

ORIGINAL ARTICLES

The Electronic Visual Acuity Tester: Testability in Preschool Children

VISION IN PRESCHOOLERS STUDY GROUP

ABSTRACT: *Purpose.* To evaluate the ability of preschool children to have their threshold visual acuity assessed using a standardized, computer-based letter test. *Methods.* Participants were 1195 3.5- to 5-year-old children enrolled in the Vision in Preschoolers Study. Monocular visual acuity was assessed by licensed eye care professionals (optometrists and pediatric ophthalmologists experimented in the examination of children), using the Electronic Visual Acuity tester, which uses the letters H, O, T, and V with a crowded surround. *Results.* Overall, 99.1% of children passed the training that consisted of identifying the letters H, O, T, and V by naming or matching the letters at 60 cm. Among those who passed the training, 99.6% completed the binocular pretest at 3 m, and 97.6% of those passing the training and the pretest completed monocular threshold visual acuity testing of each eye with the Electronic Visual Acuity tester. Testability increased with age for training ($p = 0.03$), pretesting ($p = 0.04$), and acuity testing ($p = 0.07$). Overall, 93.3% of 3.5-year-olds, 96.7% of 4-year-olds, and 98.8% of 5-year-olds completed training, pretesting, and monocular threshold acuity testing of each eye using standard letter optotypes. *Conclusion.* Using the computer-based Electronic Visual Acuity system, nearly all 3.5- to 5-year-old children can complete monocular acuity testing of each eye. (*Optom Vis Sci* 2004;81:238-244)

Key Words: Electronic Visual Acuity Tester, preschool children, threshold visual acuity, crowded HOTV letter optotypes

The Electronic Visual Acuity (EVA) system uses a standardized protocol, developed by researchers in the Amblyopia Treatment Study (ATS), to measure threshold visual acuity in preschool children.^{1, 2} The ATS protocol involves the use of the letters H, O, T, and V, which represent one of the two sets of optotypes (Lea symbols being the other set) that were recently recommended by the Task Force for Screening Vision in Preschool Children.³ HOTV optotypes have also been reported to provide good to excellent testability of preschool children in screening settings (Table 1).⁴⁻⁶

In contrast to visual acuity tests designed for adults, which involve presentation of lines of optotypes, the ATS protocol uses presentation of single optotypes, which are easier for preschool children to identify than lines of optotypes.⁵ In addition, the ATS protocol allows children to match the optotypes presented by pointing to optotypes on a lap card (crowded HOTV optotypes about the size of the 20/125 optotypes at distance). This type of nonverbal response produces higher rates of testability than does verbal identification of optotypes in preschool children.^{5, 7, 8} Crowding bars are included around each letter because they are traditionally held to improve detection of amblyopia, in comparison to testing with single letters alone,⁹⁻¹¹ although differences of opinion exist regarding the necessity of their inclusion.¹²

The ATS visual acuity protocol was initially developed for use on

the Baylor Video Acuity Tester. A computerized method (the EVA tester) was developed later to increase availability (the Baylor Video Acuity Tester had limited availability), to allow testing of larger optotypes (the Baylor Video Acuity Tester was limited to a maximal optotype size of 20/125), and to allow automation of the testing protocol.² Automation ensures strict adherence to the testing protocol's modified staircase technique because, after the tester enters the child's answer into the handheld Palm Pilot, the EVA system determines which optotype level to test. In addition, the EVA system allows a random presentation of letters and standardization of lighting and contrast. Repeatability of visual acuity results on the EVA has been shown to be good in preschool children.² In addition, initial studies showed testability for the EVA to be high across the age range from 3 to 7 years.² However, only small numbers of preschool children in the 3- to 5-year-old age range participated in these studies (Table 1). Therefore, the purpose of the current study was to evaluate testability when the EVA is used to measure monocular acuity in a large group of 3- to 5-year-old children.

METHODS

Subjects

Subjects were 1195 children who were enrolled in Head Start in one of the five cities in which a Vision in Preschoolers (VIP)

TABLE 1.
Review of vision testing with HOTV letters

Author	Hered et al. ⁴	Friendly ⁵	Merritt et al. ⁶	Holmes et al. ¹	Moke et al. ²
Subject number and age	777 subjects 3–5 years old unselected children	700 subjects 2.5–6 years old unselected children	1362 subjects 2–5+ years old unselected children	178 subjects 2–7 years old clinic patients	156 subjects 3–7 years old developmentally normal clinic patients
Setting	screening HOTV chart on chart illuminator at 10 ft; full chart format	two screening sessions isolated optotypes on wall mounted chart at 10 ft	screening HOTV optotypes on self-illuminated charts at 20 ft; full chart format	exam isolated letter, framed with crowding bars at 10–20 ft (BVAT)	exam isolated letter, framed with crowding bars at 3 m (Electronic Visual Acuity tester)
Type of pretraining or instruction used	group instruction; taught children optotypes and the method of testing; average instruction time = 94 sec	15 minute group instructional session; 2 minutes individual instruction	none	pretest was performed to determine if the child could match the HOTV letters	pretest was performed to determine if the child could match the HOTV letters
Tester	employee or volunteer of Prevent Blindness Florida (screeners pointed to optotypes)	nine testers with significant prior experience	authors	testers familiar with the acuity testing protocol	testers familiar with the acuity testing protocol
Type of patient response	matching or verbal	matching or verbal	matching	matching	matching
Definition of testable or untestable	untestable: inappropriate responses to the test or uncooperative with the test process despite best efforts of screeners	testable: able to identify all 4 letters (4/4, 5/6, or 6/8 on consecutive letter cards) during individual instruction	testable: monocular visual acuity obtained for each eye	testable: protocol could be completed for the right and left eyes on the first examination	testable: complete testing of both eyes
Testability	3 years = 85% (n = 159) 4 years = 98% (n = 182) 5 years = 100% (n = 45)	36–40 months = 84% (n = 49) 41–50 months = 98% (n = 111) 51–60 months = 100% (n = 122)	3 years = 93% (n = 496) 4 years = 99% (n = 531) 5+ years = 99% (n = 246)	2 years = 24% (n = 25) 3 years = 67% (n = 21) 4 years = 87% (n = 60) 5 years = 94% (n = 32)	3 years = 85% (n = 27) 4 years = 94% (n = 35) 5–7 years = 100% (n = 71)

clinical center was located (Berkeley, CA; Boston, MA; Columbus, OH; Philadelphia, PA; and Tahlequah, OK). Head Start is a national program that provides comprehensive developmental services for America's low-income, preschool children aged 3 to 5 years and has the overall goal of increasing school readiness of young children in low-income families.^{13, 14} All children were 3 or 4 years of age on September 1, 2001. The project was approved by the appropriate institutional review boards at each clinical center. Written informed consent was obtained from each child's parent or legal guardian after an explanation of the nature and possible consequences of participation. The mean age on the day of testing was 4.5 ± 0.6 years. At testing, 225 children were 3 years old (mean, 3.7 years; range, 3.4–3.9 years); 633 were 4 years old (mean, 4.5 years; range, 4.0–4.9 years); and 337 were 5 years old (mean, 5.2 years; range, 5.0–5.7 years) (Table 2). Efforts were made to recruit all children at each Head Start site who had failed the local Head Start vision screening and a random sample of children who had passed the screening. Among the 1195 children included in this study, 59% had failed the Head Start screening. Children with developmental delay were excluded from the VIP Study because their responses may be uncharacteristic of those of the typical preschool child.¹

Electronic Visual Acuity System

The EVA includes a personal computer and monitor that can present single HOTV optotypes that range in size from 20/800 to 20/16 and are surrounded by a crowding bar spaced at 0.5 to 1 optotype width around the letter (Fig. 1). In the current study, crowding bars were at 0.5 optotype width. The computer is connected to a handheld Palm operating system that provides prompts



FIGURE 1.
Electronic Visual Acuity Tester.

for the tester, sends instructions to the computer, displays the letter presentation for the examiner, and displays and stores test results. The system has been described in detail previously.²

Procedures

All testing was performed by licensed eye care practitioners (optometrists and pediatric ophthalmologists experienced in the examination of children) who had completed training and certification on the EVA as part of the VIP Study. All children in the VIP Study also participated in a screening session during which testing with a version of surrounded HOTV letters was attempted or completed. The screening was performed by a different doctor before the EVA testing described below (mean, 6.77 days; range, 0–108 days). The screening test involved a pretest to determine whether the child could identify single optotypes and testing with four differently sized lines of optotypes. The testers using the EVA system were masked to the results of the screening HOTV test.

During testing, the child held a lap card on which the single, surrounded H, O, T, and V letters were printed. The child was permitted to identify the letters verbally or by pointing to the matching letter on the lap card. According to the VIP protocol, the child had to initially demonstrate his or her ability to identify all four optotypes using handheld training cards held by the tester at about 60 cm. The child had up to two chances to identify each optotype. If the child could not respond correctly to all four letters, a break was allowed and the child could be given another opportunity to identify the letters as described above, if time allowed. If the child was unable to respond to all four letters, the child was scored as “unable,” and visual acuity testing ceased.

If the child passed the initial training at 60 cm, a binocular pretest was then performed, in which the child had to identify four of four or four of five optotypes appearing on the personal computer monitor at a distance of 3 m. If the child could not complete the pretest, visual acuity testing ended, and the result was scored as “unable-PC monitor.” If the child was able to complete the training and the pretest, monocular visual acuity testing was conducted at 3 m, first for the right eye and then for the left eye. The eye not being tested was occluded with an adhesive patch.

TABLE 2.
Description of VIP-examined children

Description	No.	%
Age at examination		
3 years old	225	(18.8)
4 years old	633	(53.0)
5 years old	337	(28.2)
Gender		
Female	599	(50.1)
Male	596	(49.9)
Ethnicity		
Not Hispanic or Latino	843	(70.5)
Hispanic or Latino	286	(23.9)
Unable to answer	66	(5.5)
Racial category		
American Indian only	72	(6.0)
Asian only	61	(5.1)
Black only	606	(50.7)
Native Hawaiian or Pacific Islander only	17	(1.4)
White only	196	(16.4)
Mixed race	50	(4.2)
Unable to obtain answer	193	(16.2)

As designed in the ATS protocol,^{1,2} monocular visual acuity testing involves several parts: screening, phase 1, reinforcement, and phase 2. During the screening phase, letters are presented in descending logarithm of the minimum angle of resolution steps, beginning with 20/100, to obtain an estimation of threshold. When the child makes an error, phase 1 of threshold testing begins by presentation of letters at two acuity levels (0.2 log units) above the point where the error was made. Up to four letters are presented at that level, until two errors are made or until three letters are correctly identified. If two errors are made at this acuity level, the next larger letter size is presented. This continues until three of three or three of four letters are correctly identified at an acuity level. If three letters are identified correctly at the starting acuity level, testing continues on the next smaller acuity level. Testing stops when two errors are made at an acuity level.

After phase 1, the reinforcement phase of testing is performed to recapture the child's attention. In this phase, three letters are presented. The first letter is three acuity levels (0.3 log units) above the last acuity level (largest optotype size) that was failed during phase 1. Then, one letter is presented at each of the next two acuity levels. In the reinforcement phase, the accuracy of the child's responses does not affect the acuity score or the next letter to be tested. Finally, in phase 2, the last acuity level that was failed in phase I is retested. If three of three or three of four letters are correctly identified, testing continues at smaller acuity levels until an acuity level is reached at which the child incorrectly identifies two letters. The acuity score is the smallest letter size at which the child identifies three of three or three of four letters correctly in phase 1 or phase 2 of testing.

The EVA system presents letters at random (with no sequentially repeated letters), so there is no danger of the child being aided by memorization of letters from phase 1 to 2.

Data Analysis

The VIP Study examiner at each site recorded results on a standard data collection form. The proportion of children able to complete each stage of testing was determined for each age, gender, and racial category. Confidence intervals for proportions were calculated using the Wilson method.¹⁵ Differences in proportions were

compared using the Fisher exact test and with the exact Cochran-Armitage test for linear trend in proportions when the proportions were compared across the three age categories.

Logarithm of the minimum angle of resolution visual acuity scores for the right eye (always tested first) vs. the left eye were compared using a paired t-test to determine whether practice effects or fatigue influenced the left eye scores. All calculations were performed using SAS/STAT 8.0 software (SAS Institute, Inc., Cary, NC).

RESULTS

Nearly all children (99.1%) were able to pass the training at 60 cm. Among the 1184 children who passed this initial training, 1179 (99.6%) children were able to complete the binocular pretest at 3 m, and among these passing children, 1155 (98%) were able to complete monocular visual acuity testing of both eyes with the EVA tester.

When the results were broken down by age, 97.8% of the 3-year-old, 99.2% of the 4-year-old, and 99.7% of the 5-year-old children were able to pass the training at 60 cm. The binocular pretest at distance, which was presented to the 1184 children who passed the initial training, was completed by 98.6% of the 3-year-olds, 99.7% of the 4-year-olds, and 100% of the 5-year-olds. Finally, 96.8% of the 3-year-olds, 97.8% of the 4-year-olds, and 99.1% of the 5-year-olds who passed the binocular pretest at 3 m were able to complete monocular assessment of visual acuity in the right and left eyes with the EVA protocol.

Overall, 93.3% of the 3-year-olds, 96.7% of the 4-year-olds, and 98.8% of the 5-year-olds were able to complete training, pretesting, and monocular testing of each eye. Testability increased with age for training ($p = 0.03$), pretesting ($p = 0.04$), and acuity testing ($p = 0.07$) (Table 3). Girls were significantly better able than boys to pass the binocular training at 60 cm (99.7% vs. 98.5%; $p = 0.04$). This was not the result of an age difference among 3-year-old girls and boys; the mean age for both was 3.7 years. Among children passing the initial training, no significant gender-related differences in testability were found on binocular pretesting at 3 m or monocular visual acuity testing with the EVA tester ($p = 0.21$ and 1.00, respectively). There were no significant

TABLE 3.
Testability by age

Age (yrs)	Percentage able to complete each component: training, pretesting, and monocular testing						Percentage able to complete training, pretesting, and monocular testing	
	Training cards binocular at 60 cm		Pretest binocular at 3 m		EVA test monocular at 3 m		EVA test monocular at 3 m	
	No.	% (95% CI)	No.	% (95% CI)	No.	% (95% CI)	No.	% (95% CI)
3	220 /225	97.8 (94.9, 99.0)	217 /220	98.6 (96.1, 99.5)	210 /217	96.8 (93.5, 98.4)	210 /225	93.3 (89.3, 95.9)
4	628 /633	99.2 (98.2, 99.7)	626 /628	99.7 (98.8, 99.9)	612 /626	97.8 (96.3, 98.7)	612 /633	96.7 (95.0, 97.8)
5	336 /337	99.7 (98.3, 99.9)	336 /336	100.0 (98.9, 100)	333 /336	99.1 (97.4, 99.7)	333 /337	98.8 (97.0, 99.5)
Total	1184 /1195	99.1 (98.4, 99.5)	1179 /1184	99.6 (99.0, 99.8)	1155 /1179	98.0 (97.0, 98.6)	1155 /1195	96.7 (95.5, 97.5)

EVA, electronic visual acuity; CI, confidence interval.

racial differences in testability for training, binocular pretesting, or monocular testing with the EVA tester ($p = 0.62, 0.83, \text{ and } 0.95$, respectively).

A broad range of acuity scores, from 20/800 to 20/16, was obtained from the right and left eyes of the 1155 children who completed monocular acuity testing of both eyes. The mean difference in acuity between eyes (log right eye acuity score minus log left eye acuity score) was 0.008 log units, which is not significantly different from 0 ($p = 0.11$, paired t -test), indicating no evidence that the left eye score was better because of practice or worse because of fatigue.

DISCUSSION

In this investigation, we evaluated the ability of preschool children to have their visual acuity assessed with isolated, surrounded, HOTV optotypes using a standardized, computer-based test. The percentage of children able to complete the training was comparable to that reported previously. Friendly⁵ reported 84% of 36- to 40-month-olds, 98% of 41- to 50-month-olds, and 100% of 51- to 60-month-olds were able to complete the training. Similarly, the current study found 98% of 41- to 50-month-olds and 99.5% of 51- to 60-month-olds could identify the training cards. (No 36- to 40-month-olds were tested in the current study.)

The percentage of children able to complete monocular testing on each eye was comparable to that found in screening settings in which HOTV acuity tests were used. Hered et al.⁴ reported that monocular testing could be completed by 85% of 3-year-olds, 98% of 4-year-olds, and 100% of 5-year-olds, while Merritt et al.⁶ showed that monocular testing could be accomplished by 93% of 3-year-olds, 99% of 4-year-olds, and 99.6% of children aged 5-years and older (Table 1). Similarly, the current study found that 93% of 3-year-olds, 97% of 4-year-olds, and 99% of 5-year-olds were able to complete monocular testing. The current study and these previous studies conducted in screening settings permitted children to respond by matching. In the current study, testability for 3-year-olds was slightly higher than that reported by Hered et al.⁴ and similar to that reported by Merritt et al.⁶ The differences in testability found among the three studies may be related to differences in the age distributions of 3-year-olds in the three studies. In the current study, all 3-year-olds were 3.4 years of age or older. Although it is not possible to determine the age distribution of 3-year-olds in the studies by Hered et al. and Merritt et al., it is possible that Hered et al. included a substantial number of younger 3-year-olds, who would be expected to be more difficult to test than older 3-year-olds, whereas Merritt et al. may have included primarily older 3-year-olds, similar to the age distribution in the current study. Another possible explanation for the higher testability reported in the current study and in the study by Merritt et al., as compared to that in the study by Hered et al., is that testing in the current study and the study by Merritt et al. was conducted by doctors experienced in examining young children rather than by lay volunteers. Finally, the study by Hered et al. was performed in a screening setting, whereas the current study was performed in a controlled examination setting; however, the fact that Merritt et al. found high testability in 3-year-olds with the HOTV in a screening setting suggests that there were fewer distractions in the screening by Merritt et al. or the setting in which testing occurred did not have a large effect in this instance.^{4,6}

The percentage of children able to complete monocular testing on each eye on the EVA tester was higher in the current study than has been previously reported for 3- and 4-year-olds.^{1,2} Using a criterion for testability that was the same as that in the current study, Holmes et al.¹ found that 67% of 3-year-olds ($n = 21$), 87% of 4-year-olds ($n = 60$), and 94% of 5-year-olds ($n = 32$) were testable. Moke et al.² reported that 85% of 3-year-olds ($n = 27$), 94% of 4-year-olds ($n = 35$), and 100% of 5- to 7-year-olds ($n = 71$) could complete the EVA testing protocol. As mentioned earlier, one factor that could account for the higher testability of 3-year-olds in the current study was that the age range (3.4–3.9 years) may have been older than that in other studies in which 3-year-olds were tested. In addition, children with developmental delay were not included in the current study or the study by Moke et al.² Therefore, the inclusion of children with developmental delay (11%) may have decreased the testability found by Holmes et al.,¹ because the children with reported developmental delay had significantly lower testability than the children without developmental delay (55% vs. 82%, $p < 0.001$). Another factor that could have contributed to the higher testability in the current study is that all testing was performed by licensed eye care practitioners (optometrists and pediatric ophthalmologists experienced in the examination of children). The testability found in the current study may also be slightly higher than that reported by Holmes et al.,¹ Moke et al.,² or Hered et al.,⁴ because all the children in this study had experience with surrounded HOTV letters during a previous screening session. Although children in each of the studies had training or pretesting before testing, only 60% of the children in the study by Moke et al., 40% of the children in the study by Holmes et al., and an unknown number of children in the study by Hered et al. had previous experience with isolated, surrounded HOTV letters.^{1,2,4} It is uncertain, however, how much of an effect this would have because previous studies with the HOTV in a screening setting showed good testability with^{4,5,7} and without⁶ pretraining, yet higher testability has been reported when a visual acuity test was preceded by another test of visual acuity.⁴ Finally, it is unlikely that any differences in the prevalence of vision problems contributed to any differences in testability across studies, because high testability has been found using HOTV with nonselected preschool populations^{4,6} and in preschoolers with a higher percentage of vision problems than that found in the general preschool population,^{1,2} as in the current study.

This study supports previous literature that shows high testability for visual acuity testing in preschool children using HOTV optotypes and a letter-matching format.^{1,2,5,7,16} The use of the EVA tester offers the added benefits of a well established, automated testing procedure for the detection of amblyopia,^{1,2} reliability of testing procedure,² standardization of light and contrast levels, random presentation of isolated, surrounded letters, a threshold determination, and logarithmic progression across a broad range of acuity levels.

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