Visual Acuity Screening Versus Noncycloplegic Autorefraction Screening for Astigmatism in Native American Preschool Children

Joseph M. Miller, MD, Erin M. Harvey, MA, and Velma Dobson, PhD

Introduction: Visual acuity screening (VAS) is less reliable in preschoolers than in school-aged children as a means of detecting significant refractive error. We wished to compare the effectiveness of VAS with the effectiveness of an objective method, noncycloplegic autorefraction screening (NCARS), in detecting the presence of significant astigmatism warranting spectacle correction. Methods: We examined 245 Native American Head Start registrants aged 3 to 5 years. We attempted to obtain uncorrected visual acuity using Lea Symbols logMAR Chart (Precision Vision Inc, Villa Park, Ill), noncycloplegic autorefraction using the Nikon Retinomax K-plus (Nikon Corp, Melville, NY), and cycloplegic refraction (CR) on each eye. The VAS failure criterion was either a 2-line acuity difference between eyes or acuity worse than 20/40 in either eye. The NCARS and CR failure criterion was the spectacle correction threshold exceeding the 50th percentile on the basis of a survey of AAPOS members. Results: We completed VAS in 96% of children and NCARS and CR in 100% of children. There was high prevalence (31%) of significant astigmatic refractive error in this sample. Ten subjects who did not permit bilateral visual acuity measurements were scored as having a positive test result. The sensitivity and specificity of VAS were 90% and 44%, respectively. NCARS had sensitivity and specificity of 91% and 86%, respectively. NCARS becomes cost-effective after 1044 children are screened, assuming that the cost of the autorefractor is 300 times the cost of the referral examination. Conclusion: VAS offers high sensitivity but suffers from poor specificity. NCARS greatly reduces the number of unnecessary referrals. In this population, NCARS becomes cost-effective after approximately 1000 children are screened. (J AAPOS 1999;3:160-5)

Visual acuity screening (VAS) of the preschool population is recommended by the American Academy of Pediatrics, the American Academy of Ophthalmology, and the American Association for Pediatric Ophthalmology and Strabismus.1-3 A vision assessment is required as a prerequisite for participation in the Head Start program.4 However, measurement of visual acuity, especially in the preschool-aged group, can be unreliable. Poor acuity can reflect either poor ability to see or poor ability to perform the task demanded of the child.

Does every child who fails VAS criteria or who does not cooperate with visual acuity testing warrant a referral? Amblyopia therapy initiated in the Head Start–age range results in more rapid response than treatment initiated in children older than the Head Start–age range.5,6 If a child is unable to perform the visual acuity task, amblyopia cannot be ruled out. However, even without measuring visual acuity, it is possible to determine the presence of refractive error that would warrant optical correction, regardless of whether amblyopia is present. Under such circumstances, the dispensing of spectacles might be therapeutic for refractive amblyopia or simply improve the visual performance of a child having significant ametropia. The child with myopia has a near environment that provides sharply focused visual stimulation, and the child with hyperopia can, through accommodation, receive sharply focused visual stimulation. The child with astigmatism experiences blur on a continuous basis and is at increased risk for the development of refractive amblyopia.7

Some populations appear to be predisposed to amblyopia, especially in medically underserved or economically disadvantaged areas.8 Other populations appear to be genetically predisposed to high refractive error. For example, some Native American tribes have a high prevalence of astigmatism. These include the Navajo, Pueblo, and Tohono O’Odham tribes, in which the prevalence of at
least 1 D of astigmatism has been reported to be 49%, 62%, and 61%, respectively. The astigmatism is corneal and with the rule. The refractive error in Tohono O’Odham children is rarely corrected before the children enter grade school. Therefore, an effort has been initiated to detect and treat significant refractive error in the preschool population.

Nearly all Tohono O’Odham children aged 3 to 4 years participate in the Head Start program. In August 1997, we initiated the Tohono O’Odham Vision Screening Program, which provides a comprehensive eye examination for each child twice during the Head Start academic year, an evaluation of screening strategies, spectacles for the children found to have significant refractive error, and a determination of the effectiveness of preschool spectacle use in improving vision on entry into first grade. This paper describes our initial experience comparing 2 screening strategies for the prediction of significant refractive error: VAS with the Lea Symbols logMAR Chart (Precision Vision Inc, Villa Park, Ill) and noncycloplegic autorefraction screening (NCARS) performed with the Nikon Retinomax K-plus (Nikon Corp, Melville, NY).

SUBJECTS AND METHODS
Subjects were recruited from the Head Start program administered by the Tohono O’Odham nation. Parental informed consent was obtained for all participants. All Head Start children were encouraged to participate, and all who did participate received comprehensive eye examinations and spectacles, if indicated. Because astigmatism has such a high prevalence in this and other Native American populations, we wished to determine the best way to screen for this specific disorder. Therefore, only children aged 3 to 5 years, not classified as having special needs by the Head Start program, and free of ocular pathologic disorders, including pupillary abnormalities, anterior segment abnormalities, fundus abnormalities, motility disorder (either manifest or intermittent tropia), and significant refractive error that did not include astigmatism were considered in the subject population.

Visual Acuity Screening
Visual acuity was measured at a distance of 3 m using a full-sized ETDRS-style Lea Symbols logMAR Chart (Precision Vision, Villa Park, Ill) in an illuminated cabinet. If the child came to the test session wearing spectacles, the glasses were worn for testing and the use of spectacles recorded. The child’s visual acuity and refractive error measurements were performed by trained testers who routinely examine children. The children were permitted to either name the symbol (house, apple, circle, square) or point to the symbols on a lap card to indicate their response by matching. The tester began with the top row and presented the first 3 symbols. If the child correctly identified the symbols, the tester would move down to the next line and present the first 3 symbols and continue in this manner until the child incorrectly identified a symbol. Once a symbol was incorrectly identified, the tester continued to present symbols on that line until the child either correctly or incorrectly identified 3 of the total 5 symbols on the line. Acuity was scored as the smallest line on which the child correctly identified 3 symbols. The child continued on to the next lines, until the child incorrectly identified symbols on a line, acuity was scored as the line above that line. If the child correctly identified symbols, the tester continued on to the next lines, until the child incorrectly identified 3 symbols on a line. Acuity was scored as the smallest line on which the child correctly identified 3 of 5 symbols. A positive vision screening result occurred when the acuity was worse than 20/40 in either eye or when a 2-line difference between eyes existed.

Noncycloplegic Autorefraction Screening
NCARS was performed with a Nikon Retinomax K-plus (RmaxK+) (Nikon Corp, Melville, NY). This autorefractor is a handheld device that does not require the child to be accurately positioned with a chin rest. Rather, the tester rests the instrument against the child’s forehead, and the child is instructed to view the fixation target within the instrument. Up to 8 individual refractions are collected before the reporting of a composite refraction. The autorefractor also permits evaluation of the monocular red reflex and keratometry. A positive screening result occurred when either eye exceeded the 50th percentile of a survey of pediatric ophthalmologists. (Adapted with permission from Miller JM, Harvey E. Spectacle prescribing recommendations of AAPOS members. J Pediatr Ophthalmol Strabismus 1998;35:51-2.)

Cycloplegic Determination of Refractive Error
Cycloplegic measurement of refractive error was determined by evaluation of data obtained by cycloplegic autorefraction (RmaxK+) and by retinoscopy in which the retinoscopist was unaware of the results of the noncycloplegic and cycloplegic autorefraction. Cycloplegia was induced with a regimen of a drop of proparacaine immediately followed by a drop of 2% cyclopentolate, followed 5 minutes later by a drop of 1% cyclopentolate. For small children (≤33 lb for girls, ≤35 lb for boys), a drop of 1% cyclopentolate was substituted for the drop of 2% cyclopentolate. At least 40 minutes after the first drop was administered, the adequacy of cycloplegia was assessed.

TABLE 1. Definition of significant refractive error (values in diopters)

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Less than 2</th>
<th>Between 2 and 4</th>
<th>Between 4 and 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myopia</td>
<td>4.00</td>
<td>2.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Hyperopia</td>
<td>5.00</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Astigmatism</td>
<td>2.50</td>
<td>2.00</td>
<td>1.50</td>
</tr>
<tr>
<td>Anisometropia</td>
<td>1.50</td>
<td>1.50</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Values represent the 50th percentile of a survey of pediatric ophthalmologists.
using dynamic retinoscopy. If necessary, the child was
given additional time to dilate, but no additional dilating
drops were given.

An algorithm was devised to compare masked
retinoscopy with cycloplegic autorefraction. The vectori-
ally determined dioptric distance (VDD), in diopters,
between the masked retinoscopy and cycloplegic auto re-
fraction was calculated according to the method of
Harris.\textsuperscript{14} If agreement between the two was good (VDD
$\leq 1.50$ D), then the autorefraction was used as the measure
of refractive status. If the VDD was $\geq 1.50$ D, then a sec-
dond autorefraction was obtained and the VDD between
the masked retinoscopy and the second autorefraction was
evaluated. If the second VDD was $<1.5$ D, then the second
autorefraction was used as the measure of refractive status.
If the second VDD equaled or exceeded 1.50 D, then an
unmasked final retinoscopy was performed to determi-
ne refractive error. This procedure was intended to use
the autorefractor preferentially over manual retinoscopy to
take advantage of the greater reproducibility of autorefrac-
tor measurements, while ensuring the accuracy of the
autorefraction readings through masked retinoscopy.

Prescribing of Spectacles

For data analysis, a child had significant refractive error if
the cycloplegic refraction met or exceeded the 50th per-
centile of a survey of spectacle-prescribing recommenda-
tions of the AAPOS membership, as outlined in Table 1.\textsuperscript{13}
Spectacles were prescribed for all children who met these
criteria.

RESULTS

A total of 279 children were screened from August through
November in 1997. Children identified by the Head Start
program as having special needs were excluded, as were
those with other than astigmatic refractive errors. Of the
279 children, 34 were excluded from analysis for having age
older than 5 years ($n = 2$) or younger than 3 years ($n = 7$) at
the beginning of the school year, special needs ($n = 17$) (as
identified by Head Start), congenital nystagmus ($n = 1$), sig-
nificant anisometropia ($n = 3$) and already wearing glasses
($n = 2$). No children other than those with special needs
were found to have a motility disorder. The motility exam-
ination was a screening examination performed in a man-
ner unlikely to detect a microtropia. Two additional chil-
dren's parents did not wish for them to receive dilating eye
drops; therefore, these children were excluded from analy-
sis. This yields a total sample size of 245 children, 89 (36%)
of whom were aged 36 to 47 months, 139 (57%) of whom
were aged 48 to 59 months, and 17 (7%) of whom were
aged 60 to 71 months.

VAS, NCARS, and cycloplegic refraction (CR) were
attempted on all 245 subjects. Visual acuity could be mea-
sured from each eye of 235 subjects (96%), and NCARS
and CR were completed on all 245 subjects (100%). The distribution of visual acuity results of the more poorly seeing eye is shown in Figure 1. The distribution of astigmatism found in the more astigmatic eye is shown in Figure 2.

For the 245 subjects undergoing cycloplegic retinoscopy, acceptable agreement between the masked retinoscopy and the first autorefraction was obtained in 222 instances (91%). One subject was uncooperative with cycloplegic autorefraction, and her refractive error was determined by the initial masked retinoscopy. For the remaining 22 subjects, there was acceptable agreement between the masked retinoscopy and the second autorefraction in 6 instances, and an unmasked retinoscopy was required to determine refractive error in 16 instances (7%). The prevalence of significant refractive error in this population was 31% (76/245), according to the spectacle-prescribing guidelines of Table 1. All 76 subjects with significant refractive error had significant refractive error.

True-positive, false-positive, true-negative, and false-negative rates for the 2 screening tests (VAS and NCARS) are shown in Table 2. The resultant sensitivity, specificity, positive predictive power, and negative predictive power for the screening strategies are shown in Table 3.

Sensitivity is the proportion of those children whose screening examination predicted significant refractive error among those children who were found to have significant refractive error on cycloplegic refraction. Specificity is the proportion of children whose screening examination predicted no significant refractive error among those children found to have no significant refractive error on cycloplegic refraction. The positive predictive power is the proportion of children who indeed had significant refractive error among those whose screening test predicted no significant refractive error presence.

### Table 2. Screening results

<table>
<thead>
<tr>
<th></th>
<th>Pos CR (sig ref error)</th>
<th>Neg CR (no sig ref error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pos VAS</td>
<td>Pos NCARS</td>
<td>65 (27%)</td>
</tr>
<tr>
<td>(acuity worse</td>
<td></td>
<td>11 (4%)</td>
</tr>
<tr>
<td>than 20/40 in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>either eye or</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-line difference between eyes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neg VAS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(acuity 20/40 or better in each eye, acuity within 2 lines between eyes)</td>
<td>4 (2%)</td>
<td>12 (5%)</td>
</tr>
<tr>
<td>Neg NCARS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(sig ref error)</td>
<td></td>
<td>3 (1%)</td>
</tr>
<tr>
<td>(no sig ref error)</td>
<td></td>
<td>63 (26%)</td>
</tr>
</tbody>
</table>

A positive screening test is predictive of significant refractive error.
A positive cycloplegic refraction is diagnostic of significant refractive error.
N = 245, with 31% (76/245) having significant refractive error.
CR, Cycloplegic refraction; NCARS, noncycloplegic autorefraction screening; VAS, visual acuity screening.

### Table 3. Sensitivity, specificity, positive predictive power and negative predictive power by screening strategy

<table>
<thead>
<tr>
<th>Screening strategy</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive power</th>
<th>Negative predictive power</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS</td>
<td>0.91</td>
<td>0.44</td>
<td>0.42</td>
<td>0.91</td>
</tr>
<tr>
<td>NCARS</td>
<td>0.91</td>
<td>0.86</td>
<td>0.75</td>
<td>0.95</td>
</tr>
<tr>
<td>VAS and NCARS</td>
<td>0.86</td>
<td>0.93</td>
<td>0.86</td>
<td>0.93</td>
</tr>
<tr>
<td>VAS or NCARS</td>
<td>0.96</td>
<td>0.37</td>
<td>0.41</td>
<td>0.95</td>
</tr>
</tbody>
</table>

CR, Cycloplegic refraction; NCARS, noncycloplegic autorefraction screening; VAS, visual acuity screening.

### Visual Acuity Screening

The sensitivity and specificity of VAS were 91% and 44%, respectively, with positive predictive value of 42% and negative predictive value of 91%. Visual acuity screening that was performed as the only basis for referral would have generated 163 referrals, using the criteria of visual acuity worse than 20/40 in either eye or a 2-line difference between eyes. The 163 referrals would have resulted in the detection of 69 of the 76 children requiring spectacles. Seven children (9%) requiring glasses would not receive them. The eye care practitioner would see significant refractive error in 42% (69/163) of the referrals.

### Noncycloplegic Autorefraction Screening

NCARS had sensitivity and specificity of 91% and 86%, respectively. The positive predictive value of autorefraction screening was 75%, and negative predictive value was 95%. NCARS would have generated 92 referrals to detect 69 of the 76 children requiring spectacles. Seven children (9%) requiring glasses would not receive them. The eye care practitioner would see significant refractive error in 75% (69/92) of the referrals.

### Combined Visual Acuity Screening and Noncycloplegic Autorefraction Screening

Using a strategy in which referrals would be generated only when a child had both positive VAS and NCARS resulted in sensitivity of 86% and specificity of 93%. The positive predictive value was 86%, and the negative predictive value was 93%. This restrictive referral policy (requiring a positive result on both screening tests) would have generated 76 referrals to detect 65 of the 76 children requiring spectacles. Eleven children (14%) requiring glasses would not receive them. The eye care practitioner would see significant refractive error in 86% (65/76) of the referrals.

### Combined Visual Acuity Screening or Noncycloplegic Autorefraction Screening

A combined sensitivity and specificity of 96% and 37% resulted by using a strategy in which referrals would be generated when a child had either positive VAS or positive NCARS. The positive predictive value was 41%, and the negative predictive
value was 95%. This liberal referral policy (requiring either screening test to be positive) generated the most referrals, with 179 referrals detecting 73 of the 76 children requiring spectacles. The eye care practitioner would see significant refractive error in 41% (73/179) of the referrals.

Cost-Effectiveness of Nonspheroic Autorefraction Screening

The Nikon RmaxK+ represents a significant investment. Assuming the cost of the autorefractor to be approximately 300 times that of the cost to perform a referral examination (15,000:50), the cost of the autorefractor will be recouped after 300 false-positive referrals have been eliminated by the improved screening yield offered by the autorefractor. Savings begin to accrue in the form of increased availability of eye care providers to provide services to others who need their care. These are round-number estimates based on our experience in a managed care environment. As the price of the autorefractor fluctuates and the cost to perform an examination changes, so too will the break-even ratio.

In the present population of 245 subjects, VAS resulted in 94 false-positive examinations (163 referrals, 69 subjects with refractive error). NCARS resulted in 23 false-positive examinations (92 referrals, 69 subjects with refractive error). In this population of 245 subjects, NCARS resulted in 71 (94 – 23) fewer false-positive referrals. At this rate, 1044 subjects would need to be screened with the autorefractor to result in 300 fewer false-positive referrals (the “cost” of the autorefractor).

DISCUSSION

Although visual acuity measurement is recommended as a component of vision screening, difficulties remain with obtaining reliable results. In the present study, visual acuity measurements were made in both eyes of 96% of the subjects. This high testability rate is much greater than that typically found in the office setting, where nearly two thirds of 3-year-old children have been reported to be uncooperative or “too young” to test. Some of the high testability rate can be attributed to the skill of the acuity testers, some to the motivation of the parents and children, and some to the use of the Lea Symbols test and matching. The Lea Symbols test does not have extensive normative data to confirm that the criteria we used for a positive screening examination (worse than 20/40 in either eye or a 2-line difference between eyes) represent an optimal referral threshold. Table 4 shows how sensitivity and specificity change for various positive screening examination acuity values in our subjects who underwent visual acuity measures on each eye. Revising the visual acuity referral threshold could result in a more favorable specificity (with resultant decreased cost and unnecessary use of services) but only at the expense of decreased sensitivity (with resultant failure to detect those in need of eye care). The receiver-operator curve showing this interaction is shown in Figure 3. Thus, it does not appear likely that even with nearly complete participation in VAS and revision of the visual acuity referral threshold that the power of the NCARS could be matched by VAS.

It seems unlikely that community-based visual acuity measurements would consistently be able to reproduce the testability rate observed in our study. Should VAS not be

TABLE 4. Variation of sensitivity and specificity for VAS

<table>
<thead>
<tr>
<th>Referral visual acuity</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/20</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>20/25</td>
<td>1.00</td>
<td>0.01</td>
</tr>
<tr>
<td>20/32</td>
<td>1.00</td>
<td>0.10</td>
</tr>
<tr>
<td>20/40</td>
<td>0.97</td>
<td>0.32</td>
</tr>
<tr>
<td>20/50</td>
<td>0.91</td>
<td>0.58</td>
</tr>
<tr>
<td>20/63</td>
<td>0.78</td>
<td>0.69</td>
</tr>
<tr>
<td>20/80</td>
<td>0.53</td>
<td>0.77</td>
</tr>
<tr>
<td>20/100</td>
<td>0.26</td>
<td>0.87</td>
</tr>
<tr>
<td>20/125</td>
<td>0.11</td>
<td>0.89</td>
</tr>
<tr>
<td>20/160</td>
<td>0.05</td>
<td>0.94</td>
</tr>
<tr>
<td>20/200</td>
<td>0.01</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Calculation of sensitivity and specificity based on 234 subjects who underwent Lea Symbol visual acuity testing on each eye. Visual acuity of worse-seeing eye is used for referral evaluation. Acuity equal to or worse than tabulated value produces tabulated sensitivity and specificity. Sensitivity and specificity values for referral cutoff of worse than 20/40 differ from data presented for our study population because 2-line difference between eyes is not incorporated in referral strategy presented in table.
performed or significant lack of confidence in the test results exist, it becomes more important to identify alternate screening methods that might be used with young children.

Photoscreening has been proposed as an alternative screening method for the detection of significant refractive error, media opacity, and strabismus. However, photoscreening images must be interpreted, and studies have shown that there can be considerable variability between raters in overall agreement as well as sensitivity and specificity. The autorefractor has the advantage of providing an unambiguous report of refractive error screening results. What remains to be seen is how this autorefractor will perform in the measurement of children with significant hyperopia.

Subjects undergoing autorefraction frequently accommodate to the near stimulus of the machine, and the underlying hyperopia is masked. The Nikon RmaxK+ used in the present study produces this effect. It does not appear that the cylinder magnitude is affected by accommodation, and this may explain why NCARS performed so well in our study’s population of patients with astigmatism.

In conclusion, our study demonstrates that for a group of Native American Head Start children having a high prevalence of significant refractive error that is overwhelmingly astigmatic, NCARS offers increased sensitivity and specificity over VAS and greater ease of interpretation of the screening data. With sufficient screening volume, the use of an autorefractor becomes cost-effective by decreasing unnecessary referrals. It is unclear whether this relationship would hold true when other refractive errors and nonrefractive causes of decreased vision, such as strabismus and amblyopia, are considered in a more general population. Before the results are generalized to populations with lower prevalence of astigmatism and other significant refractive error, more work is required to determine how instrument myopia may mask the presence of significant hyperopia.

The measurement (or attempted measurement) of visual acuity in the Head Start age group will continue to be necessary. Without an acuity measure, the presence or absence of amblyopia cannot be determined. However, until the child reaches an age where acuity measurements can be reliably performed, thought should be given to improving the efficiency of the vision screening process by including an objective screening tool.

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References