SCIENTIFIC REPORT

Unilateral visual impairment and neurodevelopmental performance in preschool children

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Background: Unilateral visual impairment (UVI) as a result of amblyopia or refractive error is common in childhood, but its functional significance remains largely unexplored.
Aim: To investigate the influence of visual acuity and stereoacuity on the performance of preschool children on tasks requiring visuomotor skills and visuospatial ability.
Methods: Children with normal (6/6) visual acuity (VA) in both eyes and children with UVI ranging from 6/9 to 6/60, with no strabismus and normal vision in the fellow eye, were assessed on a neurodevelopmental test battery of visually guided tasks.
Results: 50 children (mean age (SD): 52.4 (5.7) months; median (range) VA: 6/9 (6/6 to 6/60); median (range) stereoacuity: 70 seconds arc (40–absent)) completed the test battery. UVI and stereoacuity correlated moderately (Pearson's $r = 0.537$, $p < 0.001$) but seven of 28 children with impaired VA had normal stereoacuity (<70 seconds arc) while five of 22 with normal VA had abnormal stereoacuity. Stereoacuity correlated with performance on a task requiring fine hand-eye coordination and a task measuring visuomotor integration. UVI did not correlate with performance on any test battery items.
Conclusions: UVI itself does not appear to relate to visuomotor actions, except when associated with reduced stereoacuity. Stereoacuity appears to have an influential role in fine visuomotor actions and spatial representation in preschool children.

Preschool vision screening commonly detects unilateral visual impairment (UVI), a monocular loss or reduction in visual acuity. UVI may be due to amblyopia ("lazy eye") or anisometropia (an inequality of refractive error between the two eyes). Treatment for UVI consists of spectacle correction for refractive error and/or occlusion of the normally sighted eye when amblyopia is present.[1] Ideally, treatment should be undertaken during a critical period of development that lasts up to approximately 7 years of age.[2]

To ensure early intervention, many countries routinely screen for UVI in early childhood. Yet despite being the most common paediatric ophthalmological disorder, the functional significance of living with UVI is not fully understood.[3] Reduced stereopsis may be a feature of UVI. Stereopsis is the binocular perception of depth and allows fast and easy access to information contributing to our spatial awareness.[3]

Imperfect stereoacuity may disqualify a person from professions requiring a high level of visual skills—for example, piloting an aircraft or joining the police force, and has been linked to poorer academic performance in primary schoolchildren and the neurodevelopmental performance of infants with strabismus (cited by Richardson *et al*,[4] Kulp and Schmidt,[5] and Rogers *et al*[6]).

No previous studies have investigated the influence of UVI on the neurodevelopmental functioning of preschool children. This paper reports the performance of a group of children with UVI detected at preschool screen, on a battery of tasks requiring fine and gross visuomotor skills and visuospatial ability.

METHODS AND MATERIALS

Approval for this study was gained from Newcastle upon Tyne and Sunderland local research ethics committees. Informed, parental consent was gained for all participating children.

Neurodevelopmental test battery development

A test battery was developed to include items targeting performance in visuomotor integration, fine and gross visuomotor skill, and visuospatial processing. Most items were taken from existing, validated test batteries, one item (throw beanbag into basket) was devised for the study. The test battery was found to have adequate test-retest and interobserver reliability, with all items showing good stability over time in this age group (table 1).

Study participants

Two groups of children, aged 3 years to 4 years 9 months, comparable in sex and socioeconomic status:

(1) Children with UVI taking part in a three arm, multicentre randomised controlled trial of treatment for UVI, with uncorrected UVI of 6/9 to 6/60, no strabismus and at least normal (6/6) vision in the fellow eye.[1]
(2) Comparison children recruited from nurseries, with normal vision in both eyes at preschool screening.

The visual status of all children was confirmed on the day of neurodevelopmental assessment. Some children with UVI had already started glasses treatment.

Procedure

To investigate the potential consequence of untreated UVI, all vision tests and neurodevelopmental assessments were performed without refractive correction.

Visual sensory assessment

All vision tests were performed by an orthoptist on the day of, and before, the neurodevelopmental assessment. Visual acuity for distance was assessed using a Snellen based, vision test.[11] Stereoacuity was assessed using the "circles" item of the Randot stereogram test, which grades stereoacuity from 400–40 seconds of arc. At least 75% of visually normal children aged 3–5 years can achieve 70 seconds arc on the circles part of this test.[12] Children unable to correctly

Abbreviations: BPVS, British Picture Vocabulary Scale; UVI, unilateral visual impairment; VA, visual acuity; VMI, visuomotor integration

Table 1 Neurodevelopmental test battery items with scoring criteria and source

Task	Description	Scoring criteria	Ability assessed	Source
Visual search	Find rabbits hidden in array	Total rabbits located in one minute	Visual attention	NEPSY[7]
Block building	Copy construction of various designs	Graded points: 0–12	Visuospatial ability	NEPSY, McCarthy[8]
VMI (short format)	Design copying	As test manual	Visuomotor integration	Beery-Buktenika[9]
Visual tracking	Track route from start to finish with pencil line	Summary score based on time taken to track route and number of errors	Visuomotor control and accuracy of trace	NEPSY, McCarthy
Bead threading	Thread 10 beads onto shoelace	Time taken to thread 10 beads	Fine hand-eye coordination	NEPSY, McCarthy
Ball/beanbag catch	Catch a ball/beanbag thrown towards child's midline from a distance of 6 feet	3 trials each variation. Number of catches with 2 hands (ball and beanbag). Number of catches with 1 hand (beanbag only)	Gross visuomotor coordination	Bruininks-Oseresky test of motor proficiency[10] (ball assessor's own item)
Beanbag target	Throw beanbag into basket from a distance of 6 feet	3 trials. Number of correct hits	Gross visuomotor coordination	Assessor's own item
Balance	Walk forward along a taped line with hands on hips without stepping off line. Step over response speed stick held at child's midline	Pass/fail (minimum 6 consecutive steps to pass walking task) (step over stick without going off the line or touching stick)	Performance balance	Bruininks-Oseresky test of motor proficiency

Items were presented in the order they appear in this table. Intraclass correlation coefficients (95% CI) ranged from 0.70 (0.37 to 0.88) to 0.84 (0.62 to 0.93) across the test items (based on a reliability study using a convenience sample of 19 preschool children, 10 female, 9 male, at mean age of 48 months).

identify the largest disparity (400 seconds of arc) were classified as ''negative'' responders and allocated a notional score of 600 seconds of arc to enable inclusion in the analysis.

Neurodevelopmental assessment

All neurodevelopmental assessments were conducted by the first author (SR) who was masked to the visual sensory measurements made on the same day. Assessments lasted approximately 30 minutes. The British Picture Vocabulary Scale (BPVS-II) was included to screen for developmental delay, with a cut-off score of 70 or below for exclusion.[13]

Data analysis

The dependent variables were visual acuity (of the impaired eye for children with UVI and 6/6 for children with normal vision in both eyes) and stereoacuity. Logarithmic transformation of these visual sensory scores was performed to allow parametric analysis and use of the geometric mean.[14] As the test battery items were scored on different scales, standardised z scores were generated and a composite score calculated (Z score = (raw score – group mean)/group SD). The effect of UVI on test battery performance was analysed using Pearson correlation and linear regression.

RESULTS

Thirty children with UVI (of 59 eligible trial participants) were recruited. Ten children had been in glasses treatment for up to 6 weeks and five for more than 12 weeks. On the day of their neurodevelopmental assessment the uncorrected median visual acuity in the impaired eye of the recruited children was 6/12 (range 6/6–6/60). Visual acuity in all fellow eyes was 6/6. Four children (13%) had normal, uncorrected vision in both eyes; three had not been in treatment. The 29 non-participating children (49%) had a median referral visual acuity of 6/18 (range 6/9–6/60) in their impaired eye. Children with poorer monocular acuities (6/18–6/60) were significantly under-represented in this UVI sample ($\chi^2 = 4.800$, df = 1, p = 0.028).

Twenty children with normal vision in both eyes at preschool screen (non-UVI) were also recruited to the study. On the day of their neurodevelopmental assessment 2/20 non-UVI children had reduced vision in one eye (6/9 and 6/12). Substantial variation in stereoacuity values was also apparent—five non-UVI children had stereoacuity worse than 70 seconds of arc and five with UVI had stereoacuity better than 70 seconds of arc (table 2).

The data from these 50 children, at a mean age (SD) of 52.4 (5.7) months, 52% male, provided a spectrum of visual acuities from 6/6 in both eyes to a monocular impairment of 6/60, median 6/9, and stereoacuities from 40 seconds of arc to absent, median 70 seconds of arc. Five children (one non-UVI) had no measurable stereoacuity and were given a nominal score of 600 seconds of arc. No child had developmental delay.

Impaired visual acuity correlated moderately with reduced stereoacuity (Pearson's $r = 0.525$, $p<0.001$, two tailed) but did not correlate with the composite battery score or any of the individual test battery items. Reduced stereoacuity showed moderate correlations of statistical significance with poorer performance on the composite battery score: ($r = -0.417$, p = 0.002) and on three individual test battery items (bead threading: $r = -0.445$, p = 0.001; VMI: $r = -0.341$, p = 0.0; block building: $r = -0.305$, p = 0.03). In the regression model, visual acuity and stereoacuity were entered as the main predictor variables, with age and sex entered to control for any confounding effect of these variables. Impaired visual acuity

Table 2 Uncorrected Snellen visual acuity and randot stereoacuity as measured on the day of the neurodevelopmental assessment

		Stereoacuity category (seconds of arc)				
Visual acuity category		<70	70–100	101–400	600 (notional score)	Total
6/6	6/6	17	3	1	1	22
6/6	6/9–6/12	7	6	3	2	18
6/6	6/18–6/24		4	1		5
6/6	6/36–6/60		2	1	2	5
Total		24	15	6	5	50

did not predict performance on the composite battery score or any of the test battery items.

Stereoacuity and age significantly predicted the composite score (stereoacuity: $\beta = -0.298$, $p = 0.019$; age: $\beta = -0.433$, $p = 0.001$; adjusted $R^2 = 0.320$; $F_{2,47} = 12.516$, $p<0.001$). Stereoacuity and sex (positive female bias) predicted performance on the bead threading item (stereoacuity: $\beta = -0.353$, $p = 0.004$; sex: $\beta = -0.429$, $p = 0.001$; adjusted $R^2 = 0.348$; $F_{2,47} = 14.050$, $p<0.001$). Stereoacuity predicted visuomotor integration (stereoacuity: $\beta = -0.341$, $p = 0.015$; adjusted $R^2 = 0.098$; $F_{1,48} = 6.307$, $p = 0.015$).

DISCUSSION

This study demonstrated a relation of comparable strength between impaired visual acuity and stereoacuity to that previously reported in preschool children with UVI.[4] We also found that stereoacuity, and not impaired visual acuity, significantly predicted performance on a task requiring fine hand-eye coordination and on a task measuring visuomotor integration. Though this is the first study to present these findings for preschool children, a similar link between stereoacuity and fine visuomotor control has been reported in adult subjects, though the reported relation was non-linear.[15] The present findings suggest evidence of a linear relation.

Our findings support a maturational effect for the development of stereoacuity in this age group as reduced stereoacuity, though more frequently observed in children with UVI, was neither exclusive to nor predicted by having this condition.[4] These findings are limited to some extent in that some children who had begun treatment were then assessed without the benefit of their glasses. For the few children who had worn their glasses for longer than 12 weeks this may have produced a treatment effect for their VA and stereoacuity.[16] However, it is also possible that children with UVI who had achieved normal visual acuity by the time of their neurodevelopmental assessment, may not yet have normalised their stereo function, if indeed they ever would do so.[4]

Children rely heavily on visual guidance for the spatial execution of tasks involving hand and arm movements during the early years of education.[17] Binocular cues are considered to be pre-eminent in the control of visually guided reaching and grasping behaviour.[18] Low VMI scores have been found to significantly predict handwriting skill in first grade children and to be important correlates of reading achievement.[19 20] A recent study found lower levels of measurable stereoacuity to be significantly related to poorer outcome on teacher ratings of reading performance, writing ability and mathematics in children aged between 5 years and 7 years.[5] Though children with UVI do not regularly present with obvious learning difficulties, Packwood *et al* found that 52% of respondents in their survey felt their visual condition had interfered with their schoolwork.[21] Other authors have failed to find a relation between visual function and academic achievement, but such studies do not directly investigate stereoacuity.[22 23]

The present study represents the first attempt to investigate the relation between UVI detected at preschool vision screen and neurodevelopmental function in a large group of preschool children. Monocular reduced visual acuity itself was not found to relate to any of the tasks presented to our young participants, but our results suggest that stereoacuity may have an influential role for the execution of fine visuomotor actions and the development of cognitive processes involving spatial representation in preschool children of normal intelligence. As children with worse degrees of UVI were under-represented in the study group, it is conceivable that the impact of a deficiency in stereoacuity may be stronger than that reported here.

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