The Functional Significance of Stereopsis

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Purpose. Development or restoration of binocular vision is one of the key goals of strabismus management; however, the functional impact of stereoacuity has largely been neglected.

Methods. Subjects aged 10 to 30 years with normal, reduced, or nil stereoacuity performed three tasks: Purdue pegboard (measured how many pegs placed in 30 seconds), bead threading (with two sizes of bead, to increase the difficulty; measured time taken to thread a number of beads), and water pouring (measured both accuracy and time). All tests were undertaken both with and without occlusion of one eye.

Results. One hundred forty-three subjects were recruited, 32.9% ($n = 47$) with a manifest deviation. Performances on the pegboard and bead tasks were significantly worse in the nil stereoacuity group when compared with that of the normal stereoacuity group. On the large and small bead tasks, those with reduced stereoacuity were better than those with nil stereoacuity (when the Preschool Randot Stereoacuity Test [Stereo Optical Co, Inc., Chicago, IL] results were used to determine stereoacuity levels). Comparison of the short-term monocular conditions (those with normal stereoacuity but occluded) with nil stereoacuity showed that, on all measures, the performance was best in the nil stereoacuity group and was statistically significant for the large and small beads task, irrespective of which test result was used to define the stereoacuity levels.

Conclusions. Performance on motor skills tasks was related to stereoacuity, with subjects with normal stereoacuity performing best on all tests. This quantifiable degradation in performance on some motor skill tasks supports the need to implement management strategies to maximize development of high-grade stereoacuity. (*Invest Ophthalmol Vis Sci.* 2010;51:2019–2023) DOI:10.1167/iovs.09-4434

Many decisions surrounding the management of strabismus are based around the assumption that stereopsis is beneficial.[1] For example, the optimum management of infantile esotropia is debated, with some advocating early surgery to minimize the period of misalignment,[2–9] resulting in a greater chance of development of stereopsis. The presence of early stereopsis after correction of the deviation is associated with a reduction in the probability of requiring additional surgery for recurrent esotropia or consecutive exotropia.[10] Those subjects without stereopsis were 3.6 times more likely to require further horizontal muscle surgery.[10]

In addition to a greater stability of surgically corrected deviations, research has shown a significantly lower relative risk of development of severe amblyopia in patients with stereopsis (Bosworth RG, et al. *IOVS* 2003;44:ARVO E-Abstract 3183). As well as the potential benefits to ophthalmic outcome it is also believed that the presence of good binocular functions, in particular stereopsis, provides a better quality of visual function and therefore is of benefit in our everyday lives.[11] Despite this, the functional benefits of stereopsis have been largely neglected.[12]

This study was conducted to analyze the relationship between the performance on motor skills tasks and the level of stereoacuity in relation to the following questions:

1. Is the level of stereoacuity related to performance on the motor skills tasks?
2. Is there an adaptation to long-term absence of stereopsis?
3. If there is a deficit, does it change with increasing task difficulty (i.e., comparing large and small bead tasks)?
4. Does the level of acuity or presence of amblyopia influence these results?

Methods

Subjects

Subjects with normal, reduced, or nil stereoacuity were recruited from the University of Liverpool and the Royal Liverpool Children's Hospital. The inclusion criteria were age between 10 and 30 years, visual acuity of at least 0.3 logMAR in the better eye, and no known ophthalmic defect (other than refractive error, amblyopia, or strabismus) or a physical impairment that affects motor skills. Informed consent was obtained before participation from the subject, if aged 18 or above, or from parents if the subject was younger than 18 years (with an assent form signed by the subject). This research protocol observed the tenets of the Declaration of Helsinki and was approved by the Liverpool Research Ethics Committee.

Ophthalmic Measures

Monocular distance acuity was recorded with a front-lit Bailey-Lovie letter logMAR chart (Haag Streit, Harlow, UK) at a test distance of 6 m. A cover test was performed, with and without glasses at 33 cm (to a light and an accommodative target) and 6 m to identify and classify any strabismus present. Stereoacuity was measured using three different tests: Randot Preschool Stereotest (Stereo Optical Co, Inc., Chicago, IL), the Frisby Stereotest (Frisby Stereotest, Sheffield, UK), and TNO (Richmond Products, Albuquerque, NM).

Motor Skills Tasks

The subjects performed three tasks to assess motor skill function under monocular (subject chose which eye would be occluded) and binocular conditions, with the order of the tests and conditions being randomized. All tests were performed six times (three under binocular

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Table 1. Stereoacuity Results

Subjects	Frisby Median (IQR)	TNO Median (IQR)	Preschool Randot Median (IQR)
All (n = 143)	1.48 (1.3–2.08)	1.78 (1.48–2.38)	1.6 (1.48–2.3)
Constant strabismus (n = 33)	4.0 (2.38–4.0)	4.0 (4.0–4.0)	4.0 (4.0–4.0)
Intermittent strabismus (n = 7)	1.74 (1.6–2.18)	1.78 (1.78–2.68)	2.0 (1.6–2.9)
No manifest strabismus (n = 103)	1.3 (1.3–1.6)	1.78 (1.48–1.78)	1.48 (1.48–1.78)
With amblyopia	2.78 (1.6–4.0)	4.0 (2.0–4.0)	4.0 (1.9–4.0)

Stereoacuity is expressed in log arc sec.

and three under monocular conditions) with the average response calculated to minimize any practice or fatigue effects.

Pegboard Task. A standardized methodology[13] was used, with the pin task requiring the subject to place as many pins as possible in a vertical column of holes on a board within 30 seconds (Purdue Pegboard; Lafayette Instruments, Lafayette, IN). The pins were placed in the right- or left-hand reservoir at the top of the board, and the subject used the left or right column, depending on which was the preferred hand. The subject was instructed to use only one hand to place the pins one at a time, in order, from the top of the board.

Bead Task. This task involved placing a fixed number of beads onto a needle. The beads were placed on a plate to the subject's right or left side, depending on the preferred hand. The subject was instructed to use only one hand and not to touch the needle, to prevent their guiding the beads into place. The time taken to complete the task was measured with a stop watch. This task was performed twice: once with large beads on a large needle and once with small beads on a finer needle.

Water-Pouring Task. This task involved pouring a fixed amount of water (450 mL) from a jug into five measuring cylinders in a fixed position (held in place in a wooden frame). The subject was instructed to pour the water into each cylinder as quickly and accurately as possible up to the 90-mL line, marked with red tape.

Results

Subjects

One hundred forty-three subjects were recruited, with a mean age of 17.5 ± 4.5 (SD) years (range, 10–28). Of the participants, 67.1% (n = 96) had no manifest strabismus and 32.9% (n = 47) had a manifest deviation: 9.1% (n = 13) accommodative esotropia (ET); 2.1% (n = 3) infantile ET; 2.1% (n = 3) acquired nonaccommodative ET; 7.7% (n = 11) micro-ET; 5.6% (n = 8) intermittent exotropia (XT); 3.5% (n = 5) constant XT; 2.1% (n = 3) consecutive XT; and 0.7% (n = 1) micro-XT. The median values, interquartile ranges, and overall range of the stereoacuity results are presented in Table 1. For the purposes of analyses, a value of 10,000 arc sec (4 log units) is assigned to those who had no measurable stereoacuity.

Relationship among Stereoacuity Test Results

To determine whether it would be appropriate to use the responses from one stereotest or all three when evaluating the performance on the motor skills tasks, we compared the responses from each test. The data were grouped into three categories, normal, reduced, and nil, according to the level of stereoacuity on each test. Reduced stereoacuity was defined based on published normative data, as >120 arc sec for TNO,[14,15] >250 arc sec for Frisby,[15,16] and >60 arc sec for Preschool Randot.[17] As expected, due to the different test designs, there was considerable variation in the subjects' responses among the tests, two participants who showed a normal response on the Frisby Test but nil stereoacuity with the TNO, and three with a normal Frisby Test response but nil Preschool Randot Stereoacuity Test response. In addition, there were several whose performances varied by one level between the tests (including 17 who had a normal response on the Frisby Test but reduced on the Preschool Randot). Therefore, all analyses were repeated in the normal, reduced, and nil groupings based on each stereoacuity test.

Impact of Age on Motor Skill Responses

Unexpectedly, we observed an age-related change in performance in the motor skills tasks among younger subjects with normal stereoacuity. Therefore, using a bilinear fit model as described previously,[18] we determined the age at which there was a change from the steep performance/age slope that characterized the younger age range and the near-0 slope that characterized the older age range for each motor task. Figure 1 shows the best-fit bilinear model for the performance on the

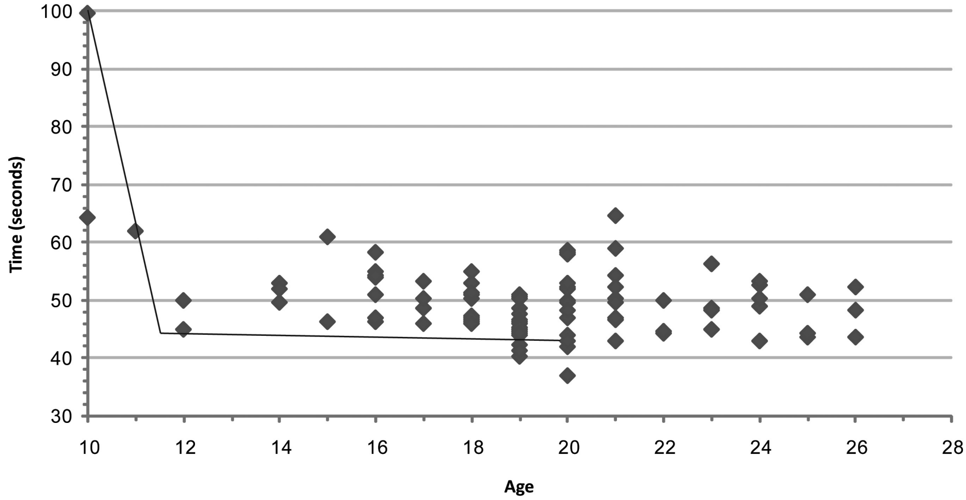

Figure 1. Response time on the large bead task against age, with the bilinear model shown by the *solid line.*

TABLE 2. Responses on Tasks under Binocular Conditions

	Frisby (n = Normal 102, Reduced 4, Nil 15)	TNO (n = Normal 98, Reduced 5, Nil 18)	Preschool Randot (n = Normal 87, Reduced 14, Nil 20)
Pegboard (n pegs placed)			
Normal	16.73 ± 1.59*	16.8 ± 1.52*	16.83 ± 1.57*
Reduced	16.67 ± 2.16	15.07 ± 2.25†	16.36 ± 1.42
Nil	15.24 ± 1.2	15.59 ± 1.49	15.45 ± 1.59
Beads task time, s			
Large beads			
Normal	49.55 ± 5.16*	49.38 ± 5.1*	48.87 ± 4.93*
Reduced	48.58 ± 0.42	51.0 ± 5.02	52.45 ± 4.72†
Nil	59.38 ± 6.89‡	58.0 ± 7.2	57.62 ± 7.14‡
Small beads			
Normal	58.15 ± 8.64*	57.9 ± 8.49*	57.27 ± 8.49*
Reduced	65.42 ± 10.16†	63.6 ± 11.54	61.36 ± 6.88
Nil	72.56 ± 10.11	71.61 ± 9.89	72.02 ± 9.51‡
Water task			
Accuracy, mL			
Normal	1.81 ± 1.51	1.74 ± 1.38	1.79 ± 1.41
Reduced	2.37 ± 1.6	2.13 ± 1.62	1.68 ± 1.29
Nil	2.6 ± 1.75	2.92 ± 2.08	2.72 ± 2.06
Time, s			
Normal	44.47 ± 11.17	44.18 ± 10.82	43.46 ± 10.91
Reduced	37.25 ± 8.18	41.0 ± 6.08	47.12 ± 9.2
Nil	47.27 ± 10.57	47.72 ± 13.13	47.58 ± 12.52

ANCOVA analysis with age as a covariate.
* Statistically significant difference ($P < 0.05$) between the normal and nil stereoacuity groups.
† Statistically significant difference between the normal and reduced groups.
‡ Statistically significant difference between the reduced and nil groups.

large bead task as a function of age; the intercept of the two lines is at 11.6 years. Similar results were obtained for the other motor tasks (range, 11.6–12.0 years). Therefore, for analyses comparing grouped data, only subjects aged ≥12 years were included. In addition, we used age as a covariate in the analysis of variance between groups, to account for any residual age effects.

Is the Level of Stereoacuity Related to Performance on the Motor Skills Tasks?

Analysis of the binocular performance was performed with an ANOVA, with age as the covariate and least-significant difference post hoc analyses.

Irrespective of which test result was used to determine stereoacuity grading, there was a significant difference on performances of the Purdue Pegboard test and the large and small bead tasks (Table 2, $P < 0.03$ in all cases, ANCOVA; age was statistically significant only on the bead tasks). Neither the time nor the error rate on the water-pouring task was significantly different between the stereoacuity groups.

Posttest analyses demonstrated that, in all cases, those with normal stereoacuity performed significantly better than those with nil stereoacuity. When comparing those with reduced stereoacuity with those with normal stereoacuity, we found a difference in three cases (shown in Table 2), once on each task, but the finding varied depending on how stereoacuity was classified. On both bead tasks, when using the Preschool Randot Stereoacuity Test results, subjects with reduced stereoacuity were quicker than those with nil stereoacuity. Therefore, the response to the question was yes, but it varied depending on which stereoacuity response was used for grading.

Is There an Adaptation to Long-Term Absence of Stereopsis?

To determine whether there is any adaptation to the absence of stereopsis, we compared the nil stereoacuity group in the binocular testing condition (long-term absence of stereopsis) and the normal stereoacuity group in the monocular testing condition (short-term absence of stereopsis). This analysis was performed in the subjects aged ≥12 years with age as a covariate.

As shown in Table 3, there was some evidence of long-term adaptation to the absence of stereoacuity. Results showed that the long-term monocular group was significantly quicker than the short-term monocular group in performing both beads tasks, irrespective of which test was used to quantify normal or nil stereoacuity ($P \leq 0.05$, ANCOVA).

In addition a direct comparison was made in those with normal stereoacuity under monocular and binocular conditions. A paired t-test showed a statistically significant difference in all cases ($P \leq 0.01$).

If There Is a Deficit, Does It Change with Increasing Task Difficulty?

As a different number of beads was used for the large and small bead tasks, direct comparison is not appropriate. Therefore, the percentage increase in difficulty in each task, within each subject, from binocular to monocular was calculated (monocular − binocular/binocular × 100).

On average, those with normal stereoacuity (under monocular conditions) took 7% longer (increase from 31% to 38%) on the small bead task than on the large bead task. In all cases this increase was statistically significant (paired t-test, $P \leq 0.001$). Figure 2 shows a similar pattern for those with reduced stereoacuity (with the exception of those coded as reduced stereoacuity on the Frisby Test); however, the difference reached statistical significance only on the Preschool Randot Stereoacuity Test data ($P = 0.03$). Those with no measurable stereoacuity were still quicker when viewing binocularly than when viewing monocularly, but the percentage increase was not significant.

Table 3. A Comparison of Short-Term (Subjects with Normal Stereoacuity under Monocular Conditions) versus Long-Term (Subjects with Nil Stereoacuity under Binocular Conditions) Monocular Responses in Subjects Aged 12 Years or More (with Age as a Covariate)

	Frisby		TNO		Preschool	
	Short-Term (n = 102)	Long-Term (n = 15)	Short-Term (n = 98)	Long-Term (n = 18)	Short-Term (n = 87)	Long-Term (n = 20)
Pegboard (n pegs placed)	16.4 ± 1.6	15.24 ± 1.2*	16.43 ± 1.55	15.59 ± 1.49	16.48 ± 1.6	15.45 ± 1.59
Beads task time, s						
Large beads	64.94 ± 10.35	59.38 ± 6.89*	64.89 ± 10.48	58.0 ± 7.2*	64.83 ± 11.0	57.62 ± 7.14*
Small beads	80.39 ± 15.55	72.56 ± 10.11*	80.16 ± 15.28	71.61 ± 9.89*	79.4 ± 15.47	72.02 ± 9.51*
Water task						
Accuracy, mL	4.0 ± 5.0	2.6 ± 1.75*	3.92 ± 5.04	2.92 ± 2.08	4.0 ± 5.26	2.72 ± 2.06
Time, s	49.23 ± 12.34	47.27 ± 10.57	49.33 ± 12.45	47.72 ± 13.13	49.12 ± 12.72	47.58 ± 12.52

* Long-term absent stereoacuity group performed significantly better ($P \leq 0.05$, ANCOVA).

Does the Level of Acuity or Presence of Amblyopia Influence These Results?

Residual or untreated amblyopia (defined as interocular acuity difference ≥0.2 logMAR) was present in 30 subjects (interocular acuity difference range, 0–1.76 logMAR): 70% (n = 21) had strabismic amblyopia, and 30% (n = 9) had anisometropic amblyopia. Analysis of covariance between subjects with and without amblyopia, with age as a covariate, demonstrated that the subjects with amblyopia were significantly slower on both bead tasks than were those without amblyopia ($P \leq 0.04$). However, several subjects with amblyopia also had reduced (7%–17%, depending on which stereoacuity value is used) or nil (47%–60%) stereoacuity. Therefore, the analysis was repeated with stereoacuity (logarithmic value) as an additional covariate (repeated for all three stereoacuity responses). This further analysis showed that the difference previously found on the bead tasks was no longer statistically significant. To ensure that the value of 4.0 log arc sec attributed to those with nil stereoacuity did not bias the statistical analysis, we repeated the analysis using a value of 0.2 log arc sec above the highest value attainable on each test (3.0–3.5 log arc sec). The results did not vary with this lower value assigned to the nil stereoacuity group.

Discussion

Performance on motor skills tasks was related to stereoacuity in a large cohort of children and adults, with and without manifest strabismus and a wide range of stereoacuity thresholds. The biggest difference in performance on the motor skills tasks was found when comparing the performance of those with normal stereoacuity with that of those with nil stereoacuity, which corresponds with previous reports.[19–23] The performance of subjects with reduced stereoacuity was also significantly better than that of those with no measurable stereoacuity on some tasks.

Other studies have previously reported that reduced stereoacuity affects more complex visuomotor tasks, including reading ability in children aged 5 to 6 years[24] and academic performance in reading, writing, math, and spelling ability in 5- to 9-year-olds.[25]

We found that the Preschool Randot Stereoacuity Test had an equal or higher number of subjects whose stereoacuity response was either reduced or nil, and the Frisby Test had the lowest number of cases of reduced and nil stereoacuity. This finding suggests that the Preschool Randot Stereoacuity Test may be more predictive of performance on these motor skill tasks.

In all motor skill tasks, the performance of those with normal stereoacuity was reduced under monocular conditions, demonstrating that stereoacuity plays a significant role in these tasks. This supports the findings of Mazyn et al.,[26] who found a significant reduction of the ability to catch a ball under monocular conditions. However, our results showed in some cases that those with reduced stereoacuity were better at the tasks than those with no stereoacuity, which is in contrast to their findings; Our results suggest that the benefit of reduced stereoacuity is task dependent.

There was some evidence of adaptation to long-term absence of stereoacuity. Subjects with nil stereoacuity performed some tasks better than those subjects with normal stereoacuity who were temporarily rendered stereoblind by monocular occlusion. On the other hand, this finding was not true of all the motor skills tasks, suggesting that there is a level of adaptation to the absence of stereoacuity, but it is variable, depending on the task.

When the task difficulty increased (comparing the small beads to the large beads), the reduction in performance asso-

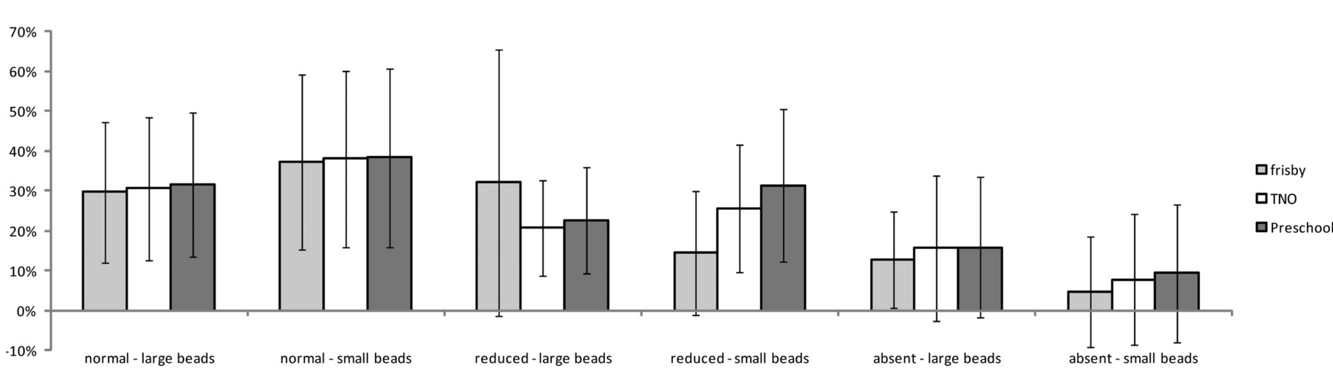

Figure 2. Percentage difference (±SD) between the binocular and monocular test conditions for the large and small bead tasks (grouped by stereoacuity levels: normal, reduced, and nil).

ciated with a lack of stereoacuity increased with increasing task difficulty (when using the TNO and Preschool Randot Stereoacuity Test measures to define levels of stereoacuity). Grant et al.[27] quantified objectively the kinematics of reaching and grasping behavior in subjects with amblyopia and stereoacuity deficits and demonstrated that overall pointing behavior was not affected by the presence of visual deficits, but that the final part of the movement (grip posture and hand preshaping) was affected. If the final part of the movement is the most important in executing the movement and picking up the object, then it may explain the relative increase in time taken when the task difficulty was increased.

The lack of association with the presence of amblyopia that we found is in agreement with that in a previous report[28] of children aged 3 to 4 years with monocular visual impairment where performance was related to the level of stereoacuity but not to the presence of unilateral vision impairment. The findings within our older age group suggest that the deficit found in the 3- to 4-year-olds persists and is not merely a reflection of a slower development. Webber et al.[29] reported that both the presence of amblyopia and stereoacuity deficits were associated with reduced performance on fine motor skill tasks; however, after multivariate analysis, the only factor associated was the presence of strabismus. Overall, the evidence supports our finding that the level of stereoacuity has a greater impact than the presence of amblyopia.

A limitation of this study is that, despite the large number of subjects, few had reduced stereoacuity (most had normal or nil stereoacuity), and their data were therefore grouped together for analysis purposes. It is not known, for example, whether someone with a value of 1980 on the screening plates of the TNO test would differ significantly from someone with a value of 120; thus, further investigation is needed in this area. However, a strength of the study is the use of three different stereoacuity tests, as the measures are known to vary within[30] and between[31] tests.

In relation to the clinical treatment for strabismus, the data presented herein support the need to maintain or restore the highest level of stereoacuity possible, with some stereoacuity being better than none. One implication of the quantifiable degradation in performance on some motor skill tasks associated with reduced stereoacuity is support for treatment that will optimize the chances for the development of stereoacuity. Our data also argue against the hypothesis that those without stereoacuity will adapt to their situation in the long term with no detriment to their motor skills.

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