in infancy predict reduced performance on the Movement Assessment Battery for Children at 3½ and 5½ years

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We have previously reported that significant hyperopia at 9 months predicts mild deficits on visuocognitive and visuomotor measures between 2 years and 5 years 6 months. Here we compare the motor skills of children who had been hyperopic in infancy (hyperopic group) with those who had been emmetropic (control group), using the Movement Assessment Battery for Children (Movement ABC). Children were tested at 3 years 6 months (hyperopic group: 47 males, 63 females, mean age 3y 7mo, SD 1.6mo; control group: 61 males, 70 females, mean age 3y 7mo, SD 1.2mo) and at 5 years 6 months (hyperopic group: 43 males, 56 females, mean age 5y 4mo, SD 1.7mo; control group: 51 males, 62 females, mean age 5y 3mo, SD 1.6mo). The hyperopic group performed significantly worse at both ages, overall and on at least one test from each category of motor skill (manual dexterity, balance, and ball skills). Distributions of scores showed that these differences were not due to poor performance by a minority but to a widespread mild deficit in the hyperopic group. This study also provides the first normative data on the Movement ABC for children below 4 years of age, and shows that it provides a useful measure of motor development at this young age.

Hyperopia is the most common type of refractive error in infancy in Caucasian populations. We have shown that uncorrected hyperopic refraction, detected in a population screening programme (the first Cambridge infant screening programme) of cycloplegic photorefraction in infancy and confirmed by retinoscopy, is a predictor of poor vision (strabismus and reduced acuity) at 4 years of age (Atkinson 1993, Atkinson et al. 1996). Observations over the course of this programme suggested that this outcome might be associated with a broader range of developmental delays, but no formal measures of these aspects of development were taken in the first Cambridge screening programme. A second screening programme of infant vision (Atkinson et al. 1995, 1996; Anker et al. 2003) included detailed assessments of the relations between early refractive measures and later outcomes, both in the visual domain and in the motor, language, and cognitive domains. In a previous paper (Atkinson et al. 2002) we reported measures showing that infants who were detected as significantly hyperopic at 9 months showed deficits compared with refractively normal controls on a range of visuocognitive and visuomotor measures at 2, 3½ and 5½ years. In the present paper we examine in detail the performance of these children on motor skills, assessed by the Movement Assessment Battery for Children (Movement ABC; Henderson and Sugden 1992) at 3½ and 5½ years. The published normalization of this test is for children of 4 years and older. In addition to providing an account of the relation between infant refraction and later visuomotor ability, the present results are to our knowledge the first normative data on the Movement ABC for children aged 3 to 4 years, and show that the test provides a useful measure at this age.

THE SECOND CAMBRIDGE INFANT SCREENING PROGRAMME

The Second Cambridge Infant Screening Programme (Atkinson et al. 1995, 1996; Anker et al. 2003) used non-cycloplegic videorefraction to detect refractive errors in a population of infants 8 to 9 months old. Analysis of the large data sets collected in the course of the programme is ongoing; we have reported data on the incidence of visual conditions detected at screening (Atkinson et al. 1996, Anker et al. 2004) and summaries of the cognitive, language, and motor outcome for children who were hyperopic in infancy and those who were emmetropic (Atkinson et al. 2000, 2002). Several groups were defined on the basis of refraction. Here we compare performance on the Movement ABC between children initially detected by non-cycloplegic screening with hyperopic focus (hyperopic refractions were subsequently confirmed by retinoscopy under cycloplegia), called the 'hyperopic' group, and those who were emmetropic (normal orthoptic examination; no significant refractive error on non-cycloplegic screening, confirmed by retinoscopic refraction under cycloplegia), who were selected at the same time as the hyperopic group, and are called the 'control' group throughout this report.

THE MOVEMENT ABC

The Movement ABC is designed to provide a standardized assessment of the everyday motor competence of children between the ages of 4 and 12 years. It comprises tasks under the three categories of manual dexterity, static and dynamic balance, and ball skills. A child's score on each test is converted to a standardized impairment score, based on centile bands for the child's age group. The particular test items change with age, with four distinct sets of tests corresponding to four age bands covered by the Movement ABC (4 to 6, 7 to 8, 9 to 10, and 11 to 12y). Scores are standardized independently for different age groups within a single band. Although at 3½ years of age our group was 6 months below the youngest age for which the test items are intended, most children completed the tests and there was no strong floor effect.

Method

PARTICIPANTS

All infants born within a 2-year period during 1992 to 1994 in the Cambridge (UK) Health District were invited for a vision screening appointment. Of these, 5142 (76%) attended (mean age 8.1mo, standard deviation [SD] 0.8) and had non-cycloplegic videorefraction and an orthoptic examination. All those meeting the criteria for a focusing error, i.e. misaccommodation on the target in one or both eyes, and/or failure on orthoptic examination (total n=491) were invited for a follow-up appointment one month later, along with 287 randomly selected, visually normal control infants from the same population. At the follow-up appointment refractive status was checked with the standard ophthalmological procedure, cycloplegic retinoscopy. Those with significant refractive errors and a control group without significant refractive errors were invited to attend continuing follow-up sessions at intervals of 4 to 6 months. Parents of these children gave informed consent for participation in this study, which was approved by the Ethics Committee of the Cambridge District Health Authority. The screening procedure and follow-up criteria are described in detail elsewhere (Anker et al. 2004); for the present paper, only the hyperopic and control groups will be considered.

To be deemed significantly hyperopic an infant had to meet the following criteria: (1) far focus at screening (at least one axis equal to or greater than +1.5 dioptres [D] on either of two non-cycloplegic videorefractions) and (2) +3.5D or more of hyperopia in at least one axis on cycloplegic retinoscopy 1 month later. To be eligible for selection as a visually normal control, an infant had to have: (1) normal focus at screening (all axes less than +1.5D and more than –3.0D, and a difference of less than 1.5D between parallel axes in the two eyes) and no strabismus or other orthoptic condition, and (2) on

Table I: Characteristics of groups tested at 3½ and 5½ years of age

Characteristic	*Group*	
	Control	*Hyperopic*
3½ years		
n (Male/Female)	131 (61/70)	110 (47/63)
Mean age, y:mo (SD, mo)	3:7 (1.2)	3:7 (1.6)
Refraction at 9 months: greatest axis D, mean (SD)	+1.80 (0.70)	+5.33 (1.48)
5½ years		
n (Male/Female)	113 (51/62)	99 (43/56)
Those also seen at 3½ years, n (%)	106 (81)	87 (79)
Mean age y:mo (SD, mo)	5:3 (1.6)	5:4 (1.7)
Refraction at 9 months: greatest axis D, mean (SD)	+1.78 (0.74)	+5.30 (1.49)

SD, standard deviation; D, dioptres.

Table II: Individual tasks comprising Movement Assessment Battery for Children (Henderson and Sugden 1992) for age range 4 to 6 years. Children aged 3½ and 5½ years were tested on all tasks

Task	*Description*	*Measure*	*Category*
Catching Bean Bag	Catching bean bags with two hands from a distance of 2m (10 attempts). Bag can be gathered to body at age 3½; must be a clean catch at 5½	Number of catches	Ball skills
Rolling Ball into Goal	Rolling a ball between two posts 40cm apart from a distance of 2m (10 attempts)	Number of goals	Ball skills
Walking Heels Raised	Walking along a line on floor with heels raised without stepping off the line for 15 steps	Time (s)	Balance
Jumping over Cord	Jumping from a stationary position with feet together over a cord positioned at knee height. Up to three attempts. Must land with feet together (age 5½); any position (age 3½)	Successful attempt: 1st, 2nd, 3rd, or none	Balance
One-leg Balance	Standing on one leg, with arms held freely at sides, for up to 20 seconds. Preferred and non-preferred legs are tested separately	Number of steps	Balance
Threading Beads	Posting 6 (age 3½) or 12 (age 5½) cube-shaped beads on a lace, one at a time, as quickly as possible	Time (s)	Manual dexterity
Posting Coins	Posting 12 plastic coins into a bank box, one at a time, as quickly as possible using one hand. Preferred and non-preferred hands are tested separately	Time (s)	Manual dexterity
Bicycle Trail	Using a standard form, the child traces along the length of a winding trail with a pen, trying to stay within its boundaries	Number of divergences from trail plus number of 12mm (half inch) lengths for which line continues to diverge	Manual dexterity

cycloplegic retinoscopy 1 month later, less than +3.5D of hyperopia in any axis, less than –3D of myopia in any axis, and a difference of less than 1.5D between parallel axes in the two eyes. The hyperopic group included children with hyperopic astigmatism, where at least one axis of one eye met the criterion of +3.5D hyperopia by cycloplegic retinoscopy.

Of the 456 with 'far focus' at screening (age 9mo), 394 attended follow-up a month later; 261 of these (129 males, 132 females) were confirmed to be hyperopic; 284 visually normal controls attended follow-up, and 264 (136 males, 128 females) were confirmed visually normal. These confirmed groups provided the children whose data are reported here. The characteristics of the groups of children tested on the Movement ABC at 3½ years and 5½ years are presented in Table I. Some children with known developmental problems (e.g. Down syndrome or mild cerebral palsy) were among the follow-up group but have been excluded from this analysis. We report data for all children who attended follow-up appointments at 3½ and 5½ years: at 3½ years this represents 42.1% of the original hyperopic group and 49.6% of the original control group, and at 5½ years 37.9% of the original hyperopic group and 42.8% of the original control group. The remaining children had moved away from the district or had not attended these appointments for Movement ABC testing. The results reported at each age come from slightly larger numbers of participants than in our previous report (Atkinson et al. 2002), because the main part of that analysis involved a large number of different developmental measures and included only longitudinal study of those children who completed all tests.

PROCEDURE

The Movement ABC, age band 1 items (Table II) were administered at ages 3½ years and 5½ years. At both ages, tests were administered as for children 4 to 6 years old (Henderson and Sugden 1992). However, due to the children's young age, the length of the battery and the need to complete several other tests at the same session, at age 3½ years each child attempted each test only once.

Between 3 and 3½ years cycloplegic retinoscopy was performed on children in both groups. The mean greatest axis was 3.05D (SD 1.78) for the hyperopic group and 0.84D (SD 0.83) for the control group, showing that there was still a

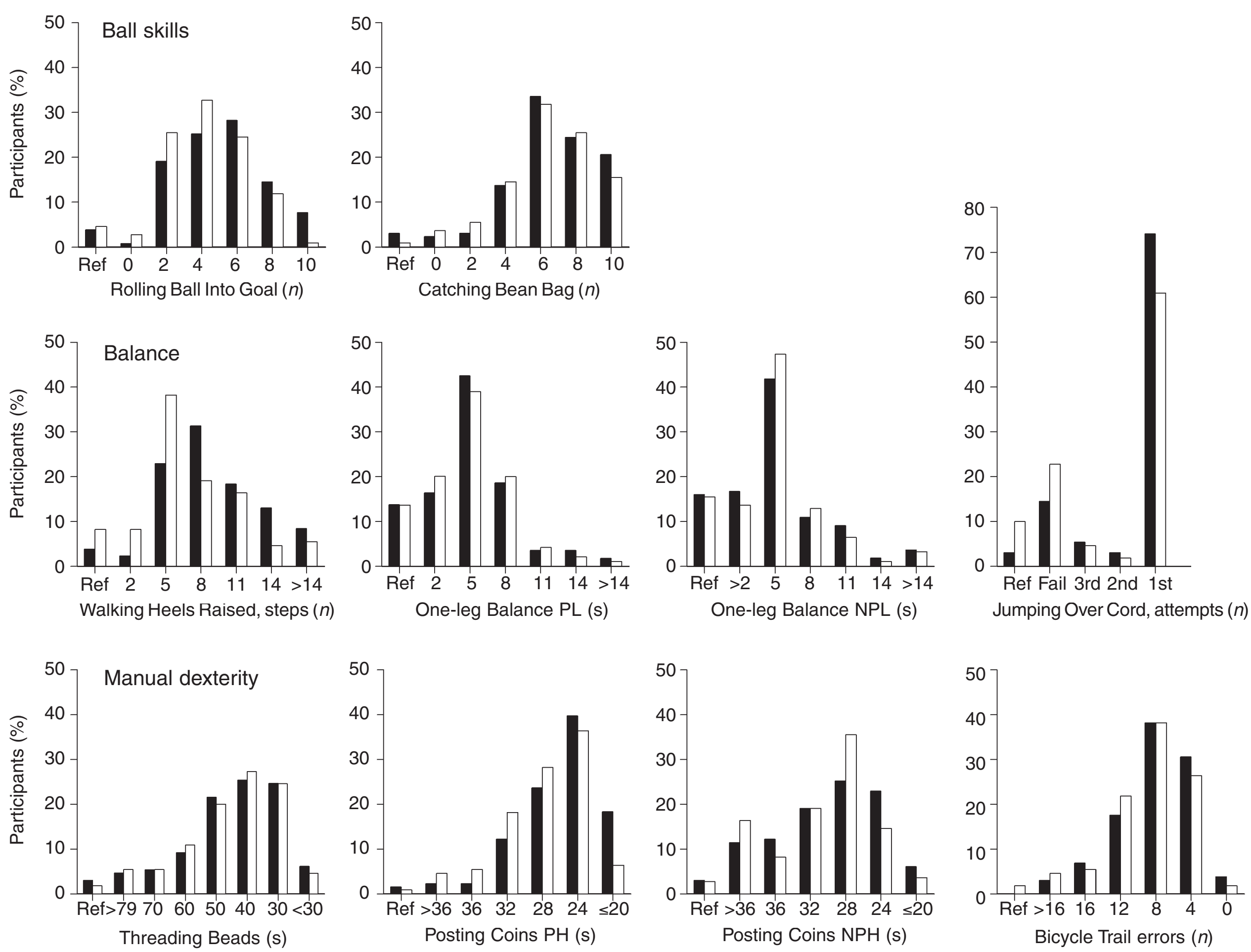

Figure 1: *Distributions of raw scores on individual tests for control and hyperopic groups at 3½ years of age. Better performance is plotted towards right of each histogram. For tests Jumping over Cord, Threading Beads, Posting Coins, and Bicycle Trail, lower numbers on horizontal axis represent better performance. ■, Control group; □, Hyperopic group; Ref, children who refused to attempt or failed to complete a test; PL, preferred leg; NPL, non-preferred leg; PH, preferred hand; NPH, non-preferred hand.*

significant difference in refraction between the groups, but it was much reduced from the difference at 9 to 10 months of age. Although we do not have measures of cycloplegic retinoscopy from these children at 5½ years, at this age we did test their accommodation on a target at 75cm by non-cycloplegic videorefraction. Mean defocus of children in the hyperopic group was 1.87D (SD 1.74) compared with 0.50D (SD 0.17) for the control group.

Children with refractions of +4D or greater on cycloplegic retinoscopy at age 10 months had been entered into a controlled trial of spectacle correction, continuing until age 3½ years (Anker et al. 2004). By the time of the first Movement ABC test (age 3½ years), any child who still had a significant refractive error of more than +1.5D in any axis wore an appropriate spectacle correction for testing with the Movement ABC.

Results

DISTRIBUTIONS OF SCORES ON INDIVIDUAL TESTS

Figure 1 shows the distributions of scores for the control and hyperopic groups on individual tests at 3½ years. Children who refused or did not complete a test are indicated ('Ref' column). Refusal suggests, but does not prove, that the test was beyond the limits of the child's competence. There was a small but consistent difference in the distributions of the control and hyperopic group's scores. All 10 graphs show a pattern with a higher percentage of the control group than the hyperopic group towards the right, and a higher percentage of the hyperopic group towards the left; that is, towards poorer performance. Nine of 10 tests had a higher proportion of the hyperopic than the control group in the lowest category depicted (poor performance); 10 of 10 had a higher proportion of the control than the hyperopic group in the highest category (good performance).

Most participants attempted the tests despite their young age. The control group's refusal or failure rate was highest on the tests of balance (18 participants for balance on preferred leg, and 21 participants for balance on non-preferred leg), with five or fewer children from the control group refusing or failing on each of the remaining eight tests. Similarly, the hyperopic group also had higher refusal rates on balance tests (15 participants for balance on preferred leg and 17 participants for balance on non-preferred leg). In the hyperopic group the

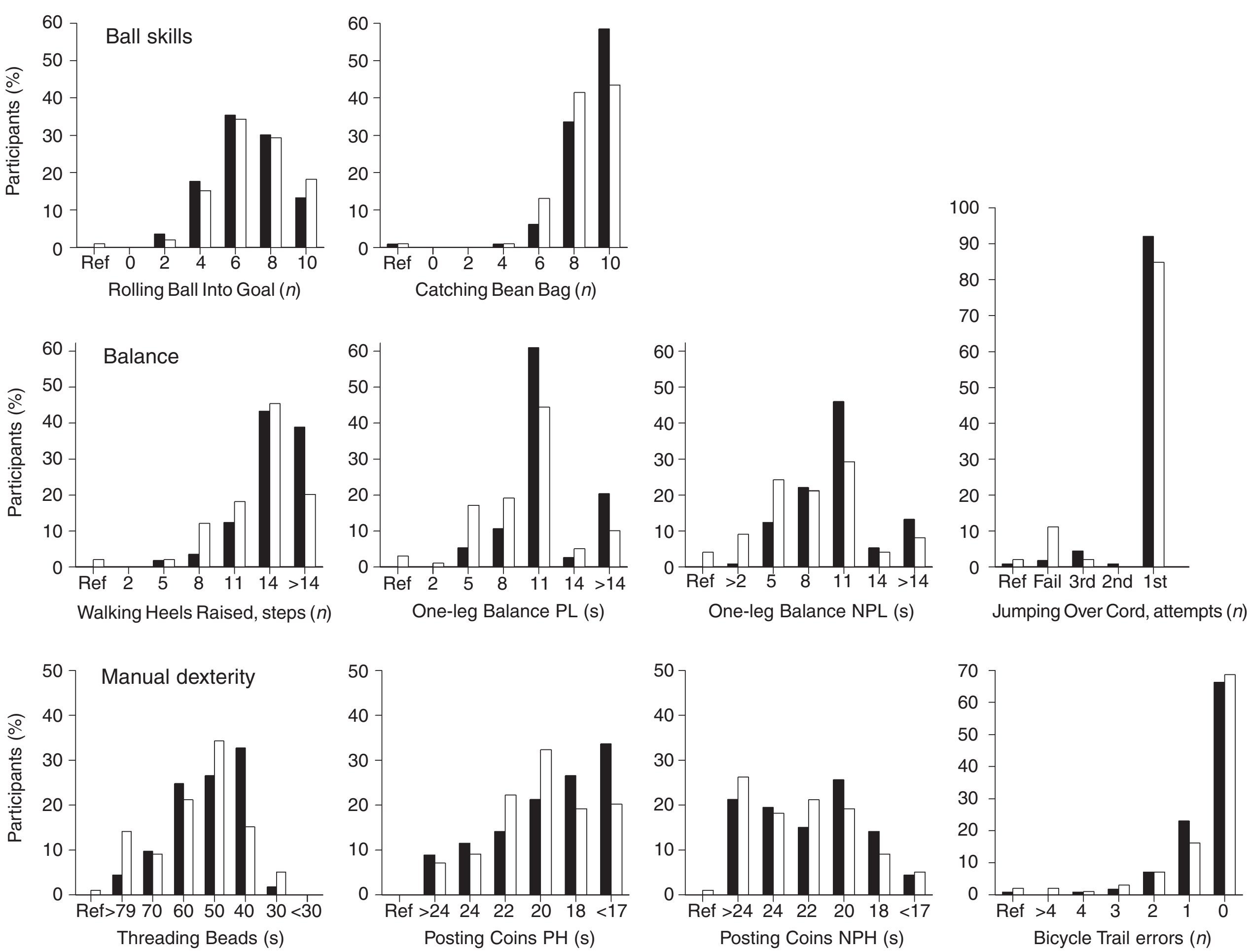

Figure 2: *Distributions of raw scores on individual tests for control and hyperopic groups at 5½ years of age. Better performance is plotted towards right of each histogram. For tests Jumping over Cord, Threading Beads, Posting Coins, and Bicycle Trail, lower numbers on horizontal axis represent better performance. Control group, ■; Hyperopic group, □; Ref, children who refused to attempt or failed to complete a test; PL, preferred leg; NPL, non-preferred leg; PH, preferred hand; NPH, non-preferred hand.*

walking and jumping tests were also refused by proportions approaching or exceeding 10% (nine and 11 participants respectively). Individually, 104 control and 84 hyperopic group children attempted all tests. Six children from the control group accounted for nearly half (33 of 68) of the control group's refusals; eight children from the hyperopic group accounted for more than half (35 of 66) of the group's refusals.

Figure 2 shows the distribution of control and hyperopic groups' scores at 5½ years of age. Again, children in the control group are better represented towards the right of the histograms, indicating better performance than children in the hyperopic group, although the pattern is less consistent than at 3½ years of age.

Both groups' refusal/failure rates were lower than they had been at the younger age; eight of the 10 tests were attempted by all 113 controls, and each of the remaining three tests were refused or failed by only one child. Only one test was completed by all 99 children in the hyperopic group, with between one and three refusals on each of the others. Four children accounted for 14 of the hyperopic group's 16 refusals.

MEDIAN SCORES AND STATISTICAL COMPARISONS

Table III shows median and mean scores at ages 3½ and 5½ years for the two groups. Mann–Whitney *U* tests comparing the groups' scores are also presented. A higher score does not equal better performance on every test; for example, with bead threading or coin posting lower times are better. Tests on which low scores are best are indicated in the table with a dagger.

At 3½ years of age, differences between groups were significant on three tests: Rolling Ball in Goal, Walking with Heels Raised, and Posting Coins with the preferred hand (see Table III). The difference between the proportion of each group refusing to attempt the jump test, was 11 of 110 (10%) hyperopic and 4 of 131 (3%) control, was significant ($\chi^2=4.94, p<0.05$).

At 5½ years of age, both the control and hyperopic groups' median scores were better than at 3½ years despite the stricter procedural requirements for the older age group on some of the tests (see Table II). The one test on which 5½-year median scores were worse, bead threading, required twice the number of beads (12) to be threaded at the later age. At age 5½ years, differences between control and hyperopic groups were significant on five tests: Catching Bean Bag, Walking with Heels Raised, One-leg Balance (preferred leg), One-leg Balance (non-preferred leg), and Threading Beads (see Table III).

TOTAL IMPAIRMENT SCORES AT 5½ YEARS OF AGE

The data presented so far have been the raw scores obtained on each test. These constitute the most sensitive measures of differences in performance; once raw scores are converted to the Movement ABC's standardized impairment scores, the top 85% of the population, scoring 0 (no impairment), become undifferentiated. To provide a direct comparison of our two groups' performance with previously published Movement ABC age norms, and to determine the proportion of children with a clinically significant impairment in each group, raw scores at age 5½ years were converted to total impairment scores. These denote performance at the level of the top 85% (impairment score 0) of children 4 and 5 years old, and those in the bottom 15% (impairment score 1), 10% (score 2), 5% (score 3), 2% (score 4), and 1% (score 5). Standard scores for balance and coin posting are obtained by averaging the scores for the preferred and non-preferred hand/leg tests. Impairment scores for the eight tests are then summed to give a total impairment score, which also corresponds to a standardized centile. At ages 4 and 5 years, a total impairment score of 17 or greater indicates performance at or below the 5th centile and a definite motor problem.

Impairment scores on individual tests at age 5½ years were summed to give total impairment scores for 113 children in the control and 98 children in the hyperopic group (one child who attempted less than six of the 10 tests was omitted from this analysis). It should be noted that the children in our groups were towards the high end of the age group (4 and 5 years) for which the scores were normalized. The control group median impairment score was 3, which corresponds to the 56th centile on the normalization for children 4 and 5 years old, whereas the hyperopic group median was 4.5, which corresponds to the 42nd centile. The difference between groups was significant (Mann–Whitney $U=4012, p<0.001$).

One child (0.9%) in the control group met the criterion for a definite motor problem (score greater or equal to 17; 5th centile), compared with five (5.1%) in the hyperopic group. A statistical comparison of these proportions did not reach significance (Fisher's exact test $p=0.10$). However, using a cut-off value to split performance into categories of such unequal size does not form the basis for a sensitive test of differences.

Table III: Median (mean) scores obtained by control and hyperopic groups on individual Movement ABC tasks at 3½ and 5½ years of age, with results of Mann–Whitney *U* tests

Test	*Units*	*Median (mean) score*		*p*
		Control	*Hyperopic*	
Age 3½ years				
Catch Bean Bag	Bags caught	6 (6.4)	6 (5.9)	*ns*
Roll Ball	Balls rolled into goal	5 (4.7)	4 (3.9)	<0.05
Walk	Steps walked	7 (8.3)	5 (6.4)	<0.001
Jump	Score[a, b]	0 (1.0)	0 (1.5)	*ns*
Balance (PL)	Seconds balanced	4 (4.7)	4 (4.3)	*ns*
Balance (NPL)	Seconds balanced	3 (4.7)	3 (4.5)	*ns*
Coin (PH)	Seconds taken[a]	24 (24.5)	26 (26.3)	<0.01
Coin (NPH)	Seconds taken[a]	27 (28.8)	28 (30.5)	*ns*
Beads: (6 beads)	Seconds taken[a]	46 (49.1)	46 (49.2)	*ns*
Bicycle Trail	Errors made[a]	6 (6.6)	6 (7.0)	*ns*
Age 5½ years				
Catch Bean Bag[c]	Bags caught	9 (8.6)	8 (8.2)	<0.05
Roll Ball	Balls rolled into goal	6 (6.1)	6 (6.4)	*ns*
Walk	Steps walked	14 (13.0)	13 (12.1)	<0.01
Jump[d]	Score[a, b]	0 (0.3)	0 (0.6)	*ns*
Balance (PL)	Seconds balanced	11 (11.8)	11 (9.5)	<0.001
Balance (NPL)	Seconds balanced	9 (9.7)	7 (7.9)	<0.01
Coin (PH)	Seconds taken[a]	19 (19.1)	19 (19.8)	*ns*
Coin (NPH)	Seconds taken[a]	21 (21.8)	22 (22.3)	*ns*
Beads (12 beads)	Seconds taken[a]	55 (57.0)	59 (63.0)	<0.05
Bicycle Trail	Errors made[a]	0 (0.5)	0 (0.6)	*ns*

[a]Lower score indicates better performance. [b]Score: 0, jump on first attempt; 2, jump on second attempt; 3, jump on third attempt; 5, fail on third attempt. [c]Bean bag can be gathered to body at age 3½ years, but must be a clean catch at 5½ years. [d]Must land with feet together at age 5½ years. *ns*, not significant; PL, preferred leg; NPL, non-preferred leg; PH, preferred hand; NPH, non-preferred hand.

MEAN *Z*-SCORES

Total impairment score is a standard overall measure from the Movement ABC, but loses much of the detail in the data and is not normally distributed (distribution peaks at lowest obtainable value, 0). An alternative outcome measure is mean *z*-score, which for each child is the average of that child's *z*-scores (number of SDs from control group's mean) on the eight tests. Because this is derived directly from the raw scores, this is the most sensitive outcome measure and it is also normally distributed. Mean *z*-scores were calculated at age 3½ years for 128 children in the control group and for 108 children in the hyperopic group. Children who did not complete at least six of the 10 individual tests were omitted; those with one to four tests missing were averaged from the tests which were performed (preferred/non-preferred values for the coin and balance tests averaged beforehand when both were available). For children age 3½ years, the control group's mean *z*-score was significantly different to the hyperopic group's score on an independent-samples *t*-test (0.01 [SD 0.50] vs –0.24 [SD 0.47]; $t=3.56$, $p<0.001$): a mean difference of 0.23 with 95% confidence interval (CI) 0.10 to 0.35. Mean *z*-scores were calculated at 5½ years of age for 113 children in the control group and 98 in the hyperopic group (one child who did not complete at least six tests was omitted). For children age 5½ years, the control group's mean *z*-score was significantly different to the hyperopic group's score (0.00 [SD 0.49] vs –0.28 [SD 0.61]; $t=3.72$, $p<0.001$): a mean difference of 0.28 with 95% CI 0.13 to 0.43. These results only confirm the significant difference already found by the non-parametric comparison of total impairment scores reported above. However, a normally distributed outcome measure makes it possible to ask a further question about the groups' distributions and the source of the hyperopic group's deficit.

DISTRIBUTIONS OF OVERALL SCORES

On total impairment scores, mean *z*-scores, and several individual tests the hyperopic group performed significantly worse than the control group. These differences could be due to a widespread but mild deficit in the hyperopic group, or they could be due to a minority of hyperopic group children performing very badly. If only the first of these effects ('widespread/mild deficit') were operating, histograms of overall performance in both groups would show similar (normal) distributions, but in the hyperopic group the whole distribution would be shifted towards poorer performance. The most commonly occurring value (peak) of the hyperopic

Table IV: Normalization calculated from control group data for 3½-year-old children

Standard score	*Centile*	*Roll Ball: balls rolled in goal*	*Catch Bean Bag: bags caught*	*Walk Heels Raised: steps walked*	*Thread Bead: time (s)*	*Post Coins PH: time (s)*	*Post Coins NPH: time (s)*	*Bicycle Trail: errors*
0	>15th	2–10	4–10	5–15	0–62	0–28	0–35	0–10
1	15th	1	3	4	63–68	29–30	36–37	11–12
2	10th	–	–	3	69–80	31–32	38–40	13–14
3	5th	0	2	2	81–88	33–37	41–46	15–18
4	2nd	–	1	1	89–95	38–40	47–49	19–21
5	1st	–	0	0	96+	41+	50+	22+

Ranges of raw scores corresponding to standardized scores (centiles) are indicated. One-leg Balance and jump tests are not shown; these tests were excluded from battery as they were considered too demanding for this age group. PH, preferred hand; NPH, non-preferred hand; –, no equivalent score for this centile.

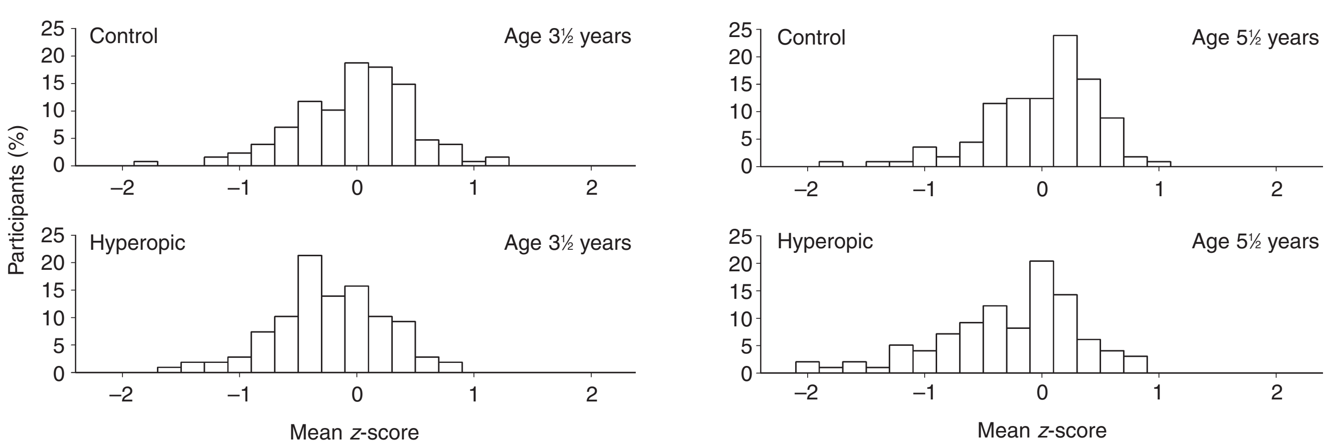

Figure 3: *Distributions of mean z-scores for control and hyperopic groups at 3½ and 5½ years of age.*

group's distribution would therefore be lower, but the shapes of the two distributions would be similar. If only the second effect ('rare/large deficit') were operating, then the hyperopic group's distribution would differ from the control group by a long tail of outlying poor performers (negative skew), but the central portions of the hyperopic group's distribution would not be shifted. If both of these effects were in operation, then the hyperopic group would be characterized by both a stronger negative skew and a shifted distribution.

Figure 3 shows the distribution of mean *z*-scores at ages 3½ and 5½ years for the two groups. At both ages the hyperopic group's distribution is shifted to the left in relation to the control group's and peaks at a lower value, but the hyperopic group's histograms do not appear more negatively skewed. Indeed, at both ages the control group's skew is the more negative: at age 3½ years the hyperopic group had a skewness of –0.23 (standard error of the mean [SEM] 0.23) compared with the control group's –0.36 (SEM 0.21); at age 5½ years they had a skewness of –0.74 (SEM 0.24) compared with the controls' –0.90 (SEM 0.23). Therefore, there is evidence for a widespread/mild deficit in the hyperopic group, but no evidence for a rare/large deficit in a subset of this group.

STRABISMUS AND PRETERM BIRTH

As has previously been reported, hyperopia in infancy significantly increases the risk of strabismus (Atkinson et al. 1996). Strabismus is also known to be associated with deficits of visual–proprioceptive coordination (Mon-Williams et al. 1999). Of the 241 children in our groups tested at age 3½ years, 12 had developed strabismus; all of these were in the hyperopic group. Of the 212 tested at age 5½ years, 15 had developed strabismus, again all in the hyperopic group. It is possible that strabismus would contribute to poorer performance in the hyperopic group, because children who had strabismus might have difficulties with components of tasks requiring stereoscopic vision.

Our analyses of overall outcome (mean *z*-scores at 3½ and 5½ years of age) were therefore repeated, making a distinction between children who had strabismus and non-strabismic children in the hyperopic group. At age 3½ years non-strabismic children in the hyperopic group had a mean *z*-score of –0.22 (SD 0.48), which remains significantly different from the control group (t=3.27, p<0.01; mean difference=0.22; 95% CI 0.09 to 0.35). This shows that strabismus alone did not account for the difference between these groups. Children who had strabismus in the hyperopic group had a mean of –0.31 (SD 0.41), which was not significantly different from the non-strabismic children in this group (t=0.59, p=0.56; mean difference=0.08, 95% CI –0.20 to 0.37), although the small group size (n=12) means that any test for differences would not be very sensitive. At age 5½ years non-strabismic children in the hyperopic group had a mean *z*-score of –0.23 (SD 0.59), significantly different from the control group (t=3.01, p<0.01; mean difference=0.23; 95% CI –0.08 to 0.38). Children who had strabismus in the hyperopic group had a mean *z*-score of –0.62 (SD 0.66) which, despite the small group size, was significantly different from the non-strabismic children in this group (t=2.15, p<0.05; mean difference=0.38; 95% CI –0.02 to 0.74). This indicates that strabismus was associated with worse performance but could not account for the deficit in the hyperopic group.

Preterm birth at less than 34 weeks' gestation is associated with subtle changes in periventricular white matter, and has been shown to predict poor performance on the Motor ABC (Jongmans et al. 1998). Of the children tested at 3½ years of age, the numbers born more than 6 weeks preterm were: control group n=5, and hyperopic group n=6. Of those children tested at age 5½ years the numbers were: control group n=6, and hyperopic group n=3. The deficit in the hyperopic group could not, therefore, be explained by a higher incidence of preterm birth in that group. Nevertheless, preterm birth might have contributed to motor difficulties. At 3½ years of age, preterm children in the control group obtained a mean *z*-score of –0.28 (SD 0.36) compared with 0 (SD 0.50) for those born at greater than 34 weeks' gestation, and children born preterm in the hyperopic group obtained a mean *z*-score of –0.54 (SD 0.49) compared with –0.22 (SD 0.46) for the children born at term. At 5½ years of age, preterm children in the control group obtained a mean *z*-score of –0.16 (SD 0.67) compared with 0.01 (SD 0.48) for children born at term; preterm children in the hyperopic group obtained a mean *z*-score of –0.45 (SD 0.66) compared with –0.28 (SD 0.61) for children born at term. The results are consistent with the previous finding that preterm birth contributes to motor deficits, although at both ages the numbers of preterm children were too low for a reliable statistical comparison with the children born at term. However, the differences between term control and term hyperopic group children remained significant at ages 3½ years (t=3.41, p<0.001; mean difference 0.22 with 95% CI 0.09 to 0.35) and 5½ years (t=3.71, p<0.001; mean difference 0.28 with 95% CI 0.13 to 0.44).

SPECTACLE CORRECTION

Of the hyperopic group tested at age 3½ years, 69 children had been included in our trial of spectacle correction. The mean *z*-score of children who wore a correction (n=37, mean z=–0.40, SD 0.46) did not differ significantly from the mean *z*-score of those who either were not treated or were treated but did not wear their spectacles (n=32, mean z=–0.26, SD 0.40). Of the hyperopic group tested at age 5½ years, 62 had been included in the trial. The mean *z*-scores of children who had worn spectacles (n=32, mean z=–0.30, SD 0.57) and those who had not (n=30, mean z=–0.37, SD 0.72) did not differ significantly.

This suggests that although compliant wearing of spectacles with a partial correction between 10 months and 4 years improves visual outcome (Anker et al. 2004), spectacle correction for hyperopia did not improve the performance of children on the Movement ABC at either 3½ or 5½ years of age.

GROUP DEMOGRAPHICS

We need to ask whether the difference in performance between the refractive groups is a consequence of some other demographic difference between these groups. The proportions of males and females in the hyperopic and control groups (see 'Participants' in Method section, and Table I) did not differ at either the stage when the children were assigned to these refractive groups (χ^2=0.23; p=0.63) or at the follow-ups at 3½ and 5½ years of age (χ^2=0.36 and 0.06; p=0.55 and 0.80 respectively). Other demographic data were not explicitly collected but, on the basis of postal codes, we can divide the families into groups from districts with higher (>£210,000) and lower mean house prices in 2003, a measure that provides a rough indicator of social–economic status. In the initial sample there was no difference in the proportion of hyperopic group children living in higher-priced areas (49.6%) compared with controls (49.4%). The difference in overall dropout rate between families from the higher-priced areas (43.4%) and those from the lower-priced areas (50.9%) was not statistically significant ($\chi^2=2.40$, $p=0.12$). Furthermore, among those attending for the motor ABC, there remained no difference between hyperopic and control groups in the proportion from higher-priced areas (hyperopic, 53.5%; control, 54.7%; $\chi^2=0.04$, $p=0.84$). Thus, such evidence as we have does not suggest a demographic difference between the hyperopic and control groups tested.

NORMALIZATION FOR AGE 3½ YEARS

The control group's data from our tests at 3½ years can be used to produce a normalization of the Movement ABC for that age. The originally published normalization (Henderson and Sugden 1992) extended down only to age 4 years. The ranges of raw scores corresponding to the top 85% (impairment score 0) and the bottom 15th, 10th, 5th, 2nd, or 1st centiles (impairment scores 1, 2, 3, 4, and 5) are presented in Table IV. Because the One-leg Balance and jump tests were refused or not completed by a high proportion of children, these were deemed too difficult to use reliably at this age and were not included in the normalization. On the other tests, refusals or failures to complete were excluded from the normalization. Our figures are based on a relatively small number of children and are therefore less precise than the published norms for older ages. Nevertheless we believe that these norms will be of value for the detection of 3½-year-old children with serious motor difficulties.

Discussion

This study has yielded two kinds of result. First, we have considered in detail the poor performance of children who had been significantly hyperopic in infancy in comparison with the control group without significant refractive errors in infancy. We will discuss this further in a later section. Second, the data from the control group provide norms on the Movement ABC for children between the ages of 3½ and 4 years, younger than the groups for whom the test has previously been normalized.

NORMALIZATION OF THE MOVEMENT ABC AT 3½ YEARS

Most of the tests have proved to be usable, sensitive measures of performance for this age group, with the exception of balancing on one leg and jumping. These tests proved too difficult for a significant proportion of children and consequently we would recommend that they not be included at this age. It must be remembered that the children only attempted each test once, and the normalization, therefore, applies only to a first attempt on each test. The scores on all other tests show improvements in visuomotor development between 3 and 4 years of age, with sufficient sensitivity to obtain useful individual scores for children in this age range.

DIFFERENCES IN PERFORMANCE BETWEEN CONTROL AND HYPEROPIC GROUPS

At both 3½ years and 5½ years of age, children who had been hyperopic in infancy performed significantly worse than controls on at least one test from each of the three categories manual dexterity, balance, and ball skills. Overall, children in the control group scored a little better on nearly all tests in both age groups. However, some of these differences between groups were quite small. When results on individual tests were summed to give an overall measure of motor competence, the hyperopic group's mean total impairment score was significantly higher, with 5.1% of the children in the hyperopic group meeting the criterion for a clinically significant impairment compared with 0.9% of the control group.

Comparison of the distribution of overall scores indicated that the modest overall deficit in the hyperopic group was not a consequence of a few individuals showing large deficits. The hyperopic distribution was characterized by a lower modal (peak) value, but the negative skew was no greater in the hyperopic group than in the control group.

Three hypotheses can be suggested for the poorer performance of children in the hyperopic group. The first possibility is that children in the hyperopic group were still significantly hyperopic at ages 3½ and 5½ years and did not fully accommodate to overcome their hyperopia. The resulting blur would have led to poorer performance on these visuomotor tests, particularly those requiring sharp vision in nearby space (e.g. bead threading). We do not think this is likely because the difference in refraction, although present, was much reduced by 3½ years of age, and any child with a remaining significant refractive error was corrected with spectacles at testing in this study. The difference in defocus measured by non-cycloplegic videorefraction between the groups was also small and seems unlikely to be a major cause of the deficit in the hyperopic group. Furthermore, the group differences were at least as marked on balance and locomotion tasks as on those requiring good accommodation and foveation (tracking, bead threading, and coin posting). Of course, it is possible that for individual children in the hyperopic group who remained markedly hyperopic and did not accommodate consistently, blurred vision might have contributed to their deficits. However, children with hyperopia over +1.5D wore spectacles for visual correction for testing.

A second possibility is that the poorer performance on the visuomotor tasks for the hyperopic group was a direct consequence of early, uncorrected refractive errors leading to mild amblyopia in many children in this group. Support for this hypothesis comes from the finding that the mean acuity of the hyperopic group was significantly lower than that of the control group at this age, even when remaining hyperopia was corrected at testing (Anker et al. 2000). A combination of uncorrected refractive error, poor accommodation, and amblyopia might contribute to the deficits on motor tasks. However, this is unlikely given that many of the Movement ABC tests do not make high demands on visual acuity, and also that we found that children who had been treated with a partial correction by spectacles in the hyperopic group and who had worn their spectacles were not significantly better on the Movement ABC tests at either 3½ or 5½ years of age than hyperopic group children who had not worn spectacles.

The third possibility is that hyperopia in infancy is associated with mild delays in brain development generally and that performance on other sensitive measures of development is likely to be poorer than in children without refractive errors in infancy. This is consistent with our result that the hyperopic group as a whole had depressed Movement ABC scores in comparison with the control group, and with our findings that the hyperopic group showed significantly poorer performance between 12 months and 5 years of age across a range of other developmental tests of visual perception and visuospatial cognition (Atkinson et al. 2002). Measures of balance have been found to be sensitive indicators of developmental coordination disorder (Wann et al. 1998); some of our hyperopic group met the criterion for developmental coordination disorder of being below the 5th centile on the overall Movement ABC score, although none had been explicitly diagnosed with developmental coordination disorder. It is also possible that there is a more general difference between children in the domain of attention. Support for this hypothesis comes from a preliminary analysis of a subset of children in these groups, in whom attentional measures at age 6 years have shown that the children who were hyperopic in infancy have lower scores on a battery of attentional tests (Atkinson et al. 2004).

Further analysis is underway to see whether there are any other identifying factors in the children showing persistent failures on these visuomotor tasks, such as a higher incidence of preterm birth, or the size and nature of initial refractive errors. Further studies are needed to see whether these persistent failures could be prevented and whether hyperopia and failure on the Movement ABC are prognostic indicators of other difficulties (e.g. attention-deficit–hyperactivity disorder and dyslexia in the early school years; see, for example, Nicolson and Fawcett [1994]). However, to separate correlational from causal factors, follow-up studies would require further extensive randomized control trials of early intervention and treatment in infancy and the preschool years.

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References

Anker S, Atkinson J, Braddick O, Ehrlich D, Hartley T, Nardini M, Wade J. (2003) Identification of infants with significant refractive error and strabismus in a population screening program using noncycloplegic videorefraction and orthoptic examination. *Invest Ophthalmol Vis Sci* **44:** 497–504.

Anker S, Atkinson J, Braddick O, Ehrlich D, Nardini M. (2000) Acuity outcome at four years for treated and untreated hyperopes detected in the second Cambridge Infant Refractive Screening Programme. *Invest Ophthalmol Vis Sci* **41:** S730. (Abstract)

Atkinson J, Anker S, Nardini M, Braddick O. (2004) Attention deficits in children who had been detected with refractive errors in infancy: infant vision screening to identify children at risk of cognitive problems in the preschool and early school years. *Paper presented at the Experimental Psychology Society Meeting, Oxford, 31st March, 1994.* http://www.eps.ac.uk/meetings/Oxfordprogramme0304.pdf (accessed 24th January 2005). p 18.

Anker S, Atkinson J, Braddick O, Nardini M, Ehrlich D. (2004) Non-cycloplegic refractive screening can identify infants whose visual outcome at 4 years is improved by spectacle correction. *Strabismus* **12:** 227–245.

Atkinson J. (1993) Infant vision screening: prediction and prevention of strabismus and amblyopia from refractive screening in the Cambridge photorefraction programme. In: Simons K, editor. *Early Visual Development: Normal and Abnormal.* New York: Oxford University Press. p 335–348.

Atkinson J, Anker S, Ehrlich D, Braddick O, Rae S, Weeks F, Macpherson F. (1995) A non-cycloplegic videorefractive infant population screening programme: design, outcome measures and cost effectiveness. *Invest Ophthalmol Vis Sci* **36:** S868. (Abstract)

Atkinson J, Anker S, Nardini M, Braddick O, Hughes C, Rae S, Wattam-Bell J, Atkinson S. (2002) Infant vision screening predicts failures on motor and cognitive tests up to school age. *Strabismus* **10:** 187–198.

Atkinson J, Anker S, Nardini M, Braddick O, Rae S, Hughes C. (2000) Do infant hyperopia and poor accommodation predict deficits in later cognitive and neurological development? *Invest Ophthalmol Vis Sci* **41:** S327. (Abstract)

Atkinson J, Braddick O, Bobier B, Anker S, Ehrlich D, King J, Watson P, Moore A. (1996) Two infant vision screening programmes: prediction and prevention of strabismus and amblyopia from photo- and videorefractive screening. *Eye* **10:** 189–198.

Henderson SE, Sugden DA. (1992) *The Movement ABC Manual.* San Antonio, Texas: The Psychological Corporation.

Jongmans MJ, Mercuri E, Dubowitz LMS, Henderson SE. (1998) Perceptual-motor difficulties and their concomitants in six-year-old children born prematurely. *Hum Mov Sci* **17:** 629–653.

Mon-Williams MA, Wann JP, Pascal E. (1999) Visual–proprioceptive mapping in children with developmental coordination disorder. *Dev Med Child Neurol* **41:** 247–254.

Nicolson RI, Fawcett AJ. (1994) Comparison of deficits in cognitive and motor skills among children with dyslexia. *Ann Dyslexia* **44:** 147–164.

Wann JP, Mon-Williams M, Rushton K. (1998) Postural control and co-ordination disorders: the swinging room revisited. *Hum Mov Sci* **17:** 491–513.