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Stereoacuity levels and vision problems in children from 7 to 11 years

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A longitudinal study of stereoacuity levels of 859 children at 7 years, 811 children at 9 years and 796 children at 11 years was conducted using the TNO random dot stereotest. The prevalence of defective stereoscopic vision was found to be between 2.1 and 3.2 per cent. A further 10–16 per cent of children had only moderate stereoacuity levels when compared with their peers. The stereoacuity levels achieved by most of the children improved with age, but the rank order correlations for the stereoacuity levels between ages 7 and 9, and ages 9 and 11, were small. Defective stereopsis and poor stereoacuity levels were clearly associated with manifest strabismus and problems of visual acuity, and if failure to pass the quantitative plates was a cut-off point for screening purposes most of the children with visual problems would have been identified.

Several authors have suggested that stereoscopic screening for amblyopia and other visual defects may be superior to the more traditional screening methods (Simons and Reinecke, 1974; Romano, Romano and Puklin, 1975; Erlich, Reineke and Simons, 1983). Simons and Reinecke (1974) suggested that because all optical, neural and motor components in both eyes must be in working order for stereo-acuity thresholds to be achieved, it was logical to believe that testing stereoscopic dysfunction was an ideal test of visual dysfunction. In the Kohler and Stigmar (1973) survey of 2500 4-year-old children, however, the stereopsis measure (in the form of the Titmus Fly test) both under-referred children with amblyopia and over-referred children with no or subclinical vision disorders. Simons and Reinecke (1974) suggested that the shortcomings of stereopsis testing for amblyopia screening were due to the shortcomings of the stereoscopic test instruments. Their study (Reinecke and Simons, 1974), of the Julesz random dot stereogram with forced choice panels gave much more reliable results for both amblyopia and a variety of amblyopia related disorders.

The TNO test for stereoscopic vision used the same principle as the Julesz random dot stereogram (Walraven, 1975). The results of comparative evaluation of the TNO and Titmus stereoscopic tests suggested that the TNO test was more reliable, particulary among 2–4-year-old children. Results based on screening carried out on 129 pre-school children suggested that the test could be handled easily by a non-professional examiner.

The results of the study by Walraven (1975) of 81 patients between 2 and 7 years of age suggest that 240 seconds of arc disparity level was an excellent screening level. However, Simons (1981a) suggested that failing to reach a level of 120 seconds of arc was an indication of a binocular vision problem. This criterion was based on a study which included 20 5-year-old children, 13 of whom failed to reach this level. In a second paper Simons (1981b) recommended 240 seconds of arc for the TNO as the pass–fail breakpoint. At this level the TNO under-referred cases; however, if the breakpoint was reduced to 120 there were no under-referrals. Hammond and Schmidt (1986) described the use of 126 seconds of arc cut-off point for 483 children aged between 5 and 13years. At this level the random-dot E test identified 89 per cent of children correctly. Ehrlich, Reineck and Simons (1985) recommend the use of a 250 seconds of arc cut-off point for screening pre-school children. At this level none of the 70 children with amblyopia, with visual acuity worse than 20/30 in either eye, or interocular acuity worse than one line between eyes, or constant tropia, passed the test.

It is difficult to equate the cut-off points on one test with those on another, as there appear to be differences among the tests. Simons (1981b) reported inter-test correlates between the TNO and other available stereo tests. While many of these correlations were statistically significant they were quite low, the highest being 0.44. Hall (1982) also reported correlations between clinical stereo tests. Again, while some were significant they were low, the highest for the TNO being 0.33 with the Frisby test. Hall provides a variety of reasons for this lack of agreement, including the presence or absence of monocular cues, and the form of discrimination required by the TNO compared with the response to the sensation of depth required by other tests. A slightly higher correlation of 0.44 between the TNO and the Frisby was reported by Heron *et al.* (1985).

In a study carried out on young adults Hall (1982) evaluated a number of commercially available stereo tests

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as well as the two needle-test. He concluded that the most accurate results were given by the two-needle test. As this was not commercially available he suggested that the modified Frisby test gave good estimates. Its main disadvantage was that it failed to differentiate between subjects who lacked stereopsis but used monocular cues, and binocular subjects with poor stereopsis. As young children may still have poorly developed stereopsis a test such as the TNO which has no monocular cues appears to be more appropriate. It has the advantage of a wide range of disparity as well as being readily available, widely used and relatively inexpensive. It has been suggested that some children find it hard to understand the test, because identifying wedges is not as straightforward as identifying shapes portrayed in vectograms. Nevertheless, Simons (1981b) believes that the tests seem completely reliable for detecting children with substantial binocular dysfunction.

Stereopsis screening was carried out on a large sample of Dunedin 7 year olds who had been followed up at ages 3 and 5 years by the Dunedin Multidisciplinary Health and Development Research Unit. The purpose of this study was to estimate the prevalence of stereoscopic disorders among a general population of children and describe the visual disorders associated with defective stereoscopic vision and the various stereoacuity thresholds. The prevalence and significance of disorders of distance visual acuity, near visual acuity and eye movements was described by Simpson, Kirkland and Silva (1984). Many of the children who were examined at age 7 were seen again when they were aged 9 and 11 years.

Method

Subjects

The sample consisted of 859 of the children enrolled in the Dunedin Multidisciplinary Health and Development Study. The children were part of a birth cohort born at Queen Mary Hospital, Dunedin, between 1 April 1972 and 31 March 1973. To be eligible for inclusion in the sample, the children's mothers had to be resident in the Dunedin area at the time of their child's birth. Around the time of the child's third birthday, 1139 children were traced and permission given for 1037 of them to take part in the study. Of the 1037 children who were assessed at age 3, 991 (96 per cent) were followed up at age 5, and 954 (92 per cent) were reassessed at age 7. Those lost to the sample did not differ in terms of socio-economic status from those who remained in the study. The sample was known to be representative of Dunedin children, but slightly socio-economically advantaged in comparison with most of New Zealand. It was known also to be under-representative of Maori and other Polynesian children. The sample has been described in detail by McGee and Silva (1982).

Of the 954 children, 877 were assessed within 1 month of their seventh birthday at the study centre. A further 77 children were assessed by the Psychological Service of the Education Department, at home or at school. There were a few days when either the vision tester or stereopsis test were not available, so not all the children completed the vision tests. One child had had uniocular retinoblastoma so was excluded. The 859 children who did complete the stereopsis tests at age 7 did not differ from the remainder of the sample in terms of sex or socio-economic status.

Eight hundred and eleven children were assessed at age 9 and 796 at age 11.

Measures

Stereopsis – Stereoscopic vision was measured using the TNO test described by Walraven (1975). The test consists of a series of red–green anaglyph random dot stereograms which contain both monocular and stereoscopically hidden objects. There were three qualitative plates with retinal disparity of 33 minutes of arc and three quantitative plates which measured retinal disparities of 480, 240, 120, 60, 30 and 15 seconds of arc respectively. The plates were always presented in the same order. The children wore the coloured spectacles supplied. In addition their own spectacles were worn if appropriate and available. The test was administered in accordance with the manufacturer's instructions.

Distance visual acuity – Distance visual acuity was assessed using the Sheridan–Gardiner test (Sheridan and Gardiner, 1970) which comprises single optotypes at 6 m. Each eye was tested separately while the contralateral eye was occluded without pressure on the globe. The tests were repeated with spectacles if these were usually worn. The stereopsis and visual acuity tests were carried out by a Department of Health Vision tester who was seconded to the research unit.

Cover test – A cover–uncover and an alternate cover test were carried out by one of the authors (AS) to detect strabismus and phorias respectively. The child was asked to fixate on a small target at approximately 0.5 m. The eye movements were assessed in nine positions to check for the presence of non-concomitant strabismus. A general eye examination was also carried out, and any abnormalities of the pupils, eyes and adnexa were noted. A funduscopic examination was not included.

Socio-economic status – Socio-economic status (SES) was recorded at the time of the child's birth. The SES which depended upon the father's occupation was based on an index described by Elley and Irving (1972) for use in New Zealand. The four highest categories were for professional and skilled workers while the two lowest categories were for semi-skilled or unskilled workers.

Overall assessment of the child – Each child completed the eye tests as part of a day of comprehensive assessment at the study centre. The other tests included measures of cognitive ability and school achievement, a medical examination, hearing tests and measures of blood pressure. All the procedures were explained to the children and their parents before the child was tested.

Results

The stereoacuity levels achieved by 859 children at age 7, 811 children at age 9, and 796 children at age 11 are reported in *Table 1*. A number of children failed the screening plates as well as the quantitative plates, so it was assumed that they had defective stereoscopic vision. There were other children who passed two of the screening plates but failed the quantitative plates. It should be emphasized that the children who passed, for instance, the plate which measured a disparity of 60 seconds of arc, also passed the quantitative plates which measured greater angles of disparity. This meant that the prevalence of defective stereoscopic vision defined in terms of failure to pass any of the TNO screening plates in this sample

Table 1 Percentage of children achieving various levels of stereoacuity at 7, 9 and 11 years of age

Level achieved	*Age 7*	*Age 9*	*Age 11*
'Failed' quantitative plates (no stereoscopic vision)	3.3	2.1	2.3
'Passed' at least two screening plates but 'failed' quantitative plates	10.1	1.8	2.5
'Passed' quantitative plates at:			
480 sec of arc	24.9	5.4	1.5
240 sec of arc	2.7	2.6	2.8
120 sec of arc	6.3	4.4	6.2
60 sec of arc	48.7	58.8	53.1
30 sec of arc	3.8	24.0	28.3
15 sec of arc	0.2	0.7	3.4
Total	859	811	796
Median	57.7	40.4	38.1

of children from a normal population was 3.3, 2.1 and 2.3 per cent at ages 7, 9, and 11 respectively. At age 7, 10.1 per cent passed the qualitative plates but failed the quantitative plates. The percentages at ages 9 and 11 were 1.8 and 2.5 respectively. At ages 9 and 11, 14 per cent and 16 per cent of the children respectively had stereoacuity levels below the modal value of 60 seconds of arc achieved by the sample as a whole.

There was marked improvement with time reflected by the increase in the number of children passing the fourth plate (60 seconds of arc), or finer between ages 7 and 9, 52.7 per cent and 83.5 per cent respectively. The rank order correlations between the levels for the children who completed the tests at ages 7 and 9, and ages 9 and 11, were 0.29 and 0.34 respectively. While these correlations were statistically significant ($p < 0.05$) they do not indicate a high level of consistency over time.

The children were divided into six groups on the basis of the stereopsis measurement taken at age 7. Those with defective stereopsis failed all tests, those with poor stereopsis passed at least two of the screening plates but failed to reach the lowest threshold on the quantitative plates, and the other four groups were described in terms of the level they reached on the quantitative plates. Children were described as having normal visual acuity if their vision was 6/6 or 6/9 in both eyes without glasses or with glasses if they were worn. The results in terms of sex, SES, unilateral or bilateral distance visual acuity on the cover test are presented in *Table 2*.

χ^2 tests indicated that the stereopsis group to which a child belonged was independent of their sex and SES. Further χ^2 tests showed that there was a statistically significant relationship ($p < 0.05$) between stereopsis groups and distance and visual acuity, as well as the results of the cover test. *Table 2* clearly shows that visual acuity problems were more common among children who failed all stereopsis tests and those with poor stereopsis than among children who passed at least some of the qualitative plates. Both manifest and latent strabisums are also associated with defective stereoscopic vision.

All seven children with poor distance visual acuity in the defective stereopsis group had moderate or severe unilateral impairment (6/6 or 6/9 in the better eye and 6/12, 6/18, 6/60 or worse in the other eye). Eight children had moderate unilateral visual acuity impairment in the poor stereopsis group and five other children had impaired unilateral visual acuity, but with some stereoacuity.

Twenty two children who failed all stereoscopic tests had a manifest squint. One of these children, however, passed all the qualitative plates and more than one of the quantitative plates at ages 9 and 11. Two others also passed the qualitative plates at age 11. The poor stereoacuity level of five of the six children who had manifest strabismus had improved by age 11.

If the measurement of the stereoscopic dysfunction were an effective test of visual dysfunction the TNO tests should be able to indentify children with impaired distance visual acuity as well as manifest strabismus or amblyopia. The referral patterns for children with these conditions for various stereoacuity levels are reported in *Table 3*. The positive predictive value of the test is more than 70 per cent for stereoacuity levels equal to or better than passing the qualitative plates. At this level the incorrect referral rate is only 11 per cent, and the sensitivity and specificity of the test 33 per cent and 98 per cent respectively.

Discussion

The rates for defective stereopsis – 3.3, 2.1 and 2.3 per cent at ages 7, 9 and 11 respectively – were similar to those reported by Richards (1970) among a university student

Table 2 Relationship between stereoacuity levels and sex, SES, distance visual acuity and the cover test for the 7-year-old children

Measure	*Defective stereopsis (n = 28)*	*Qualitative plates (n = 87)*	*Passed at 480 sec disparity (n = 214)*	*Passed at 240 sec disparity (n = 23)*	*Passed at 120 sec disparity (n = 419)*	*Passed at 60 sec disparity (n = 35)*
Background measures						
Gender (boys)	51.1	43.7	46.7	52.2	55.7	100
SES (low, levels 5 & 6)	21.4	23.0	14.9	30.4	17.9	
Distance visual acuity						
Normal (6/6 or 6/9) with glasses if worn	67.8	90.8	95.8	86.9	98.8	100
Unilateral impairment	25.0	9.2	1.4	–	0.4	–
Bilateral impairment	–	1.1	–	4.3	0.8	–
Cover test						
No strabismus	10.7	73.5	83.2	32.5	75.5	77.1
Manifest strabismus	71.4	4.6	0.5	–	0.8	–
Esophoria	7.1	10.3	3.3	–	1.6	–
Exophoria	3.6	11.5	13.1	17.4	22.6	22.8

Note: Not all the children completed the vision tests.

Table 3 Correct and incorrect referral patterns for various cut-off points for 854 children

	Correct referrals			*Incorrect referrals*					*Position prediction value* (%)
Level passed	*Referral* (%)	*Non-referral* (%)	*Total* (%)	*Over-referral* (%)	*Under-referral* (%)	*Total* (%)	*Sensitivity* (%)	*Specificity* (%)	
120 seconds of arc	6.1	4.1	10.2	89.8	1.2	91.0	6	100	100
240 seconds of arc	4.9	57.8	62.7	36.1	1.2	37.3	12	98	81
480 seconds of arc	4.9	60.4	65.3	33.5	1.3	34.7	13	98	79
Qualitative plates	4.3	85.0	89.4	8.2	1.8	11.0	33	98	71
Failed all tests	2.6	93.4	96.0	0.5	3.5	4.0	85	96	42

sample. He reported a prevalence rate of 4 per cent and suggested that a further 10 per cent may have had difficulties. He pointed out that this prevalence rate was very similar to the 2.8 per cent prevalence rate for squint among the general population. Newhouse and Uttal (1980) also report prevalence rates of less than 6 per cent based on a sample of 103 adults. They commented that their prevalence rates agreed with those reported by Patterson and Fox and this suggested that the rates of stereo-anomaly in the community were quite low.

The stereoacuity of the children in this study improved quite markedly between ages 7 and 9 and to a lesser extent between ages 9 and 11. The stereoacuity levels for the 7 year olds are, however, not as good as those reported by Heron *et al.* (1985). The median score for 9 and 11 year old lies well within the 95 per cent confidence intervals for both the 5-year-old children and the adults. Only 3.4 per cent of children aged 11 attained the minimum measurable stereoacuity level of 15 seconds of arc, fewer than the 9 per cent of young adults reported to have achieved this level by Hall (1982). In his study 59 per cent of adults achieved 60 seconds of arc or less, compared with 31.7 per cent in this study.

The between-occasions rank order correlations for the stereoacuity levels were significant but quite low, although the general level of stereoacuity improved. The low between-age correlations reported for this study suggest that the acquisition of stereoscopic acuity was not highly correlated with age. Stereoacuity for some children may have improved as a result of treatment or deteriorated after cessation of treatment. It should be emphasized, however, that whether a child has stereoscopic vision or not appears to be relatively stable: 17 of the 20 children with defective stereoscopic vision who were re-tested at age 9, still had defective stereoscopic vision.

Conclusion

Using the 240 seconds of arc cut-off point recommended by Walraven (1975) and Simons (1981b) correctly identified 63 per cent of the children. Its high specificity of 98 per cent means that children who passed the tests were unlikely to have vision problems. The sensitivity of the test, which was 12 per cent, was disappointing. As the children in this study did not achieve such good stereoacuity levels as some in other studies, passing the qualitative plates only may be a more appropriate cut-off point. In this case the specificity was still 98 per cent while the sensitivity increased to 33 per cent. At this level the stereoacuity test would identify most children with stabismus and visual acuity problems but at the expense of a high false-positive rate. However, as testing can easily be carried out by ancilliary staff, as it was in this study, it may be cost effective as a screening procedure.

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