The Moving Dynamic Random Dot Stereosize Test: Development, Age Norms, and Comparison With the Frisby, Randot, and Stereo Smile Tests

Susan J. Leat, BSc, PhD; Jessica St Pierre, OD; Saloumeh Hassan-Abadi, OD; and Jocelyn Faubert, PhD

ABSTRACT

Purpose: To determine the response of infants and children to the Moving Dynamic Random Dot Stereosize (MDRS) test and to collect cross-sectional age-related data.

Methods: Sixty visually normal individuals were divided into four age groups: 0.5-<2, 2-<5, 5-<8, and 8-<20 years. Stereopsis was measured with the MDRS test on two occasions, plus the Frisby, Randot, or Stereo Smile tests, as was age appropriate.

Results: All children aged >2 years and 80% of the children between ages 6 months and 2 years were able to perform the MDRS test on at least one occasion. Sixty percent of the 6-month to 2-year-old children were able to perform the Stereo Smile test on both occasions. Performance on the MDRS test improved with age up to 9 years. Improvement on the Frisby and Randot tests was seen in children aged up to 7 years. Mean and 95% confidence interval ranges for each test are given.

Conclusion: This study gives evidence that aspects of the visual system are not fully mature until age 7-9 years. The MDRS test is a visually demanding but cognitively simple test that shows potential for detecting visual anomalies in young children.

Journal of Pediatric Ophthalmology and Strabismus 2001;38:284-294.

From the School of Optometry (Dr Leat), University of Waterloo, Waterloo, Ontario; and the Ecole d'optometrie (Dr Faubert), Universitéde Montreal, Montreal, Québec, Canada.

This study was supported by Kid Action Research formely Easter Seal Research Institute) Grant Nos. 9629 and 9733 and by the Canadian Optometric Education Trust Fund.

This study was conducted at the School of Optometry, University of Waterloo, Waterloo, Ontario, Canada.

This material was presented at the annual meeting of the American Academy of Optometry; December 10-14, 1998; San Francisco, Calif:

The authors thank all of the participants who took part and Ken Robertson for comments on the text.

Originally submitted July 27, 2000.

Accepted for publication October 26 2000.

Reprint requests: Susan J. Leat, BSc, PhD, School of Optometry, University of Waterloo, Waterloo, Ontario, Canada.

INTRODUCTION

The measurement of stereopsis is an important component of an ocular assessment or a vision screening procedure, It can assist in ruling out strabismus, anisometropia, and amblyopia.' The demonstration of typical stereopsis for age indicates normal development of sensory and motor functions.[2] However, not all stereotests provide equally valuable information. In general, random dot stereograms that are believed to measure global stereopsis are more valid than contour stereograms that measure local stereopsis. Contour stereograms

can sometimes be passed by people with strabismus by making use of positional placement clues,[3-5] whereas it generally is agreed that random dot stereograms are more effective at detecting strabismus, amblyopia, poor visual acuity,[6,7] and anisometropia.[8] Even random dot stereograms with large disparities such as the Lang I stereotest effectively detect constant strabismus,[9] medium to high hyperopia, and acuity worse than 6/18,[10] although they may fail to detect microtropia.[2]

Simons et al[11] suggest small stereo targets are likely to be more sensitive for detecting binocular vision defects (eg, anisometropia) than stereotests with larger targets. They demonstrated that small angle .strabismus and anisometropia with good visual acuity could be detected, even using a large disparity *(600")* if the angular subtense is small. However, it has been suggested that there are monocular clues even with random dot stereograms. The use of video presentation has allowed the development of dynamic random dot stereograms in which monocular clues are virtually eliminated.[12]

Most studies agree there is a rapid development of stereopsis during the first 3-5 months of life.[12] However, many early studies used one level of stereopsis or very large disparities[13,14] so disparity thresholds were not obtained. More recent studies have determined a threshold for stereopsis in the infant population and have shown the rapid onset is followed by a slower improvement in stereoacuity, which may not be complete for several years.[15-18]

Birch and Petrig[19] used a stereogram with dynamic random dots and reported a rapid rise of stereoacuity during the first 7 months of life to "near-adult" levels. Other studies have shown a development in stereoacuity until age 12 months when near-adult levels of stereoacuity are reached.[15,18] Few data have been reported on stereoacuity for infants between ages 6 months and 2 years. Ciner et al[17] conducted a study that covers this higher age range (6 months to 5 years). They reported stereoacuity developed from an average 300 arc seconds at age 6-11 months to 30 arc seconds at age 5 years, with a sudden improvement at age 2 years. Birch and Salomao'[8] demonstrated improvements in stereoacuity, noting log stereoacuity was linearly related to log age up to *24* months.

The present study determined the response of infants and children to a new stereopsis test, the Moving Dynamic Random Dot Stereosize (MDRS) test,[20] and collected cross-sectional age-related data. The MDRS test is a computer-generated stereotest that uses a dynamic random dot background to minimize false cues to stereopsis and a disparate target that moves horizontally across the screen in random directions, from either right to left or left to right. Dissociation is by means of red-green filters. The test was developed to measure stereo thresholds in infants and populations with multiple challenges, including communication difficulties.

As there are few studies that provide age-related norms for commonly used tests such as the Randot and the new Stereo Smile test, we measured and present cross-sectional data on the Randot contour stereotest, Stereo Smile test, and Frisby test. All of these are static tests. There are no currently available clinical tests that use dynamic random dots or moving targets.

MATERIALS AND METHODS

Sixty-two healthy individuals with normal vision, ranging in age from 6 months to 19 years, were contacted from among the faculty, students, and staff of the School of Optometry and patients attending the School of Optometry Clinic at the University of Waterloo. Informed consent was given for each individual after the individual or his or her parent or guardian reviewed a letter of information. The individuals were selected to represent four age groups: 6 months to <2 years (n=15), 2-<5 years (n=15), 5-<8 years (n=15), and 8-<20 years (n=17). Exclusion criteria included: a known ocular pathology, strabismus or other oculomotor difficulties, a habitual spectacle correction, history of eye surgery or strabismus, refractive error or visual acuity outside the normal age range, and systemic illness. In the oldest group, spectacle wearers were included as long as their refractive error was $<\pm 5.00$ diopters (D), $<\pm 2.00$ diopters of cylinder, and <2 D of anisometropia.

Each individual was required to attend at least two sessions. Between *4* hours and 15 days passed between each session. Stereotests were performed on both occasions.

Preliminary Testing

Most of the preliminary testing was performed on the first visit. In younger children, when cooperation was waning, ophthalmoscopy was performed

on the return visit. The following were determined:

- A case history recording general health status, including information about any medications taken by the individual, any known allergies, previous ocular history, and familial history of strabismus.
- Oculomotor status was measured using the unilateral and alternating cover test and/or the Hirshberg test (depending on the age and cooperation of the individual), and the broad H test for commitancy.
- Visual acuity was determined with habitual correction, if worn, in place. The test for visual acuity was dependant on the age, ability, and cooperation of the individual. Tests were used in the following order of preference: Bailey Lovie Chart #4 at 3 m, Cambridge Crowding Cards at 3 m, Cardiff Acuity Cards,[21] or Teller Acuity Cards.
- Manifest refractive error using standard noncycloplegic static retinoscopy or Mohindra retinoscopy followed by subjective refraction, all depending on the age and ability of the individual. In the case in which a subjective refraction was not possible, the retinoscopic results were taken as the manifest refraction.
- Habitual spectacle lenses by lensometer.
- Ocular health by ophthalmoscopy (direct or monocular indirect or both).
- Individuals in the three oldest age groups also were tested for suppression using the Worth Four Dot test at near (one individual was unable to perform the test).

Stereoacuity Measurement

Stereoacuity was measured using the Randot Contour Circles test (Stereo Optical Co Inc, Chicago, Ill) and the Frisby Stereotest (Clement-Clarke Ltd, Harlow, UK). In the case of the youngest control group, the Randot Stereo Smile Test was used (Stereo Optical Co Inc, Chicago, Ill).[17]

The Randot contour (circles) test was performed at *40* cm similarly to the normal clinical procedure. Starting with the largest disparity in a descending scale, the individual was asked to point to or verbally identify the circle at each level that appeared to be floating in front of the page or jumping out of the page. The last level for which the individual answered correctly was considered to be the level of stereoacuity. Once the individual's level of stereoacuity was determined, the examiner went back three levels and repeated the test. The final threshold was derived as the mean of these two results. If the individual was unable to comprehend the task, the Randot Animals test was used following the same procedure.

The Frisby test was performed initially at 80 cm, decreasing this distance as needed. With a long paintbrush, the individual was asked to point to (or verbalize) the square on the plate that contained the circle. The lowest disparity for which this task could accurately be performed at least two of three times was deemed to be the level of stereoacuity. This level was taken as threshold, since it is a four-alternate, forced-choice test with a 25% guessing level. Therefore, the threshold was taken as 62.5% (midway between 25% and 100%), which is approximately two of three.

For individuals who were uncooperative or too young to perform these tests, the Stereo Smile test, a preferential looking random-dot stereoacuity test, was performed. The demonstration card was shown first to ensure the child was able to make a preferential look. Starting with the largest disparity, the level at which the individual could point or preferentially identify correctly at least three of four times (a threshold of 75% for a two-alternate, forced-choice test) was deemed to be the level of stereoacuity This criterion is different from that recommended in the instructions from the manufacturer in which it is recommended that the looking responses be correct four times of four for the child to "pass" each level.[22] However, our initial experience with the test suggested this criterion might be too strict, resulting in too many children failing the test. For example, a child would be classed as failing if he or she had one mistaken judgment or experienced a lapse of attention. This seemed too severe. The "three of four times" procedure is similar to the methodology used by Ciner et al,[17] in which a two-down/one-up procedure that approximates the 75% correct threshold was used.

Stereosize Measurement

Stereosize threshold was assessed using a computer program MDRS test, designed by Faubert and Larson.[23] The program generated a red-green dynamic random-dot pattern on a 21″ computer screen. When the program is activated, the dot pattern moves randomly while a green and red dot dis-

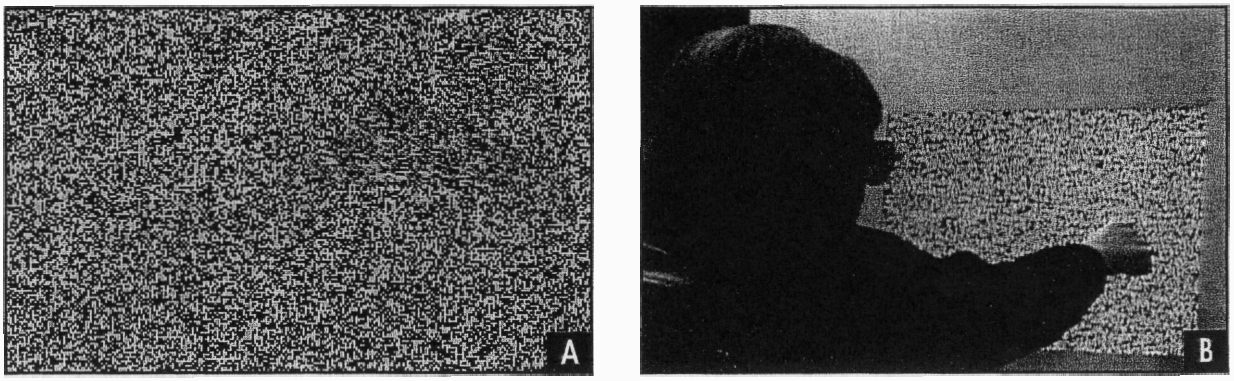

Figure 1: The stimulus is composed of a red/green random dot pattern **(A).** In one area of the screen, the red dots are displaced laterally from the green dots. Without red-green glasses, this appears as an area of red dots displaced from the green dots. However, wearing the red-green glasses results in a disparity and the appearance of depth. The shape of this disparity is a duck. In the Moving Dynamic Random Dot Stereosize test, the red-green dots are dynamic (ie, the random pattern changes rapidly with time, and the area of disparity moves across the screen). The child is asked to point to or watch the direction of the duck. The apparatus is shown with a child taking the test **(B).**

parate image of a duck moves horizontally across the screen (Figure 1). When this image is viewed with red-green dissociation glasses, the image of the duck appears in front of the screen (crossed disparity). The size of the dots composing the duck image and the random dot background pattern were the same (10.26 minutes of arc). This dot size was chosen after considering the visual acuity of infants aged ≥6 months,[24-26] to ensure the dots would be resolved by the infant visual system. The disparity was 616 seconds of arc, which is equal to one dot size, The target moved across the screen in 2.5 seconds (22.5° per second) from either left to right or vice versa. The vertical angular subtense of the target for a 50-cm viewing distance varied from 11°-0.18° in 13 steps (levels), each level being a 0.5 octave change. A white screen of luminance 74 cd/m^2 surrounded the computer screen. The average luminance of the computer screen was 40 cd/m^2.

In the MDRS test, the target size is the independent variable, rather than the disparity for the following reasons. Firstly, preliminary testing showed a wide variability of stereoacuity thresholds, even among adults, which made using a variable viewing distance necessary. This would change the angular subtense of the target and the dots. Secondly it was difficult to obtain a disparity smaller than the dot size without reducing the luminance of the screen and therefore it would be difficult to obtain disparities small enough to measure thresholds at a distance of 50 cm. For infants, a close working distance is necessary to engage their attention. Lastly Simons et al[11] suggest using small targets as a more sensitive method of detecting anisometropia.

Testing began by positioning the individual's eyes 0.5 m from the screen, with the eyes set level with the area of the screen where the duck image would appear, just above the center. The red/green glasses were worn and positioned over the individual's habitual spectacles, if worn. In cases in which a younger child was resistant to wearing the glasses, a pair of filters was held over the child's eyes by one of the experimenters. When the manifest refraction was different from the habitual spectacle lenses, it was corrected with trial lenses in a trial frame and pre-cut red/green filters were positioned over each trial lens. The individual was instructed to watch for the shape of a duck floating before the screen background that would move either to the left or right. Older individuals were asked to indicate in which direction the duck appeared to be moving by verbalizing or pointing (Figure 1). They also were told that the duck image size would get smaller and were asked to guess the direction of movement when not sure.

Infants sat on a parent's lap and were encouraged to observe the screen by calling and talking to the child, or were entertained with small toys shown between presentations. Verbal encouragement and positive feedback were provided when the child fixated on the screen. For these younger individuals, an observer, who was naïve about the direction of movement, made a forced choice judgement based on the child's eye movements. If the child lost attention and was not fixating on the screen, the trial was repeated. When a younger child's eye movements did not correspond with his or her pointed or spo-

TABLE 1
PATIENT CROUPS

Group	N	Mean Age±SD (y)	Age Range (y)
6 mo-<2 y	15	1.09±0.36	0.5-1.8
2-<5 y	15	3.84±0.74	2.3 3-4.9
5-<8 y	15	5.9420.92	5.0-7.75
8-<20 y	17	13.07±3.58	9.08-19.25

ken answer, the direction of eye movement was taken as the most accurate answer. The same observer observed all stereosize tests.

Stereosize threshold was determined using a staircase procedure with two stages, based on an approach developed by Atkinson et al.[27] Phase 1 was a determination of a starting point for the staircase and phase 2 was the actual staircase. Phase 1 was a one-down procedure. A single stimulus was presented at the maximum size. The size was decreased in octave steps until an incorrect response was given. Phase 2 (the actual staircase) started at one octave above the first incorrect response given. When an incorrect response was given to the first presentation (maximum size), an additional two presentations were made at the same level. If all were incorrect, the experiment was terminated, as it was concluded that the individual was unable to perform the test. If one of three was correct, phase 2 started at level 1 (maximum size). If two of three were correct, phase 1 continued (ie, one presentation at level 3). Thus, one error at the first level was permitted.

Phase 2 was a two-down/one-up procedure using 0.5 octave steps (ie, two correct responses were required before the test proceeded to the next lowest level, but only one incorrect response was required for the test to go to the next highest level). The run terminated when four reversals were obtained. If the staircase moved back to level 1 and the individual made three errors in a row, the run was terminated. In cases in which the test returned to level 1 and four reversals were not obtained, the individual was said to have failed the test if the percent correct at level 1 was <75%.

Cooperation during the stereosize procedure was rated using the following scale: 3=individual was cooperative with 100% attention; 2=hard to keep the individual's attention, with 50% attention; 1=individual wore glasses and looked at the screen, but with very limited attention; and 0=extremely difficult, individual would not wear the glasse or look at the screen. Half scores (eg, 2.5) also were used for those individuals whose cooperation was judged to be between levels.

RESULTS

The details of the four age groups are shown in Table 1. All had normal binocular vision and ocular health according to the screening tests that were performed.

success Rata

All individuals ≥2 years were able to perform the MDRS and Frisby tests on both test and retest, and all were able to perform the Randot test on at least one occasion. Children between the ages of 6 months and <2 years (n=15) were more varied in their ability to perform the test, with 9 of 15 individuals able to perform the MDRS test on both occasions. Of this group, 3 children were able to perform the MDRS test on at least one occasion. Three children were unable to see the MDRS test according to our criteria on either occasion; 2 individuals evidenced poor cooperation (eg, very limited attention or would not wear the red/green glasses). Therefore, there was only one reasonably cooperative individual in this group who was unable to pass the criteria for the MDRS test. This individual was able to respond to the Stereo Smile test on both occasions. For the Stereo Smile test, 7 children responded on both occasions (ie, they were correct at least three of four times for the largest disparity), 3 responded on one occasion, and 5 were unable to respond to the test.

Analysis of Stereosize Results

The MDRS test was assessed in several ways. Me calculated the test-retest coefficient of repeatability[28] for the first two reversals, the last two reversals, and all four reversals. The reason for considering this was repeatability may be better for the first two reversals (when the child's attention is better) or the second two (when the child is more accustomed to the test) or for all four (because this represents an average of more data points). We also calculated the coefficient of repeatability for the log of the Randot and Frisby results (Table 2).

For the MDRS test, there is slightly better repeatability in three of four age groups by taking the mean of four reversals for the threshold. This will then be used for all following calculations

TABLE 2

REPEATABILITY OF TESTS*

Tests	6 mo-<2 y	2-<5 y	5-<8 y	8-<20 y
Stereosize				
First two reversals	d=0.14; c=0.57	d=0.17; c=1.17	d=0.15; c=0.53	d=0.08; c=0.63
Last two reversals	d=0.08; c=0.42	d=0.07; c=1.11	d=0.18; c=0.45	d=0.15; c=0.72
All four reversals	d=0.11; c=0.44	d=0.11; c=1.07	d=0.17; c=0.43	d=0.01; c=0.58
Frisby		d=0.09; c=0.55	d=0.08; median=0, mode=0, 95%=0.3	Mode=0, median=0, 95%=0.12
Randot		d=0.02; c=0.48	d=−0.04; c=0.21	d=0.03; mode=0; median=0, 95%=0.097
Stereo Smile	Mode=0, median=0, 95%=−0.2			

*Mean difference between test and retest (d) and coefficients of repeatability (c=1.96×SD of differences in log units). In cases where the data are skewed (where there are many zero differences), the median, mode, and 95 percentile (95%) for differences is shown.

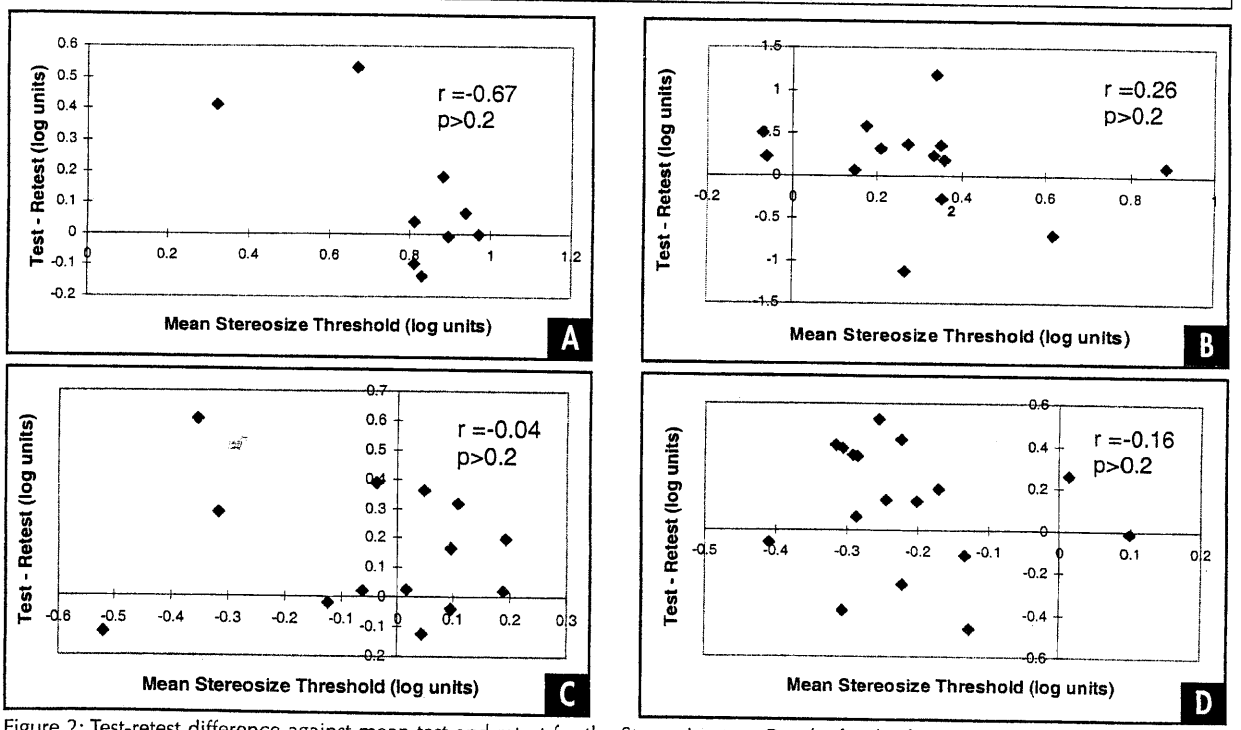

Figure 2: Test-retest difference against mean test and retest for the Stereosize test. Results for the four age groups are shown: ages 6 months-<2 years (A), 2-<5 years (B), 5-<8 years (C), and 8-<20 years (D). The correlation coefficient and its significance are shown.

unless otherwise stated. Figure 2 plots test-retest against mean for four reversals for each age group. The correlation coefficients and *P* values for a *t* test for significant correlation are shown, none of which is significant. This indicates there is no trend of test-retest differences with respect to the mean.

Results With Respect to Age

Figure 3 shows the distribution of stereosize threshold against age. There are two sections to the results: a linearly decreasing section up to the age of 9 years and little change in ages ≥9 years. Therefore, the two oldest groups were regrouped. Children aged ≥9 years were grouped together, so that the oldest two groups became ages 5-<9 years and ages 9-<20 years.

Figure 4 shows the results of the Frisby, Randot, and Stereo Smile tests measured against age.

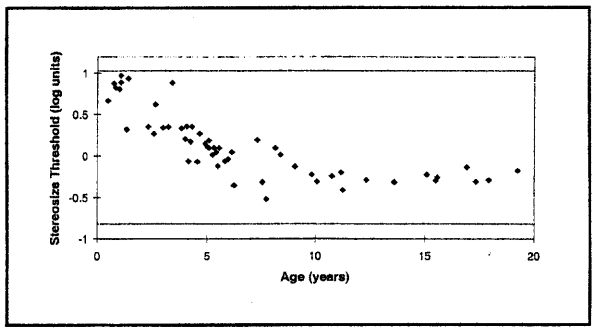

Figure 3: Stereosize threshold (mean of two visits) is plotted against age. The horizontal dashed lines represent the upper and lower limits of the test.

Performance on the Frisby test improves until age 7 years, at which time most individuals were able to obtain 1.3 (20″). However, a few showed poorer performance, down to 1.67 (46″). Similarly, performance on the Randot test improves until age 7 years, but after that age there is less variability between individuals, the poorest performance being 1.39 (24″). The Stereo Smile test results show little change in performance between the ages of 6 months and 2 years.

The final means (test and retest), standard deviations, and 95% confidence intervals (CI) are shown in Table 3. In certain cases, there was a floor effect for the test (eg, for the Randot and Frisby tests in the older age groups), therefore, most of the individuals reached the lowest possible level (20 secs of arc). In these cases, the mode and total range are shown.

In clinical practice, usually only one measurement would be taken. It also is possible the child's attention would be maintained only for the first two reversals. For the MDRS test, we considered the agreement between the test and test-retest mean and the first two reversals and the test-retest mean. There was good agreement in both cases. The difference between the mean was 0.08 and 0.06, respectively, and the coefficient of agreement was 0.39 and 0.34, respectively.

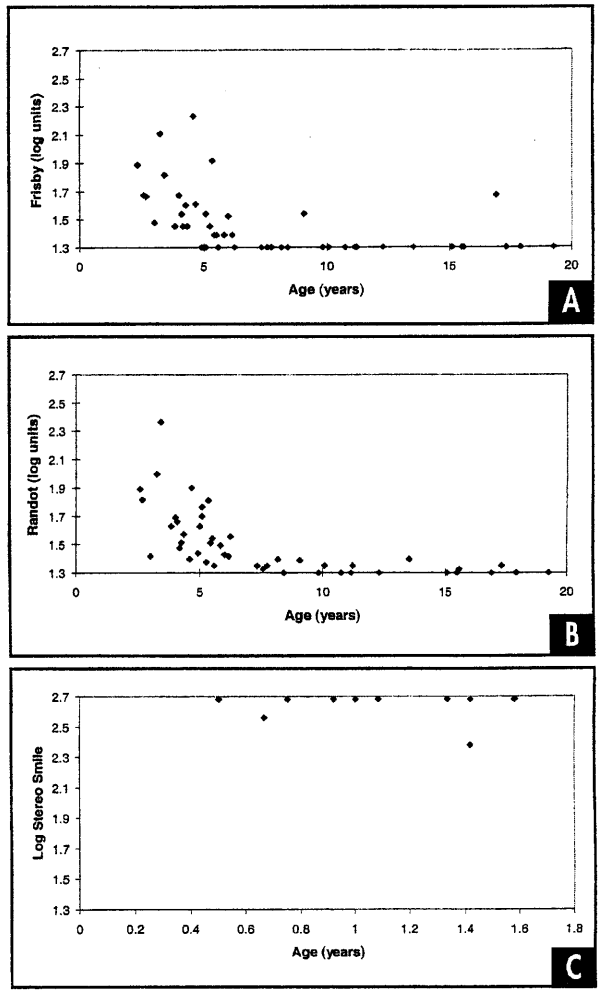

Figure 4: Frisby (A), Randot (B), and Stereo Smile (C) thresholds (mean of two visits) plotted against age.

Discussion

Repeatability and Success Rates of the MDRS Test

Repeatability for each age group was compared to that for adults[20] in whom it was found that the repeatability was 0.28 log units=two levels of the test and for whom it also was found that repeatability was optimal when using the mean of four reversals. The repeatability for children aged 5-<20 years was poorer than that of the adults, approximately 0.5 log units=3.5 levels of the test. Therefore, a change of ≥4 levels from one occasion to another would represent a significant change in performance. Repeatability was poorer in the group aged 2-<5 years (1.07=nearly four levels). A change of this size would mean the child was no longer able to perform the test. Interestingly, the youngest group demonstrated better repeatability. However, this is because there is a ceiling effect. They are performing close to the upper (largest) limit of the test, thus limiting the range of threshold values that may be obtained.

For the youngest group, one individual was unable to pass our test criteria (apart from those who showed poor cooperation). This indicates that for cooperating individuals, 92% with normal binoc-

TABLE 3
MEANS AND NORMAL RANGE*

Test	Age Groups 6 mo-<2 y (N=15)	2-<5 y (N=15)	5-<8 y (N=17)	8-<20 y (N=15)
Mean MDRS				
Mean	0.79±0.2	0.30±0.24	−0.024±0.2	−0.25±0.075
Range	0.4 to 1.1	−0.158 to 0.764	−0.414 to 0.364	−0.4 to −0.105
Log Frisby				
Mean		1.66±0.26	1.3†	1.3†
Range		1.3 to 2.16	1.6‡	1.57‡
Log Randot				
Mean		1.7±0.27	1.48±0.158	1.3†
Range		1.3 to 2.23	1.3 to 1.8	1.39‡
Log Stereo Smile				
Mean	2.68‡			
Range	2.38-2.68§			

*Means and normal range (95% confidence interval [CI] of normal according to age) in log seconds of arc. In places where the lower end of the calculated normal range exceeds the limits of the test, the limit of the test is given as the lower limit of normal. The means are the average of two visits.
†Mode and median.
‡95 percentile (95%).
§Total range.

ular vision can perform the test (73% on the first occasion). For children >2 years, this becomes 100%—all individuals with normal binocular vision were at least able to detect the largest target.

Response to the Stimulus

Some discussion is warranted regarding the fact that a few infants with otherwise normal binocular vision do not track the target, at least on some occasions, with the result that they did not meet our criteria for passing the test. One possibility is that the target movement was too fast for the infant visual system to track. For the MDRS test, the target velocity is 22.5°/sec and its duration is 2.5 seconds. Phillips et al[29] showed 4-month-old children can follow a 24°/sec, and even a 32°/sec, target moving in a stop-ramp-stop pattern. However, this tracking is accomplished with a mixture of smooth pursuits and saccades, and they tended to lag behind the stimulus more than an adult. Targets moving at 24°/sec were tracked with an average velocity of 20°/sec by 4-month-old children. Average latency for onset of eye movements was 381 msec for 24°/sec target, usually followed by a saccade and then a smooth pursuit. Eye movements persisted for an average 176 msec after the target movement had ceased.

Shea and Aslin[30] used a step-ramp target (ie, it jumps in one direction and then starts moving smoothly). They reported 2.5-month-old infants could follow targets up to 12°/sec although their average gain was lower than that of adults. Our target motion is more similar to Phillips et al[29] than Shea and Aslin.[30] These figures indicate our youngest individuals do have the ability to track the target and would have had time to make the eye movement for it to be observed. It is worth mentioning that the youngest children in our study were aged 6 months, older than the youngest children in the studies of Phillips et al[29] and Shea and Aslin.[30] The fact that eye movement might lag slightly behind the target would not interfere with the observer's judgement of direction.

The study by Atkinson and Braddick[31] also is of relevance. They report infants ≤4 months will follow an easily visible target moving from the center of the screen either left or right, with either a pursuit or saccadic following movement 70% of the time. Although a target is well above the children's threshold, they will not follow it 100% of the time. If this phenomenon also occurs in slightly older infants (there are no known similar data for infants >4 months), it could explain why some infants did not reach our criterion of 75% correct eye move-

ments, although they have normal vision according to other tests.

Dobson and Sebris[14] used a moving dynamic random dot target with red-green dissociation, similar to the present study in which observers had to detect the movement of the target from the infant's eye or head movements or from other cues (eg, pointing). They used a fairly strict criterion for passing the test (5 of 5 or 8 of 9 correct). They used both a larger disparity and dot size than that used in the present study (disparity=4560″ and dot size=1800″), which may make the target more compelling. However, they found a high rate of infants did not meet this criterion and relaxed their criteria to allow a judgment on all available information. The percentages in the control groups demonstrating stereopsis were: 6 months, *42%;* 9 months, 40%; 12 months, 50%; 18 months, 75%; and 24-36 months approximately 90%-95%.

Fox et al[13] used a similar target to Dobson and Sebris.[14] It had a minimum disparity of 2700". In infants ≤4.5 months, they found the child would follow a physical, monocularly visible form approximately 95% of the time and the stereo target approximately 70% of the time, which was statistically different from chance (50% being a 2AFT task). It seems infants do not follow targets with 100% probability, although the target is easily visible. These previous findings may explain why some of the individuals in our youngest group did not reach our criterion level for detecting the stimulus.

The percentage of children who were cooperative and could perform the Stereo Smile test was lower (71% with *46%* on the first occasion) than for the MDRS test (92% and 73%, respectively). This success rate for the Stereo Smile test is lower than that found by Ciner et al[17] who reported a figure of 98%. However, there were several procedural differences that may account for this apparent disagreement. First, we were not using the surrounding screen as described in their study. Infants may have been more distracted by the surroundings and less likely to search for and find the Stereo Smile target. Second, they used a two-downlone-up procedure whereas we required the response to be correct at least three of four times to proceed. Third, they calculate the specificity across their entire population from 6 months to 5 years, whereas we only used this test with the younger age group. Last, the **cards** that were used for their study are different from those that are commercially available, having six different cards, each with a different disparity. The commercially available set incorporates two cards, and additional disparities are obtained by increasing the test distance. We found children were less responsive, and it was harder to maintain their interest when the working distance was increased from 0.5-1 m. Although this would not change the specificity calculation (they only have to obtain 480 to pass), it may affect the thresholds. Indeed, we found poorer thresholds than Ciner et al[17] reported. In their group of children aged between 6 and 17 months, they found a mean of 300″, whereas we find a mode of *480"* with only two children performing better.

success Rates

One hundred percent and 93% of 2- to <5-year-olds were able to perform the Frisby and Randot test, respectively, on the first occasion. This compares with Saunders et al[32] who found almost 100% were able to obtain 600" on the Frisby test, and 60%-80% obtained 300" in this age group. It also compares with Broadbent and Westall[2] who found 90% of 2-year-old children could perform the Frisby test, and Simons[33] who found 97% of 3- to 5-year-old children could do it. The results also are similar to the Randot test. Simons[33] found 97% of 3- to 5-year-old children could perform the Randot test. We found that not *only* were children >2 years able to perform the test, but they also obtained stereoacuities of 123" or better (mean of two visits). If we consider the naïve data (first visit), we found that all children in this age group were able to obtain at least 170".

Comparison With Other Studies

To tell whether a particular patient's stereopsis falls within normal, it is necessary to know the normal range for each age group. There are few studies that quote not only means and percentages of young children who are able to complete a test of stereopsis, but also the range of normal values. Our results for the normal range for the Stereo Smile test are similar to those of Ciner et al[17] who reported a mean of 302″±15.4″ for ages 6-11 months and 300″±14.7″ for ages 12-17 months. This gives a 95% CI (based on 1.96×SD) of 441" at age 6-11 months and 356" at age 12-17 months. When we consider the 360" card does not exist in the commercially available set, this is effectively the same

upper limit of normal as found in the present study *(480")*. For the Frisby test, for 3 to 5 year olds, Simons[16] found a mean of 251" and 95 percentile of 250". We found a mean of *46"* and the 95% *CI* was *146"*. However, Simons[16] mentions his threshold of 250" may be underestimated because of the single distance used in his study. For the Randot test, our results (2 to 5 year olds, mean 50"; 95% CI=170) are poorer than both Lam et al[34] *(98.7%* achieved *70")* and Simons[16] (mean 64", 75%=70"), but this may be explained by the fact that younger children are included in the present study. Simon's data 'were for 3 to 5 year old children, and the data from Lam et al[34] was for children between ages 4.5 and 5.5 years.

Stereopsis Development

There is a rapid onset of stereopsis followed by a slower maturation of stereoacuity to adult levels. There still seems to be some uncertainty when this slower development is complete. Our results show there is an improvement in stereosize threshold, up to age 9 years. Frisby and Randot thresholds improve to age 7 years (although there were two outliers in the Frisby data). The data from Simons[16] also show an improvement in the mean stereo threshold between ages 3 and 5 years and adulthood for both the Randot and Frisby tests. Because Simons[16] finds a similar amount of improvement for a number of different tests that are suitable for children, he argues there is actual improvement in visual function after that age (ie, the visual system is not completely mature by age 5 years).

O'Dell and Boothe[35] compared the development rate of stereopsis between human and rhesus monkey infants. They found a difference between the rate of onset of stereopsis and the subsequent slower development to near adult levels of stereoacuity and suggest this is due to different maturation rates of different factors within the visual system. One possible mechanism for the rapid onset of stereopsis is the segregation of layer *4C* of V1 into ocular dominance columns, which occurs in the first few months of life in humans, and this might be a necessary first substrate for stereopsis. Alternatively, Chino et al[36] showed cells in the striate cortex of neonatal, week-old monkeys that were sensitive to disparity, although the responses were immature and the eyes had to be stabilized to demonstrate them.

O'Dell and Boothe[35] suggest there are neurons in the extra striate areas that are disparity sensitive that might be responsible for the slower phase of maturation of stereoacuity. Thus, the necessary substrate for crude stereopsis and subsequent refinement of stereoacuity may be different, and there may be a number of maturations that must take place for the latter to occur.

Accurate and stable ocular alignment also is necessary for the development of behavioral responses to disparity. Smooth pursuit eye movement accuracy is not fully developed (ie, completely adult-like) until the late teens.[37-39] The current data also are in agreement that some aspects of the visual system develop relatively late. Thresholds for the MDRS test continue to improve after those of the Randot and Frisby tests. This is likely because the MDRS test is a higher level test requiring functioning of a number of aspects of the visual pathway. To obtain a low threshold, good stereopsis, visual acuity, and the ability to track targets are required. It is likely the MDRS test requires functioning of both parvo- and magnocellular pathways. It is a moving target with low frequency components (the dot size is quite large) that would stimulate the magnocellular pathway. However, as the test progresses, the target becomes smaller, involving the parvocellular pathway. It has been suggested that the parvocellular pathway develops later than the magnocellular pathway, but there is little data.[40] Thus, although the test is cognitively easy to perform, visually it is complex.

CONCLUSION

The MDRS test has been shown to be a sensitive measure of visual development, demonstrating visual performance is still developing up to age 9 years. The repeatability measures are disappointing. With the present configurations, the test is not adequate for detecting small changes in visual performance, such as changes in an individual over time. Such changes would be hidden by the limits of test-retest repeatability. Variation of the test parameters, such as the speed of movement, dot size, and disparity may influence the repeatability. This test is still under development and these parameters may be changed to give better repeatability and optimal sensitivity to binocular vision anomalies.

Because the MDRS test is a high-order test requiring good performance in a number of aspects

of visual performance, the test may be less useful for studying the development of particular aspects of the visual system, but more useful for screening, as a number of visual functions or abilities must be intact to pass it. Any one of a number of aspects of the visual system that are not functioning within the norm (eg, visual acuity, ocular movements, ocular alignment, stereopsis) would result in a failure. Previous work has demonstrated the test shows promise for being sensitive for the detection of anisometropia and strabismic amblyopia.[20] Current studies are under way to further determine the optimum combination of dot size, disparity, and movement for detecting amblyopia.

REFERENCES

1. Mohindra I, Zwaan J, Held R, Brill S, Zwaan F. Development of acuity and stereopsis in infants with esotropia. *Ophthamology.* 1985;92:691-697.
2. Broadbent H, Westall C. An evaluation of techniques for measuring stereopsis in infants and young children. *Ophthal Physiol Opt.* 1990;10:3-7.
3. Cooper J, Feldman J, Medlin D. Comparing stereoscopic performance of children using the Titmus, TNO and Randot stereo tests. *J Am Optom Assoc.* 1979;50:821-825.
4. Scheiman M, Wick B. *Clinical Management of Binocular Vision.* Philadephia, Pa: J.B. Lippincott Co; 1994.
5. Birch E, Williams C, Hunter J, Lapa MC. Random dot stereoacuity of preschool children. ALSPAC "Children in Focus" Study Team. *J Pediatr Ophthalmol Strabismus.* 1997;34:217-222.
6. Reinecke R, Simons K. A new stereoscopic test for amblyopic screening. *Am J Ophthalmol.* 1974;78:714-721.
7. Rosner J, Rosner J. *Pediatric Optometry.* 2nd ed. Boston, Mass: Butterworths; 1990.
8. Griffin JR, Super S, DeLand PN, Lee A. Effect of anisomtropia on global and local stereopsis. *Optom Vis Sci.* 1992;69(suppl):105.
9. Manny RE, Martinez AT, Fern KD. *Excepta Medica.* Section 12 (Ophthalmology). 1992;47:44.
10. Schmidt PP, Kulp MT. Detecting ocular and visual anomalies in a vision screening setting using the Lang stereotest. *J Optom Assoc.* 1994;65:725-731.
11. Simons K, Avery KE, Novak A. Small-target random dot stereogram and binocular suppression testing for preschool vision screening. *J Pediatr Opbthalmol Strabismus.* 1996;33:104-113.
12. Birch E. Stereopsis in infants and its developmental relation to visual acuity. In: Simmons K, ed. *Early Visual Development. Normal and Abnormal.* New York, NY: Oxford University Press; 1993:224.
13. Fox R, Aslin RN, Shea SL, Dumais ST. Stereopsis in human, infants. *Science.* 1980;207:323-324.
14. Dobson V, Sebrii SL. Longitudinal study of acuity and stereopsis in infants with or at-risk for esotropia. *Invest Ophthalmol vis Sci.* 1989;30:1146-1158.
15. Birch EE, Gwiazda J, Held R. Stereoacuity development for crossed and uncrossed disparities in human infants. *Vis Res.* 1982;22:507-513.
16. Simons K. Stereoacuity norms in young children. *Arch Ophthalmol.* 1981;99:439-445.
17. Ciner EB, Schanel-Klitsch E, Herzberg C. Stereoacuity development: 6 months to 5 years. A new tool for testing and screening. *Optom Vis Sci.* 1996;73:43-48.
18. Birch EE, Salomao S. Infant random dot stereoacuity cards. *J Pediatr Ophthalmol Strabismus.* 1998;35:86-90.
19. Birch EE, Petrig B. FPL and VEP measures of fusion, stereopsis and stereoacuity in normal infants. *Vis Res.* 1996;36:1321-1327.
20. Moussa MA, Leat SJ, Faubert J. The moving dynamic random-dot stereotest (MDRS): validity and repeatability, *Invest Ophthal. Vis Sci.* 1998;39(suppl):558.
21. Adoh TO, Woodhouse JM, Oduwaiye KA. The Cardiff test: a new visual acuity test for toddlers and children with intellectual impairment. A preliminary report. *Optom Vu Sci.* 1992;69:427-432.
22. *Randot Stereo Smile Test: Instructions.* Chicago, Ill: Stereo Optical Co Inc; 1997.
23. Faubert J, Larson W. A new stereopsis test for pediatric vision. *Optom Vis Sci* 1993;70(suppl):89.
24. Sebris S, Dobson V, McDonald M. Acuity cards for visual acuity assessment of infants and children in clinical settings. *Clinical Vision Sciences.* 1987;2:45-58.
25. Gwiazda J, Brill S, Mohindra I, Held R. Preferential looking acuity in infants from 2 to 58 weeks of age. *Am J Optom Physiol Opt.* 1980;57:428-432.
26. Mayer DL, Dobson V. Visual acuity development in infants and young children as assessed by operant preferential looking. *Vis Res.* 1982;22:1141-1151.
27. Atkinson J, Wattam-Bell J, Pimm-Smith E, Evans C. Comparison of rapid procedures in forced choice preferential looking for estimating acuity in infants and young children. In: Jay B, ed. *Detection and Measurement of Visual Impairment in Preverbal Children.* Boston, Mass: Martinus Nijhoff/Dr W Junk Publishers; 1986:192-200.
28. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* 1986;i:307-310.
29. Phillips JO, Finocchio DV, Ong L, Fuchs AF. Smooth pursuit in 1-4 month-old human infants. *Vu Res.* 1997;37:3009-3020.
30. Shea SL, Aslin RN. Oculomotor responses to step-ramp targets by young human infants. *Vis Res.* 1990;30:1077-1092.
31. Atkinson J, Braddick O. Development of optokinetic nystagmus in infants: an indicator of cortical binocularity? In: Fisher DF, Monty RA, Sender JW, eds. *Eye Movements: Cognition and Visual Perception.* Hillside, NJ: Erlbaum Associates; 1981:53-64.
32. Saunders KJ, Woodhouse JM, Westall CA. The modified Frisby stereotest. *J Pediatr Opbtbalmol Strabismus.* 1996;33:323-327.
33. Simons K. A comparison of the Frisby, Random-dot E, TNO, and Randot circles stereotests in screening and office use. *Arch Ophthalmol.* 1981;99:446-452.
34. Lam SR, LaRoche RG, De Becker I, Macpherson H. The range and variability of ophthalmological parameters in normal children aged 4½ to 5½ years. *J Pediatr Ophthalmol Strabismus.* 1996;33:251-256.
35. O'Dell CD, Boothe RG. The development of stereoacuity in infant rhesus monkeys. *vis Res.* 1997;37:2675-2684.
36. Chino Y, Smith E, Hatta S, Cheng H. Postnatal development of binocular disparity sensitivity in neurons of the pimate visual cortex. *J Neurosci.* 1997;17:1-12.
37. Katsanis J, Iacono WG, Harris M. Development of oculomotor functioning in preadolescence, adolescence and adulthood. *Psychophysiology.* 1998;35:64-72.
38. Haishi K, Kokubun M. Developmental trends in pursuit eye movements among pre-school children. *Percept Mot Skills.* 1995;81:1131-1137.
39. Kowler E, Martins AJ. Eye movements of preschool children. *Science.* 1982;215:997-999.
40. Dobkins KR, Anderson AM, Lia B. Infant temporal contrast sensitivity functions (tCSFs) mature earlier for luminance than for chromative stimuli. Evidence for precocious magnocellular development? Vis *Res.* 1999;39:3223-3239.