PRESCHOOL VISUAL ACUITY SCREENING TESTS*

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INTRODUCTION

THERE IS GENERAL AGREEMENT THAT VISUAL DEFECTS SHOULD BE identified as early in life as possible. Early detection provides the most favorable opportunity for effective treatment of a large number of conditions that produce poor vision, including most types of amblyopia. The duration of occlusive therapy for strabismic amblyopia is directly related to the age of the child at the time treatment is initiated.[1] The greater visual needs of the school age child, the greater social pressures on older children, and the difficulties encountered in obtaining their cooperation are additional reasons for treating amblyopia in the preschool period.

Significant refractive errors should likewise be identified early in life. The young child entering the school system should not have to endure the burden and stress of poor visual acuity due to uncorrected refractive errors which can interfere with learning.

Although strabismologists debate the wisdom of very early, early, or delayed[2-6] surgical ocular alignment for infantile esotropia, there is no disagreement that at a minimum a cosmetically acceptable ocular alignment should be obtained prior to school matriculation.

Blepharoptosis, nasolacrimal duct obstruction and other congenital abnormalities of the eyes, and ocular adnexa should also be corrected prior to school entrance. Conspicuous physical defects that set children apart from their peers should be ameliorated early in life to avoid their stigmatizing effects and the emotional sequellae.

Children with poor corrected vision need to be identified early so that teachers and caretakers can orient their activities to meet the special needs of these handicapped individuals. In some instances, early identification of such children will influence family planning.

For all these reasons, it would be desirable from an idealistic standpoint to perform eye examinations immediately after birth and

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periodically thereafter. As stated in 1972 by the Committee on Children with Handicaps of the American Academy of Pediatrics,[7] this goal is presently beyond reach because of the large number of children involved, limited trained personnel and financial support, and lack of understanding by the public as to the need for early eye care. The Committee stated that the most practical approach is presently one of "vision screening as part of the total health supervision of the preschool child. This would encompass children from three to five years of age and could be performed by trained paramedical personnel or volunteers with a minimum of equipment." The conditions to be detected in the screening program, according to the Committee, consist of refractive errors, muscle imbalance, amblyopia, and some eye diseases.

Certainly, visual acuity is by far the most important visual function to be evaluated regardless of the methodology employed. In considering the large variety of tests advocated for vision screening of preschool children, one must not overlook the critical importance of visual acuity. The eyes, after all, are the organs of vision, and visual acuity is the quantitative assessment of the keenness of sight. The thrust of this report will therefore be on central visual acuity measurement.

Because the various tests devised to evaluate the visual function of the preschool child are not all based on the same basic principles, it is necessary to review the basic principles before considering the specifics of each test. The first section of this paper, therefore, reviews some basic aspects of visual acuity.

The second section deals with general aspects of preschool vision assessment, including consideration of the magnitude of the task, approaches used, techniques employed, test results and limitations.

The third section reports a field study in which two currently popular methods of measuring central acuity are compared and contrasted.

PART I

BASIC CONSIDERATIONS OF RELEVANT VISUAL ACUITIES

Visual acuity as a concept is vague, yet the term requires elucidation since it is the most important quantity measured in preschool and school vision tests. It is probably best to consider "visual acuity" as a nonspecific term for a variety of psychophysical threshold measurements. Thus one may speak of minimal detecta-

ble (visible) acuity, minimum separable (resolvable) acuity, minimal recognizable (legible, cognizable or Snellen) acuity, minimum misalignment (vernier) acuity, minimum binocular horizontal disparity (stereoacuity), and motion (dynamic) acuity. Although the differences between the various types of acuities are not always as clearcut as the foregoing listing would imply, the distinctions are nevertheless extremely important from both conceptual and practical standpoints. Failure to separate the various types of acuities has resulted in considerable confusion in the relevant literature.[8]

A good example of this is the Stycar Graded-balls Vision Test introduced by Sheridan.[9] The test consists of the examiner rolling white balls of various diameters on a black surface before a young child. The balls are rolled at right angles to the child's visual axes in the frontoparallel plane and his eye movements are observed. If his eyes appear to be following the rolling balls, it is assumed that he is able to detect the moving objects. Sheridan is careful to point out that what is being measured is the least visible rather than the least resolvable; yet Snellen-type "equivalents" for the test objects are given even though the basis by which these are derived is unstated.

This clinical test requires detection of a light stimulus on a dark background and is not a resolution task. The threshold for this type of stimulus depends on many factors including the state of adaptation of the eye, the retinal locus receiving the image, the size of the test object, its rate of movement, and the contrast between target and ground. The unit of measurement for the least visible light on a black background is quanta of radiant energy. The unit of threshold measurement of a white target on an illuminated field of lower contrast is lamberts. The unit of measurement of contrast resolution, on the other hand, is degrees. The two thresholds are totally dissimilar, as everyday experience demonstrates. A bright star at night can be seen by a person with poor resolution acuity. One is aware of an object approaching from a distance before its details can be resolved. A child with very poor Snellen acuity can detect a small but high contrast object at a great distance, a feat that causes no end of overoptimism for unwary parents (and some ophthalmologists).

The Graded-balls Vision Test may be an improvement over Worth's Ivory Ball Test[10] in which five balls 1/2 inch to 1-1/2 inches in diameter are projected with a spin to make their paths unpredictable, about 20 feet from the child, who is then directed to retrieve them after they stop rolling. Both tests require great caution in

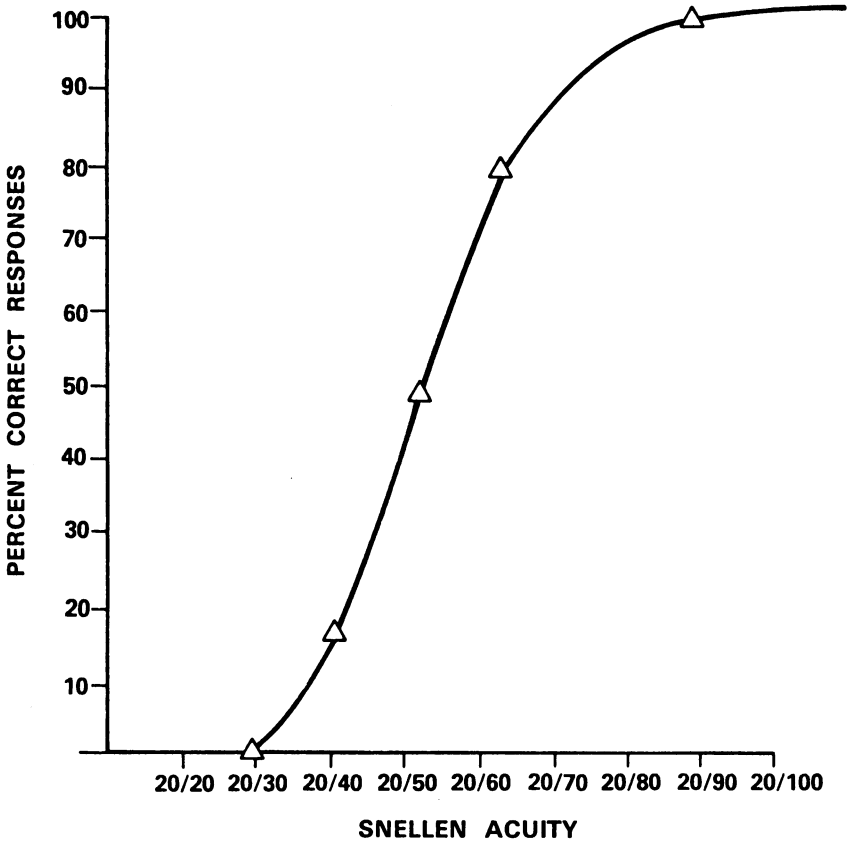


FIGURE 1

Characteristic sigmoid shaped curve relating Snellen acuity and percent correct responses. The curve is for a patient who correctly identifies one-half of the letters on the 20/50 line. See text for details.

interpretation because they are fundamentally different from the type of tests usually given to older children and adults — i.e., legibility type tests.

The conclusion drawn from these considerations is that visual acuity is a broad, nonspecific term, not particularly useful in the abstract. Not only are there many types of acuities, but each type of acuity is dependent upon a variety of psychological and physical conditions operative at the time of measurement. These conditions must be specified in detail if the measurement is to be meaningful, particularly if intra- and interoffice findings are to be compared.

THRESHOLD MEASUREMENTS

A threshold is a situation in which a stimulus just produces or just fails to produce a specific effect. Thresholds and sensitivities are reciprocally related. The higher the threshold, the lower the sensitivity, and vice versa. The common Snellen fraction represents a sensitivity measurement. Its reciprocal in decimal form is a threshold measurement.

Statistical probability is involved in threshold determinations. Because of moment-to-moment physical and biological fluctuations, which are often significant at threshold conditions, some sort of averaging of response is essential and a criterion level must be stipulated. For example, what is the Snellen acuity of a person who misses none of the letters on the 20/80 line, 20% of the letters on the 20/60 line, 50% on the 20/50 line, 83% on the 20/40 line, and 100% on the 20/30 line? An approach to the problem is to plot the proportion of correct responses to each Snellen acuity line presented. A sigmoid curve usually results from this type of threshold testing. The 50% level of probability is generally selected as the threshold since it is the most accurate[11,12] and stable level[13] from test to test (Fig. 1).

THE MINIMAL DETECTABLE

A luminous stimulus on a black background

If the eye is dark adapted, the detection of a photopic stimulus is essentially a question of the absolute light threshold. Light directed into the eye is partially reflected by the cornea, partially lost in the preretinal media, and partially effectively absorbed by the visual pigments in the outer segments of the photoreceptors. Only the latter photons can lead to sensation. It has been estimated that under optimal conditions effective capture of only a handful of quanta of radiation can lead to sensation.[14]

When the problem of a threshold response to an illuminated target on an extended field of lesser illumination is considered, the situation is different. Here, Weber's rule (or law) must be considered. This psychophysical relationship states that the minimal detectable increment in stimulus intensity (ΔI) required for subjective detection divided by the level of background stimulation (I) is constant. The differential light threshold is sometimes referred to as the Fechner fraction and in middle ranges of light intensity is approximately 1/100. The value is higher in both lower and higher ranges of illuminance. If the separate illuminances of both the

target and the background are kept constant and the size of the target is progressively decreased, a retinal target image incremental of illuminance will be reached at which detection is no longer possible. What limits the visibility of the target under these conditions is the differential light threshold, i.e. $\Delta I/I$, not the absolute light threshold. The target could be made visible again if the target illuminance is increased without increasing the size of the target, and the process could be repeated no matter how small the target if exposure time is not limited. When flash exposures are used (under approximately 0.1 secs.), time also becomes a variable. The quantities of differential intensities, area, and time are thus interrelated in producing a threshold sensory effect.[15]

A black stimulus (target) on a white background is different from the above in that there is a finite target size below which increases in intensities will not make the target visible. Hecht and Mintz[16] viewed black wires across luminous backgrounds. They found the threshold subtense of the wire to be 0.44 seconds of arc with their highest background intensity. Such a low threshold can be explained on the basis of the retinal diffraction pattern and the Fechner fraction. At threshold, the difference in illuminance across the retinal image is approximately 1/100.

The existence of an irreducibly small visible black target on a white field of variable luminance is predictable on the basis of Weber's law. Once the intensity of the background field has been raised to the level that produces minimal retinal image $\Delta I/I$ and the target is reduced in size until its diffracted image illuminance equals this minimal value, raising the intensity of the illuminance further will not permit detection of a smaller target because a smaller target would result in a retinal image contrast below threshold.[17]

The objective physical contrast of a particular black figure on a particular white background is independent of illuminance. What makes the figure easier to detect and resolve as illuminance is increased is the state of retinal adaptation and the relationship of the retinal image $\Delta I/I$.

Two examples illustrate the difference between white on less-white and black on less-black situations. One would see a star in full daylight if the intensity of the light from the star became sufficiently high to reach the critical retinal image $\Delta I/I$ for the observer. On the other hand, sunspots cannot be seen by the naked

eye because the retinal image ΔI/I is below threshold. When the sun is viewed through a smoked glass the contrast is not changed, but the retinal image illuminance is reduced sufficiently in intensity to permit detection, i.e. ΔI/I is above threshold.[18]

RESOLUTION ACUITY

Checkerboards and gratings are frequently used in laboratories to measure resolution acuity. They have not been used for screening purposes on preschool children because of difficulties in comprehension and communication. Yet they are purer than the tests usually employed which demand recognition of form, a second order task.

Two black bars on a white background are said to be resolved when the subject is aware of their separateness. The retinal image under these threshold conditions consists of two diffraction patterns. Each consists of a central minimum and progressively less intense crests and troughs of illuminance to both sides. The composite (actual) image is the arithmetic sum of these two illuminance patterns over all retinal loci. The two patterns can theoretically just be resolved when the center of a single receptor unit located between the two deepest troughs receives ΔI more illuminance than the units to either side. In the fovea, the center of the receptor unit approaches the diameter of a single cone. If the diameter of a foveal cone is assumed to be 2.0 microns or 2/5 minutes of arc, then the theoretical limit of foveal resolution in terms of wave length, based on the retinal mosaic pattern, would be 4/5 the accepted empirical clinical standard of about one minute — i.e., 48 seconds of arc. Campbell and Green,[19] using interference patterns which largely bypass the optical imperfections of the eye, found a retinal mosaic resolution limit of about this magnitude. Diffraction effects varying inversely with pupillary size and spherical aberration varying directly with pupillary size reduce resolution angular subtenses to levels slightly higher than the retinal mosaic threshold. Under normal photopic viewing conditions the effects of diffraction are paramount.[20]

The one minute of arc, or in terms of spatial frequency, 60 cycles per degree, that has been found to be the approximate resolution limit of human eyes under clinical testing conditions is not to be confused with the one minute of arc subtended at the posterior nodal point by the width of both the black strokes and white interspaces of the 20/20 Snellen E symbol. When this letter is

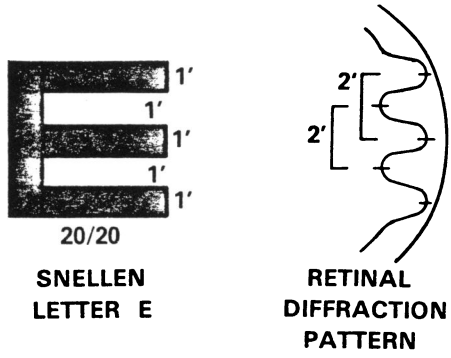


FIGURE 2

The retinal diffraction pattern produced by the image of the 20/20 E symbol is shown schematically. The angular subtenses between adjacent troughs and adjacent crests are both two minutes of arc.

viewed and the retinal diffraction pattern analyzed, it is apparent that the distance between the centers of the two major peaks (corresponding to the white interspaces) and the distance between the centers of each of the three major troughs (corresponding to the black strokes) are both two minutes of arc (Fig. 2)! Thus the 20/10 Snellen symbol rather than the 20/20 Snellen symbol more nearly approaches the clinical threshold. Twenty-twenty visual acuity is therefore less than optimal. Its spatial frequency "equivalent" is 30 cycles per degree.

Resolution is somewhat inferior with white targets on black backgrounds compared to black targets on white backgrounds. This is because the threshold resolution of white targets on black backgrounds in high intensity ranges increases with increased illuminance. The cause of this decrease in sensitivity is thought to be the spread of light by scattering and by neural irradiation. This means that "negative" and "positive" visual acuity charts are not exactly interchangeable — they will not provide precisely the same acuities.

The Landolt ring is a type of resolution target widely used in the laboratory. It consists of a broken ring with the gap equal in length to the width of the stroke of the ring, and the diameter of the figure five times this dimension. The angle of resolution is defined as the subtense of the gap at the posterior nodal point. The target has not proved popular in clinical use[21] even though it was adopted as an international standard test target in 1909 by the Eleventh International Ophthalmological Congress.

Gratings have been increasingly used in recent years as resolution targets. An important property of gratings is that resolution threshold depends not on the thickness of the alternating white and black stripes, but only on their frequency. This experimental finding is actually predictable from a consideration of the retinal diffraction patterns involved. It is the distance between the crests and troughs of retinal illumination that is critical, and if frequency is constant, these distances will not vary with line width. This fact has implications regarding the design of optotypes.

It is possible to design gratings in such a manner that the contrast transitions between lighter and darker bands vary sinusoidally, i.e., as the curve of a sine function. Such patterns produce a true sinusoidal retinal image despite optical imperfections of the eye. They permit application of Fourier theory and analysis of the change in contrast as a function of frequency, the so-called "modulation transfer function."

The concept of producing interference patterns on the retina originated with Le Grand[22] and has been used extensively since. Present methods direct two beams of coherent light from a continuous laser source into the eye. By varying the phase difference between the two beams, the frequency of the interference pattern of the retinal image can be varied and a subjective threshold resolution determined. The method is not affected by refractive errors and is to some extent independent of irregular optical densities within the media of the eye.[23] Some individuals do not see these interference patterns, and amblyopic eyes demonstrate a marked improvement in acuity.[24] The equipment is bulky and expensive, and the test is time consuming. It has not been thought appropriate for preschool vision screening.

INFLUENCE OF CONTRAST AND LUMINANCE ON RESOLUTION ACUITY

Contrast is defined as the difference in reflectance between the surround and the test object divided by the reflectance of the surround. With present day high contrast acuity charts the reflectance of the white background is approximately 80% and that of the black letters is approximately 5%. The contrast is therefore $\frac{.8-.05}{.8} = .94$. If the contrast between target and surround is high, moderate increases or decreases in contrast will have only negligible effects on acuity providing the luminance is in the photopic range.[21] Under such conditions of high contrast and high luminance moderate

changes in luminance will also only slightly affect acuity.[21] The retina should be kept in a light adapted state for optimum acuity performance.

SNELLEN ACUITY

The type of acuity measured with conventional Snellen charts is not strictly speaking resolution acuity. It is more accurately termed cognitive acuity. The recognition of the capital letter A does not demand resolution of the cross stroke but only perception of the overall shape of the figure. Once the direction of inclination of the sides is discerned, the letter becomes "identifiable" since no other letter has such a configuration. The same recognition pattern applies to other letters such as V and L. These letters are clearly not resolution targets at all. Their early recognition depends to a large extent on prior knowledge of the type of targets being presented; i.e., the previous experience of the patient with the optotypes influences the results obtained.

Some letters more clearly demand resolution of component parts. For example, the letters C and U approach the Landolt ring task of discerning the orientation of the gap. Many attempts have been made to rank letters according to relative ease and difficulty of identification. Obviously details of construction of the letters is relevant, but the observation of interest is that there is considerable disagreement among different investigators regarding legibility.[21 and 25]

Although not intended for a single style of type, the sequences which follow represent letters thought to be of approximately equal difficulty: ACEHLNOT (Hay),[26] BCDEHORSU (Cowan),[27] NHXPFZUTD (Hartridge and Owen),[28] CDEFHNOPRUVXYZ (Coats and Woodruff),[29 and 30] ZNHRVKDCOS (Sloan).[31] Banister[32] in his group 2 found the sequence of letters from easiest to most difficult to be: LJFBZENTADIKUHPRCVSOXYWMGQ. In 1968, a British Standard on Specifications for Test Charts was approved by the Ophthalmic Standards Committee.[33] The letters selected were: DEFHNPRUVZ. Casellato[34] has recently recommended letter pairs that are convertible by 90 degree rotation: ADCUHINZ.

Gothic style letters (letters without serifs) are generally used in acuity charts. These letters are usually constructed according to Snellen principles so that each symbol can be enclosed in a square five times the thickness of its stroke. The width of the strokes and the separation between them are each one-fifth the overall letter

size. Visual acuity with such test type is expressed as a fraction with the numerator representing the testing distance and the denominator representing that distance at which the stroke widths and interspaces would subtend an angle of one minute at the posterior nodal point if the eye is refracted according to strict geometric principles; i.e., diffraction is not considered. The testing distance is conventionally 20 feet or 6 meters. A minimal recognizable acuity of 20/40 is therefore twice the threshold of 20/20. This does not mean that 20/40 "vision" is one-half as "good" as 20/20 "vision." The comparison only applies to the threshold or sensitivity function. Because of these unwarranted but inevitable implications it is probably wiser, as Snellen himself recommended,[35] to record the results as fractions and not reduce them to a form that invites comparison (i.e., decimal equivalent notation). Another reason to avoid reduction to decimal form is that the testing distances used are not always the same. Obviously, uncorrected refractive errors will result in different acuities at different testing distances.

Another area of general agreement concerns the range of acuities to be presented. Most clinicians accept an acuity array that extends from a Snellen-type subtense of one minute, or slightly less, to a value 10 times this large.

There is a lack of standardization concerning not only the particular letters to be used but also on the gradation of letter size from one line to the next. The proponents of geometric progression invoke Fechner's principle — i.e., that arithmetically equal steps in sensation are produced by stimuli that vary geometrically (logarithmically). Supporting evidence has been produced by Lythgoe,[11] Ogle,[36] and Dreyer.[37] Dreyer also provided data which support the recommendation of Green that the ratio of visual angles subtended by the details of consecutive lines be 1.26. This value was apparently originally based on the rather arbitrary decision to insert two values between any particular value and its double.[38] Thus if the ratio of increase is designated as R, then the sequence starting with the value X becomes X, RX, R(RX) and 2X. Since 2X must equal the next lowest value times R, $2X = R(R^2X)$. Therefore, $2X = R^3X$ and $R = \sqrt[3]{2} = 1.26$. The chart designed by Sloan[39] uses this R of 1.26.

Evidence has been presented by Sloan[21] suggesting superiority of an arithmetic progression if the object of visual acuity testing is to measure impairment due to uncorrected refractive errors. She found an approximately linear relationship between ametropia and visual acuity. Ogle,[36] using some of the same data analyzed by

Sloan, reached the conclusion that the relationship between ametropia and visual acuity was logarithmic rather than linear. He urged caution in interpreting the relationship between these two variables because of the variation in the data between different investigators.

More recent studies by Peters[40] show significant departures from linearity with hyperopic refractive errors. The relationship between hyperopia and acuity was also demonstrated to be age dependent — a not-unexpected finding.

The types of Snellen acuity charts in current clinical use (wall-mounted or projected) frequently have an irregular type of progression. Such charts provide meager test material at the larger subtenses — e.g., usually no step between 20/100 and 20/200 and often only three symbols on both lines combined. These charts are therefore unsatisfactory for low vision patients. For such patients specially designed charts[39] are preferable.

Standardization is also lacking in the spacing between letters of a row. This problem centers on an acuity-degrading effect of unknown cause referred to as contour interaction or the crowding phenomenon. Numerous investigators have shown that visual acuity (regardless of level) can be reduced by the presence of additional contours in the vicinity of the test optotype or pattern.[41-45] Moreover, the poorer the acuity, the greater the angular range in which interference is produced.[41,42] Contour interaction has been said to be a "universal phenomenon".[41] The degree of separation difficulty appears to be more clearly related to the visual acuity per se than to other parameters, including the cause of the reduced acuity — most notably, amblyopia. The presentation of whole lines of optotypes undoubtedly improves sensitivity for amblyopia detection even though not all amblyopic eyes demonstrate the crowding phenomenon.[46] There is, however, no acceptable evidence that such "linear" testing improves specificity because patients with poor acuity regardless of cause tend to do worse with such presentations.

Recently, Flom[47] has devised a set of E acuity test cards with confusion bars on all four sides to produce contour interaction (Fig. 3). These cards are designed to be presented at either 10 or 20 feet in any one of four different orientations. This clever test gets around the communication problem of indicating to the young child which one of several linearly juxtaposed chart symbols is to be interpreted, and yet it provides for contour interaction. It re-

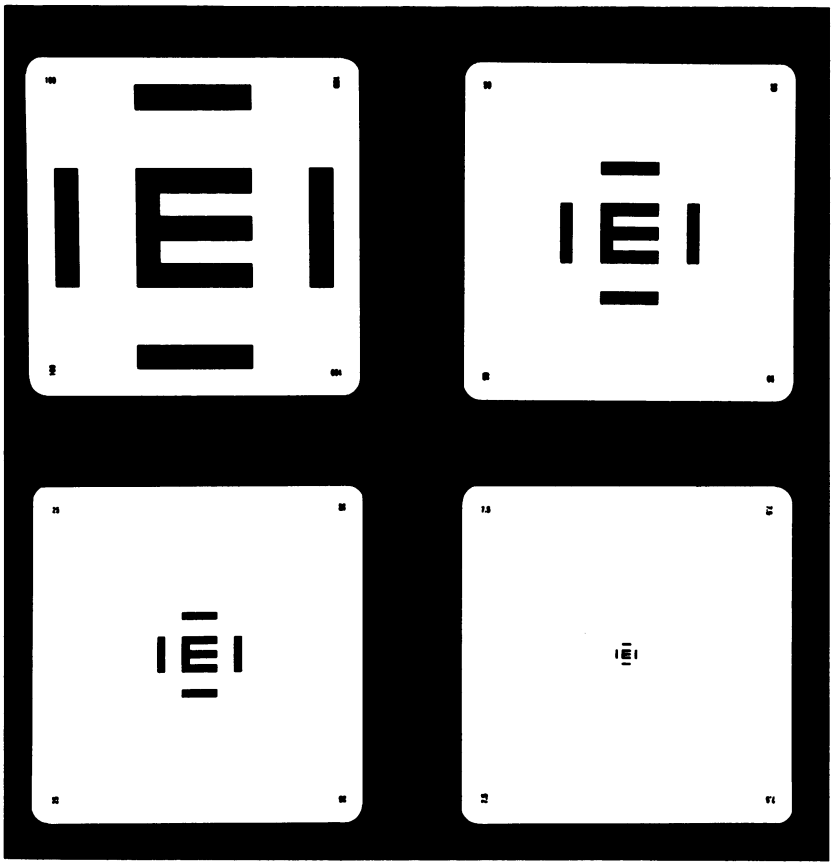


FIGURE 3
E-Test cards with confusion bars for contour interaction courtesy of M. C. Flom.

mains to be seen whether or not these cards will prove to be more reliable and valid than conventional methods for visual acuity screening of young children.

Despite all its unsettled characteristics, variations, and imperfections, the Snellen chart has been found to be by far the most clinically useful method of measuring visual acuity. It is capable of high reliability,[48-50] but such performance, particularly in the case of young subjects, requires attention to detail such as the constancy of testing distances, lighting and contrast conditions, the speed and manner of presentation (one letter at a time vs. a whole line), the encouragement, acceptance, or rejection of guesses, method of scoring, and time allowances. The emotional attitudes and motiva-

tion of the examiner and patient as well as their mutual rapport are important. The familiarity of the patient with the test material, his attention span, his intelligence, his comprehension, and his ability to produce the expected responses are significant considerations. Distractions such as noise or the presence of other people are highly relevant variables. The state of the patient's retinal adaptation is another potential source of variation.

VERNIER ACUITY

The alignment power of the eye is extremely impressive. Horizontal displacements of vertical lines in the order of two seconds of arc can be detected.[51] Only stereoscopic acuity can approach vernier acuity in terms of angular threshold sensitivity. Vernier acuity is fundamentally different from resolution acuity because it is not based on contrast gradient sensitivity. Here contrast is usually high. A great many linearly arrayed photoreceptors are strongly and simultaneously stimulated.

The neural networks of the retina, lateral geniculate body, and cortex are designed to enhance contour discrimination. The receptive fields of the retinal ganglion cells and of the lateral geniculate body cells are circular with on or off centers and opposite type peripheries. The receptive field annular peripheries of the neurons within the lateral geniculate body are greatly enhanced compared to that of the retinal ganglion cells to cancel the effect of the center. This results in improved discrimination of spatial differences in retinal illumination. The receptive fields of the simple and complex striate primate cortical cells, however, are linear in configuration. The simple cortical cells are stimulated by properly positioned and oriented stationary slits, bars, or edges of light on their receptive fields; the complex cortical cells respond by sustained firing to properly moving linear stimuli.[52] Contour sharpening mechanisms and the directional sensitivity of the cortical neurons are undoubtedly fundamental to vernier acuity.

STEREOSCOPIC ACUITY

Stereopsis is the sensation of depth created by the simultaneous stimulation of horizontally disparate retinal elements.

Within certain limits horizontal image disparities can be fused. This area of fusion is known as Panum's area of single binocular vision. The horopter, a toric surface located within Panum's space, is defined as the locus of points imaged on corresponding retinal points at a given angle of convergence of the visual axes. Object

points located within Panum's space and behind the horopter have geometrically determined nasal retinal disparity and are perceived as more distant than objects on the horopter. Object points located within Panum's space and in front of the horopter have geometrically determined temporal retinal disparity and are perceived as nearer than objects on the horopter.

Neurophysiologists have demonstrated the presence of neurons that receive input from both eyes within the visual cortex that are specifically sensitive to retinal image disparities. Such cells have been identified in electrophysiologic experiments on anesthetized animals utilizing microelectrode probes and receptive field mapping by light stimuli. Receptive field disparities are created by prisms, and responses in cortical cellular firing rates are observed. Disparity specific binocular responses have been identified in the cat[53,54] and monkey.[55] Indirect evidence based on psychophysical experiments suggests their presence in man as well.[56]

Consideration of the fundamental difference between contrast resolution and stereoacuity would suggest that the relationship between these entities would not be precise. Matsubayashi[57] has provided supporting evidence for this hypothesis. By means of gelatin filters placed before one eye of a human subject it was shown that stereoacuity thresholds as measured by stationary and moving rods were not significantly raised until Snellen acuity was uniocularly decreased to 20/60. Levy and Glick[58] used unilateral cycloplegia and convex lenses on ten healthy adults to produce ametropia. Stereoacuity was measured by means of the Titmus circle stereotest for each monocularly degraded level of Snellen visual acuity. A correlation coefficient of .83 was found between the two variables.

There is evidence that some apparently normal persons lack or have a subnormal level of stereopsis.[59,60] It has been suggested that some such persons may have an unrecognized monofixation syndrome[61] or microstrabismus.[62] Regardless of the mechanism, patients are seen from time to time who have deficient stereopsis though without gross strabismus and with good Snellen acuity in both eyes. While no large scale population studies have been done, the prevalence of patients with disparity perception defects in one or both hemispheres may be much higher than generally recognized. Moreover, such defects may be dominantly inherited.[60]

"OBJECTIVE" VISUAL ACUITY ASSESSMENT

The so-called "objective"methods — and not all will be discussed here — include opticokinetic nystagmus, pendular following movements, visually evoked potentials, and galvanic skin responses. Pearson[63] and Linksz[64] have reviewed aspects of the subject in some detail.

Opticokinetic nystagmus and pendular following movements are used as a basis for Snellen acuity assessment either by stimulating or by arresting ocular dynamic responses to moving stimuli. Either type of test may utilize resolution or nonresolution targets. When a nonresolution target is used, the minimum visible rather than the minimum resolvable is measured, since details of the object do not have to be discerned to arrest or to stimulate eye movement. Conversion to Snellen "equivalents" would appear to be more rational based on resolution rather than on nonresolution targets, although there have been many attempts based on empirical methods to do so[65-68] with the latter. Goldmann[69] has devised an ingenious objective acuity test that requires resolution. The test consists of viewing through an aperture — to obscure target edges — a moving course checkerboard pattern within a larger background fine checkerboard field pattern. When viewed from a distance, the target — consisting of both checkerboards — appears homogeneously gray, but as the viewing distance is decreased a point is reached at which the course pattern is resolved; pendular eye movements are then observed.

Presumably all tests that utilize the initiation or cessation of eye movements as a criterion can be made more precise by obtaining time synchronized recordings of stimulus patterns and response changes of eye position. This may be accomplished by a variety of eye movement monitoring devices such as those which employ electro-oculographic and infrared photoelectric sensing techniques.

The Pearson correlation coefficients between acuities obtained by devices which utilize opticokinetic nystagmus or pendular eye movements and Snellen acuities have varied considerably in different series. For example, Reinecke and Cogan[70] obtained a rho of 0.66, Voipio[71] a rho of .92 to .94 and Wolin and Dillman[67] a rho of .85. The differences in results are largely due to the specific techniques employed and to the types of patients utilized. This second point is well illustrated by a study of Millodot, Miller, and Jernigan[72] in which the Eye-Trac eye movement monitor was used on

both a heterogeneous group of clinic patients and on undergraduate students familiar with visual experimentation. Employing graded sinusoidally moving gratings, correlation coefficients of +0.50 and +0.90 were obtained respectively on the two disparate populations.

The same type of variation was found by Khan, Chen, and Frenkel[73] who utilized oscillating symbols of various angular subtenses. They obtained a correlation coefficient of +0.911 in normal eyes of volunteers fogged with convex lenses and a correlation coefficient of +0.606 in a clinical group of patients with a variety of ocular diseases.

The resolution threshold for a moving target cannot ever be as low as for a stationary target.[74] This finding may be relevant to the common observation of higher Snellen acuities than dynamic acuities in patients with good vision.[70,72,73] Patients with poor Snellen acuities tend to have higher dynamic acuities.[72,73] This may be related to the characteristics of the receptive fields of the cortical complex cells which react preferentially to moving targets.

The tests based on eye movement actually require considerable patient cooperation and are thus not truly objective. Attention and fatigue are both highly relevant variables. Patients are encountered who can voluntarily suppress the pendular response to oscillating targets,[73] and some patients are said to lack an opticokinetic response.[72]

Snellen visual acuity has also been correlated with the amplitudes of occipital cortex potentials evoked by visual stimuli in the form of gratings and checkerboards. These techniques have been applied to infants and interestingly suggest that six-month old infants have the mechanism for contrast resolution acuity equivalent to adults. What is measured in such experiments is a computerized average of time-locked occipital responses to changes in form rather than to light. The early responses, although cortical in origin, probably reflect retinal and lateral geniculate processing rather than extensive cortical processing. Hence the amplitude of the responses cannot be directly related to cognitive visual functions. Nevertheless, in a recent report a grating frequency of 30 cycles per degree first gave a minimal visual evoked potential when shown to four- to six-month-old infants. This frequency is "equivalent" to 20/20 Snellen acuity in adults.[75] Similarly, in a related report, using pattern reversal checkerboards, investigators found relative peaks of visually evoked amplitude to checks subtending 10 to 20 minutes of arc in five- to six-month-old infants but

not in younger infants. Checks of this size give maximum cortical responses in adults with 20/20 Snellen acuity.[76]

Visually evoked potentials can also be used as an objective method of refraction and for evaluation of amblyopia. Sokol[77] has recently reviewed the literature on the theory, techniques, and clinical applications of the visually evoked response.

Cortical recording of electrical responses to visual stimuli requires expensive, delicate, nonportable instrumentation. Patient cooperation, either voluntary or induced by light sedation, is necessary for satisfactory measurements. Testing is generally performed in a laboratory-type setting by a skilled technician. A fair amount of time and patience are required. The procedure does not presently seem applicable for mass screening of preschool children.

THE GALVANIC SKIN RESPONSE

This method was devised by Wagner[78] and is based on the lie detector principle. A stimulus to which the patient is conditioned produces a decrease in skin resistance which permits an increased flow of current. This is the psychogalvanic or galvanic skin response.

Patients were conditioned by Wagner to a certain letter by means of painful electric shocks. After completion of conditioning, individual letters of progressively smaller size were viewed by the patient. Threshold was identified by observing the smallest Snellen optotype that would produce a galvanic skin response.

No correlations have been made between this method and Snellen acuities. The technique was introduced primarily to detect visual loss in hysterical and malingering children and adults. It has also been used in animals as an objective measure of acuity.

This background information on relevant visual acuity tests is important in evaluating the various methods proposed to measure the central vision of preschool children. Several points made in this section will be cited where appropriate in the second section which deals with specific aspects of preschool visual acuity testing procedures. It is important to realize that thresholds of visual acuity vary according to the nature of the test employed, the procedures used, and the conditions extant at the time of measurement. The different types of visual acuity determinations are interdependent but not interchangeable. Since acuity measurements are to a degree test dependent, the type of test actually employed should be specified.

PART II

THE NATURE OF THE PROBLEM

In virtually all preschool vision screening programs reported to date, refractive errors have been by far the leading cause of reduced visual acuity. Strabismus and amblyopia are respectively the second and third most prevalent abnormalities. The relative frequency of these conditions is demonstrated in data obtained by the National Society for the Prevention of Blindness and its state affiliates.[79] In 1973-1974, 235,186 children were screened in projects with complete reports. Of the 6,404 referred children with complete examination reports, 70% of the conditions (or abnormalities) identified were refractive errors, 15% were muscle imbalance, and 14% were amblyopia. The percentage breakdowns are similar for previous years.

Surprisingly little information is available concerning the normal cycloplegic refractive errors of preschool children. Sorsby,[80] using atropine cycloplegia, reported a peak in the distribution curve of refractive errors in children four to eight years old at 2.3 diopters of hypermetropia. The curve was fairly symmetrical: only about 3% were 0.5 diopter myopic or worse, and about 3% were 4.5 diopters hyperopic or worse. Somewhat higher mean values for atropinized eyes of office patients were reported in this age group by Slataper,[81] who included in his statistics young children previously studied by Brown.[82]

Of considerable importance is the question of what constitutes an abnormal refractive error in the age group under consideration. That problem is reviewed in the third section of this report in some detail and will not be discussed here. It is sufficient to point out now that the clinical determination of the types and magnitudes of refractive errors actually resulting in reduced acuity appears to be a more rational approach to the solution of the problem than has been used in the past. (See third section of this report.) An unanswered further question is concerned with the types of refractive errors requiring observation or treatment. Inability to resolve satisfactorily this dilemma, as well as controversy over the limits of normal phorias, are major causes of disagreement on the correctness of referrals from screening programs for professional examination.

The prevalence of strabismus in the preschool population, based on the cover test, is probably about four or five percent (Table I). Publications on the prevalence of amblyopia in representative pre-

TABLE I. STRABISMUS PREVALENCE IN SOME REPRESENTATIVE SAMPLES OF PRESCHOOL CHILDREN AS REPORTED IN THE LITERATURE

Author	Location	N	Date	Prevalence
Frandsen[83]	Denmark	3,570	1960	4.5
Nordlow[84]	Sweden	6,004	1964	3.9
Gansner[85]	Switzerland	11,879	1968	1.7
Kohler and Stigmar[86]	Sweden	2,390	1973	3.8
Schutte[87]	Germany	4,229	1976	4.5

school populations are scarce. Two or three percent is a reasonable estimate based on information currently available.[85,86] The reported prevalence and incidence of strabismus and amblyopia in children has recently been critically reviewed by Reinecke.[88]

THE MAGNITUDE OF THE PROBLEM

The leading authority on vision screening programs in the United States is the National Society for the Prevention of Blindness. According to the Society,[89] there were approximately 11,460,000 preschool children (ages three to five) in the country in 1974. Of this population the Society estimates that one in 20 (or 573,000) has a vision problem requiring observation or treatment. This is probably a conservative estimate because of the tendency of those under treatment for known eye defects or visual impairments to avoid screening programs.

A major difficulty in the design of preschool vision screening projects is the absence of a totally captive target population. The preschool population is not as accessible as the school population. In this nation, preschool vision screening is highly fragmented in terms of responsible agencies, and the quality is quite variable because of differences in the training and experience of the individuals involved. In addition to Prevention of Blindness affiliated and independent agencies, such diverse groups as Delta Gamma Fraternity, Junior Chamber of Commerce, Junior Leagues, Junior Women's Clubs, Parent-Teacher organizations, Lions Clubs, American Legion Auxilliary, Telephone Pioneers of America, Councils of Jewish Women, state agencies for the blind, etc., all participate. State and local health departments, as well as federally supported programs (Head Start and the Early and Periodic Screening, Diagnosis and Treatment Programs, or EPSDT) are also involved.

The backgrounds of the persons who actually do the screening vary as widely as the agencies themselves. The spectrum of competence extends from the inexperienced to the highly experienced,

from teachers and lay volunteers to para-professionals and professionals. School nurses and public health employees frequently participate.

The total impact on the health of preschool children of this largely uncoordinated effort is impossible to assess.

EPSDT (the larger of the two federally supported programs) in fiscal year 1976 screened 131,623 children of all ages for vision defects (90). Follow-up treatment and reports on children referred for professional examinations are frequently not obtained by EPSDT.

In 1973-74, 368,246 preschool children were screened by the National Society for the Prevention of Blindness affiliated and independent agencies. Of the estimated 7,626,441 children three to six years old in the 22 states with Society affiliates, only 4.8% were screened by the affiliated agencies.[89]

It would seem accurate to state that only a very small fraction of American preschool children are presently receiving vision screening.

THE IMPORTANCE OF THE PROBLEM

Children with reduced visual acuity regardless of cause are usually unaware of their problem. Unless the defect is severe and bilateral, the parents of affected children rarely detect the presence of reduced vision. There is generally a total absence of pain and discomfort or complaints of any kind. Preschool children with poor vision apparently assume that others see as they do. Those with unilateral disability rarely discover their defect by performing alternate monocular occlusion and observing the difference in acuity between their two eyes. In most instances there are no external signs suggesting ocular abnormality as well as a lack of symptoms.

Children with amblyopia secondary to large angle strabismus tend to be referred at an earlier age than those with either anisometropic amblyopia or amblyopia secondary to small angle strabismus. The absence of a cosmetically apparent defect frequently results in delayed professional care for children with the latter two prevalent conditions until the age of six or seven years. Many children do not receive their first vision screening test until they reach elementary school grades. At this age occlusive therapy is poorly accepted, and even with good cooperation acuity is more resistant to improvement. The presence of unilateral amblyopia may preclude a few select occupations, but its greater significance

is the reduction in vision should disease or injury impair the sound eye. In this sense unilateral amblyopia is more a potential than actual handicap.

High bilateral uncorrected refractive errors may impede learning. Children with such defects should be recognized early and provided with glasses before entering school. At least suggestive evidence has been presented by Nordlow and Joachimsson[91] that early correction of refractive errors is more likely to result in higher acuity with time than later correction. The authors found that children given glasses at four years of age had statistically significant better corrected vision after wearing glasses for three years than did a comparable group of older children after three years of wearing glasses. The children in the latter group received their glasses when they were seven to eight years old.

Visually handicapped children need to be identified prior to matriculation in the educational system in order to assure proper school placement. For a variety of genetic, social and economic reasons early detection of such children may influence family planning.

Many visually handicapped children can be placed in classrooms with their normally sighted peers, but their problems need to be identified and quantitated as early as possible so that appropriate allowances for their disabilities may be made and special attention, if needed, may be provided.

THE SCOPE OF PRESCHOOL VISION TESTS

Almost all preschool vision screening programs include a measurement of central acuity. There is disagreement as to the best test to use for this purpose and also as to whether other tests, particularly those which provide information concerning ocular alignment, should be included. The National Society for the Prevention of Blindness recommends the Snellen E chart, correlated with observation of the child's eyes for abnormalities. It advises against the Hirschberg test and cover tests. It also feels that neither ophthalmologists nor optometrists should participate in the screening tests so that parents do not erroneously conclude that a professional eye examination has been performed.[92]

There is no acceptable evidence that cover testing for strabismus cannot be adequately performed by non-ophthalmologists (see third section of this report), despite statements to this effect[93] in the literature. Competency is the product of ability, training, and expe-

rience. If competent persons are available to screen for strabismus, the cover test should not a priori be excluded from screening procedures. If such persons are not available, the cover test should be deleted.

The towering importance of central acuity evaluation in preschool vision testing is well-documented in a recent study by Kohler and Stigmar.[86] These investigators reported that of the four-year-old children referred from screening and found to have eye defects, 97% were detected by visual acuity testing alone. This is particularly noteworthy in view of their modest overreferral rate (16.5%).

WHAT IS THE NORMAL VISUAL ACUITY OF PRESCHOOL CHILDREN?

There is fairly uniform agreement that four- and five-year-old children normally should have at least 20/30 acuity or the equivalent. There is, however, some difference of opinion regarding children between three and four years old. As long ago as 1939, Chavasse[94] stated that the normal acuity of three-year-old children is 20/30. However, the more lenient standard of 20/40 for this age group is presently endorsed by the National Society for the Prevention of Blindness[92] and the Committee on Children with Handicaps of the American Academy of Pediatrics.[7]

Many field workers are of the opinion that under optimum conditions the visual acuity of testable, normal three-year-olds is at least 20/30 or the equivalent.[95-101] In this connection the 1973-1974 experience of the Prevention of Blindness Society of Metropolitan Washington is of particular interest.[102] Of the 3,890 three-year-olds that attended the screening, 20% were untestable by the E-Test using single optotypes. However, only 8.9% of those that were testable had less than 20/30 acuity. The highly experienced individuals who obtained these results with isolated E optotypes are the same persons who did the testing reported here in Part Three.

The Maryland Society for the Prevention of Blindness has likewise found that most 3-year-old children have at least 20/30 acuity. In data on 1,923 3-year-old children screened over an eight-year period with isolated E optotypes, only 10% of the children had vision less than 20/30 in either eye.[103]

Both of the above Societies stress the importance of adequate child preparation for screening. The prerequisite training may be provided by parents and/or teachers.

It is also important to note that both of these Societies emphasize the need to rescreen those children who fail the original acuity test. The results cited were obtained using these techniques.

A study from Japan[104] has shown that the distribution of acuities of a group of nursery school children between three and four years old had a mean of .82 (20/24). Children in two health centers, three years ± two weeks old, had a mean acuity of 0.56 (20/36). These children had not received any prior training. For both populations, isolated Ffooks-type symbols and Landolt rings were used. The former consist of a triangle, square, and circle; a matching response was required. The authors used a lenient passing criterion — two consecutive correct responses for the Ffooks symbols. With only three symbols, the probability of two consecutive correct responses by chance alone is $1/3 \times 1/3 = 1/9$ or 11%. This is a higher probability level than is generally permitted in acuity testing. None of the children was prepared in advance. Retesting did improve the scores by about 0.1 for the children who were just three years old.

It is important to distinguish failure due to subnormal acuity from failure due to other causes. A child with poor understanding of what is required in the way of a motor response is likely to falter when under maximum stress, i.e., when targets approach threshold; hence the importance of thorough preparation for the task.

It seems likely that with adequate prior training a majority of even these 36-month-old children would have had the equivalent of 20/30 acuity or better. This hypothesis requires clinical verification. Such an experiment would appear to be essential for the establishment of meaningful standards.

MORE COMMON VISUAL ACUITY TESTS USED FOR PRESCHOOL CHILDREN

No attempt will be made to survey the entire multitude of preschool vision tests that have been proposed. Reviews of the subject include papers by Holt,[105] Savitz,[106] Lippmann,[107] and Lin-Fu,[108] the book by Apell and Lowry,[109] and the chapter on Eye Function by Barker and Barmatz in Pediatric Screening Tests.[110] A practical manual for lay persons contemplating the organization of a preschool vision screening project is available.[111]

The tests selected for discussion here are the E-Test and Sjogren hand test, symbol matching tests, and picture tests.

The E-Test and Sjogren Hand Test

The E-Test, which Duke-Elder attributes to Albini,[112] is the most widely used method of assessing acuity of preschool children in the United States. It is recommended by the National Society for the Prevention of Blindness for both group screening projects and home use.

The test consists of presenting the letter E, constructed according to Snellen principles, to a child at a specific test distance. Individual optotypes printed on cards, cubes or rotating discs, or whole-line chart presentations, may be used. Box-like table-top instruments, such as the Titmus Vision Tester and the American Optical Project-O-Chart, also use this test symbol. The latter two instruments are relatively expensive. The table-top instruments are portable and require little space but have the disadvantage of frightening some young children and occasionally stimulating excessive accommodation. The extent of cooperation required makes them relatively less satisfactory for preschool vision testing.[113] The projection devices require a darkened room but offer convenient control over the test material. They are heavy and are not designed for portable use.

The child indicates the orientation of the strokes or "legs" of the letter E by pointing or orally stating the direction. Up, down, right, and left presentations are used.

Virtually all who have used the E-Test have noted laterality confusion in some children. This phenomenon is probably a manifestation of the general right-left confusion tendency and is particularly prominent in young children, as evidenced by d-b, p-g, and s-z reversals. Children rarely, however, mistake b for p or d for q. The same error pattern is evident in children in all situations in which directional concepts are involved. The increased confusion in children between right-left as opposed to up-down has been documented by Rudel and Teuber.[114] A similar error preference tendency has been found in the rat[115] and octopus.[116] The reason for this possibly ubiquitous pattern is not established but may relate to the fact that in nature up and down as directions are much more strongly differentiated (by gravity) than are right and left. There is no comparable vector force that distinguishes right-directed objects

from left-directed objects, and, in fact, the two become interchanged simply by moving behind one or the other.

Right and left as directional concepts are much more abstract than up and down — not only because of gravity but secondarily to the right-left symmetry of animal and vegetable forms, including our own bodies. There is little to distinguish right and left extremities, but gross dissimilarities between heads and feet are apparent to even young children.

It is not unusual to find a preschool child who can quite consistently identify vertically oriented E symbols and just as consistently fail to correctly identify horizontally directed E symbols. Another occasionally encountered problem with the E-Test is the awkwardness experienced by some right-handed children in pointing toward their right and by some left-handed children in pointing toward their left. At times a three-dimensional E letter, hand held and directed by the child, will help in overcoming this particular difficulty.

Since only four orientations are ordinarily used, it is necessary to make allowances for correct guessing. This same necessity, of course, applies to any test that makes use of the same symbol in different orientations or any test that requires recognition of a limited number of known symbols.

Testability is a function of age with all subjective acuity tests regardless of the particular test employed. This does not mean that testability proportions for a given age level are the same for all subjective acuity tests. The first point is well-demonstrated for the E-Test by data provided by the Prevention of Blindness Society of Metropolitan Washington. In 1973-1974 the Prevention of Blindness Society of Metropolitan Washington[102] attempted screening on a total of 14,559 preschool children with isolated E optotypes. Seven hundred and eight-six (20%) of the three-year-olds were untestable, 246 (3.7%) of the four-year-olds were untestable, 24 (1.0%) of the five-year-olds were untestable and 2 (0.2%) of the six-year-olds were untestable.

Some insight as to the extreme variation in testability reported for the E-Test is gleaned from the report of Savitz[106] who found 41/59 (69%) of children 36-48 months old untestable by the E-Test and the Maryland Prevention of Blindness Society data reported by Patz and Hoover,[103] which revealed that only 31 of 1,954 (1.6%) of 3-year-old children were untestable by the E-Test. The difference between these extremes is probably due to a variety of causes

including parental attitudes, preparation of the children prior to screening, intelligence of the children, their attention and interest, and the testing conditions and procedures, as well as the attitude, ability, motivation and diligence of the testers. Comparisons between testability proportions for different tests on similar age groups are rather pointless unless all relevant factors are controlled. This is best accomplished by a randomized clinical trial.

A clever modification of the E-Test has been advanced by Blackhurst.[117] The test chart has a movable E in the center which can be directed toward one of four pictures — flower, rabbit, sky, and ground — located to the left, right, up, and down respectively. The child indicates direction by naming the reference picture rather than by pointing. The device is called the Michigan Junior Vision Screener. Miniature reproductions of the chart, with directions, are sent to the children's parents prior to screening for instructional purposes. The raison d'être for this modification of the E-Test is, of course, to improve testability; yet no controlled studies have been published that demonstrate this presumed advantage.

The E optotype is not equivalent to a grating because the stroke that connects the three parallel strokes provides an orientation clue that would not exist for a grating-type target. This clue is accentuated in the Sjogren hand optotype.[118] In this test the silhouette of a human hand with fingers slightly separated is presented. Progressively smaller size figures are shown until threshold is reached. As in the conventional E-Test, a pointing-type response is required. The "blob," which represents the palm of the hand, makes all attempts to express results in Snellen equivalents rather futile. An attempt to eliminate this undesirable attribute has been reported by Borg and Sundmark.[100] It has not been established that testability is higher with the Sjogren hand than with the E optotype.

Symbol-Matching Tests

Dr. Mary Sheridan has developed a multitude of vision screening tests for children[119] to which she has given the acronym STYCAR for screening tests for young children and retardates. The letters A, C, H, L, O, T, U, V, and X were selected according to psychological principles based on the findings that a child is normally able to copy a vertical line at age two years, a horizontal line at age two and one-half years, a circle at age three years, a cross at age four years, a square at age five years, a triangle at age five and one-half years, and a diamond at seven years. At first, children were instructed to

say the letters aloud as they were pointed out on a chart, or to draw them in the air. Later, matching key-cards were introduced whereby the child pointed to the same letter on the card as that shown by the examiner.

In testing children three to five years of age it was found advantageous to reduce the testing distance to 10 feet in order to maintain rapport between examiner and child. Responses were more satisfactory with the single-letter cards than with charts. In testing 2 1/2-year-olds and some 2-year-olds the most satisfactory letters were found to be H, O, T, and V. These letters have the advantage of being symmetrical about their vertical axes. This property eliminates the right-left directional difficulties which plague the E-Test.

Dr. Sheridan states[96] that all 4-year-old children of normal intelligence can be tested by this method (using the seven letters A, H, O, T, U, V, and X), that approximately 80% of 3-year-olds are testable (using the five letters H, T, O, V, and X), and that about 30% of 2-year-olds can be tested (using H, T, O, V, and X, or better, H, T, O, and V). Any child, regardless of age, who fails the 6/12 line (20/40 equivalent) should be referred for professional examination since this acuity level is stated to be abnormal for all age groups. Pugmire and Sheridan[120] found that 76% of 5-year-old school entrants had 6/6 acuity or better in each eye with STYCAR letters.

The high degree of testability claimed by Sheridan has been confirmed by Lippmann,[113] who found highest acuity scores, shortest testing time, and highest testability ratios with this testing method. Keith, Diamond and Stansfield[121] reached the same conclusions in their evaluation of several types of acuity tests for preschool children (see below, section on Comparative Studies). Browder and Levy[122] found that 35 of 36 retarded children with mental ages over 3 years and chronological ages of 5 to 14 years could be tested by this method.

The major objection to this test is that amblyopia tends to be underrated[44,45] because individual optotypes rather than whole lines of test type are presented. The same point could be made with equal validity with respect to any test in which isolated symbols are used. Yet the overwhelming consensus among experienced screening personnel is that this type of presentation is essential for children under five years of age (see third section of this report). The National Society for the Prevention of Blindness concurs with this view.[92] Limited interest, short attention span, and easy distractabil-

ity make linear presentations impractical for children in this age group.

The Lotto test, developed in France, and the Holt test,[105] developed in the United States, are similar to the STYCAR letter-matching tests.

Ffooks[123] introduced a symbol-matching test employing a triangle, square, and circle. The test is designed for 3- and 4-year-old children. The use of three symbols rather than the more common four symbols (or four orientations of the same symbol) slightly increases the probability of correct responses by chance. As with most other visual acuity screening tests for preschool children, no reliability or validity data are available.

Picture Tests

Perhaps the best known picture tests are those designed by Osterberg[124] and Allen.[125,126] Only these two will be considered here although countless others have been devised.

Osterberg initially drew pictures made up exclusively of positive and negative elements of equal width. No attempt was made to maintain the same overall size. Thirty-eight original test pictures were devised and presented to 2- to 5-year-old children. Twelve were discarded because they were too stylized to permit identification or because the subject material was unfamiliar to the children. Ten adult emmetropes scored the pictures in terms of recognition distance, which turned out to be quite different for different pictures. Those that could be recognized only at distances considerably closer than the others were discarded. This trial-and-error process was repeated with the remaining 18 pictures, using 13 emmetropic children and modifications in the pictures — the roof of the house was made thicker, the roof of the railroad carriage thinner, etc. Further experience with 26 children led to additional eliminations. The remaining 12 pictures formed the material from which the original pictorial chart was finally elaborated. The pictures, which are intended to be viewed from six meters, were: a swan, boat, house, horse, railroad train, key, horse and wagon, man on bicycle, tree, human figure, cup and saucer, and scissors. The test chart has been revised several times since the original was published.

The Allen pictures were developed initially by designing several versions of the same object with variable proportions of black and white in the internal structure. By viewing preliminary drawings through blurring convex lenses, designs were selected that could

be recognized at 20 feet with about the same facility as letters on the 25- and 30-foot lines of the Snellen chart. Trials with preschool children resulted in the selection of eight pictures which seemed to have the most consistent recognition distances. These pictures could be recognized by most normal 4-year-old children at 20 feet and by most normal 3-year-olds at 15 feet. Adults with reduced vision often showed a wide variation of recognition distances for different pictures. Details[125] are provided for both Snellen chart acuity levels and picture recognition distances for one child (with unilateral amblyopia) and three adults (one with bilateral retinal disease and two with unilateral amblyopia). Acuity of 20/30 Snellen or worse gave results under 20 feet for every picture but one. Acuity of 20/70 Snellen or worse permitted recognition at 12 feet or less. The test consists of four pages, one picture per side, in a ring binder. The pictures are: a cake, telephone, jeep, house, panda, tulip, tree, and horse with rider.

Dr. Allen feels that the E-Test and Sjogren Hand Test are "undoubtedly superior and better standardized for children who can use them."[125] He therefore recommends that the picture test should be used only if a child is unable to understand or perform either of these two directional tests.

The pictures used in both of these tests are stylized black and white line drawings of real three-dimensional objects. The abstract nature of these two-dimensional representations may create more recognition difficulty for some children than for others and may also be partially responsible for the documented intraobserver variability with different pictures. Nonuniform familiarity with the test picture subject material, based to a certain extent on cultural and socioeconomic factors, may also be relevant variables as is the necessity to produce a verbal response. The requirement to name the object correctly or at least consistently imposes an additional burden that may be critical for some young children. Verbalization is not required for either the E-Test or the symbol-matching tests.

STEREOPSIS TESTING OF PRESCHOOL CHILDREN

There has been recent interest in using stereopsis tests to screen for amblyopia in preschool children.[62,88,127] The rationale for using stereopsis for detection of vision defects is that stereopsis is a binocular act that stresses a large portion of the visual system. Therefore, stereopsis testing should constitute a high yield method for finding abnormalities within the system, particularly an altera-

tion in the normal competition of both eyes at the level of the lateral geniculate body and/or striate cortex.[88]

There are both theoretical and practical problems with this approach. The theoretical difficulties were enumerated in the preceding section. An essential point is that the relationship between stereo acuity and visual acuity is only approximate when acuity is artifically[57,58] or pathologically[128] reduced in one eye. This is hardly a revelation in view of the fact that stereopsis is a totally distinct central percept which, sui generis, provides relative depth clues by means of horizontal retinal image disparities. There may be specialized cells in the cortex responsible for this unique sensory phenomenon.[52,53] Resolution acuity, on the other hand, is essentially the detection of contrast differences at limiting spatial frequencies and is, fundamentally, a monocular process.

A practical difficulty with this approach is that a poorly defined but possibly large portion of the otherwise normal adult population may have deficient or absent stereo acuity.[60] Furthermore, thresholds are test-dependent and presumably age-dependent and are not established for the preschool population. Using polarized vectographic random-dot stereograms, Reinecke and Simons[62] found a range of 220 to 59 seconds in "normal" children, 31- to 82-months-old.

An additional practical problem with the use of stereopsis as a test for visual disorders is that appreciation of depth in haploscopically presented test material requires a variable amount of perception time for different observers.[129-131] Therefore time is a variable that needs to be controlled in this type of testing format. Still another difficulty is that stereo acuity discrimination ability improves with practice.[132] This has obvious implications if retesting is to be incorporated in the screening procedure. Finally, if stereopsis testing is only conducted at a near distance, many patients with intermittent exotropia would be expected to pass. This is indeed what has been found experimentally.[62]

Two field studies have been recently published which suggest the use of stereoscopic tests for the detection of visual dysfunction (particularly amblyopia) in preschool children.

Reinecke and Simons[62] presented crossed polarized vectographic random-dot stereograms — viewed through right and left crossed polarized spectacles taped to the forehead — to 70 patients, 87% of whom were over four years old. All of these patients had known visual dysfunctions resulting from amblyopia, anisometropia, and

strabismus, or some combination of these conditions. A lenient criterion for passing (500 seconds) was used. Of the 27 patients who passed the test, 23 had strabismus either intermittently or constantly. Many of the latter patients had small angle deviations. One of the patients who passed had 20/70 acuity in the worse eye. Utilizing a stricter standard of 250 seconds, for the most part, only patients with one line or less difference between the eyes and patients with intermittent exotropia passed.

In a second experiment reported by the authors, 121 preschool children in two local day-care centers were tested by means of Allen cards to determine visual acuities (those with less than 15/30 failed) and random-dot stereograms (pass-fail level 250 seconds). Children who failed the visual acuity test or the stereoscopic test were studied further; with four exceptions this consisted of only the four-diopter base-out prism test and cover test. Those failing the acuity test were not retested, but those failing the stereoscopic test were retested. On this basis, 24 children were "overreferred" by the visual acuity test and two children by the random-dot stereoscopic test. No children were "underreferred" by the visual acuity test, and two children were "underreferred" by the stereoscopic test. Three children with "noteworthy" abnormalities were detected. All failed the stereoscopic test and also the visual acuity test. Only these children plus one other received a full clinical work-up. Repeat random-dot stereo acuity testing of 21 of the 121 children revealed significant variation in threshold measurements.

Comparative judgments based on the above experiment must be tentative at best in view of the experimental design of the study, the lack of procedural details provided, the incomplete nature of the ophthalmologic evaluations, the small number of children involved, and the particular visual acuity test employed.

Walraven[127] reported findings obtained with the Titmus Stereo test and personally designed random-dot stereograms prepared as anaglyphs (TNO test) — viewed through colored glass spectacles. The screening plates have disparities of 1,980 seconds at the 40 cm test distance. The first of three quantitative plates consisting of figures with retinal image disparities of 480 and 240 seconds at 40 cm was also used.

Eighty-one children (two to seven years old) with and without visual dysfunction received both types of stereoscopic tests. Two classes of pathology were established. Children were designated as "patients" if the visual acuity of the worse eye was less than 0.7

"associated with a constant tropia or anisometropia, or both. 'Potential patients' had visual acuities of 0.7 or better, often associated with intermittent esotropia." The screening plates of the TNO test referred 30 of the 37 patients and five of the 12 potential patients. They referred none of the 28 normal patients. The quantitative plate referred all seven of the remaining patients and all seven of the remaining potential patients. The quantitative plate also referred two of the 28 normal patients. The Titmus test did not perform as favorably.

Details are not provided on the type(s) of visual acuity test(s) used or on the exact numbers that would have been detected on the basis of visual acuity testing alone, although presumably all of the patients would have been detected solely by this method. Therefore, the relative efficiency of the stereoscopic tests compared to visual acuity tests with and without cover tests cannot be evaluated.

In a second experiment reported by Walraven,[127] screening plates of both the TNO test and the Titmus test were shown to 129 children two to five years old in a nursery and in a day-care center. The Titmus Fly screening plate has 3,000 seconds of disparity at the 40 cm testing distance. The screening plates of the TNO test referred 18 patients, the screening plate of the Titmus test referred 15 patients. Ten of the 15 patients referred by the Titmus Fly were not referred by the TNO screening plates. Six patients were not referred by the Titmus Fly but were referred by the TNO screening plates. Since no clinical details are provided for any of these patients (including visual acuity) no meaningful statements can be made concerning possible advantages of this form of testing.

A review of these two field studies leads to the conclusion that to date, stereoscopic testing has not been demonstrated to be superior to more conventional techniques for preschool vision screening purposes.

PRESCHOOL VISUAL ACUITY TESTS FOR HOME USE

Studies have been made that point to the feasibility of visual acuity testing at home.[133-135]

In order to reach more effectively the millions of preschool children in the United States, the National Society for the Prevention of Blindness instituted a nationwide home visual acuity test in 1972. As of 1977, approximately five million of these tests had been distributed.[136] The test consists of a modified Snellen E chart. It is designed for use at 10 feet. Failure is considered repeated inability

TABLE II. PRESCHOOL VISUAL ACUITY TESTS FOR HOME USE

Source	Date of Inception	Type of Test	Testing Distance	Referral Standard
Prevention of Blindness Society of Metropolitan Washington *	1962	Isolated E Optotypes	20 feet	Repeated failure to identify correctly the 20/30 optotype with either eye
Eau Claire Wisconsin City-County Health Department*	1966	Single 15/30 E Optotype	15 feet	Repeated failure to identify correctly the optotype with either eye
American Academy of Pediatrics	1967	Single 12/24 Sjogren Hand Optotype	12 feet	Repeated failure to identify correctly at least 4/6 positions of the optotype with either eye
American Association of Ophthalmology*	1971	Single 20/20 E Optotype (and) Seven 10/15 Allen Pictures	15 feet for 3-year-olds, 20 feet for 4 and 5-year-olds 10 feet	Failure to identify correctly two or more of six positions of the optotype or a marked difference between the two eyes A consistent difference of three feet or more in the distance which each eye requires to see the pictures
National Society for the Prevention of Blindness*	1972	E Chart	10 feet	Repeated failure to identify correctly the 10/20 line with either eye or different line acuities with either eye

*Currently available

to interpret the symbols on the third line from the top with each eye (10/20 line) or a difference in acuity between the two eyes. A reporting card is included. Preliminary results[137] revealed a reported failure rate of 83/1407 (7.2%). Of the 83 failures, 35 children were professionally examined and 24 were found to have a visual problem.

There may be a tendency for lower socioeconomic families not to seek out such tests,[135] and no studies have been done in which a representative sample of those tested at home were subsequently examined professionally. Therefore the underreferral rates are unknown. This is particularly important in view of a study by Trotter[97] in which 217 preschool children were given the E-Test at home by their parents and later ophthalmologically retested by the same method and examined. Only 6/217 (3%) of the children were overreferred, but 8/16 (50%) of the children who were failed by the ophthalmologist had been previously passed by their parents at home. An underreferral is a more serious error than an overreferral. It is more important to establish the frequency of such events than to establish the frequency of overreferrals, although ideally both should be known.

Experience with home acuity tests that incorporate a reporting form[133,134,137] indicates that a high proportion of parents will not return the form even though requested to do so. There is evidence that such nonreporting families may have a higher incidence of eye abnormalities than those who do report.[134] Professional follow-up studies on those who fail the home vision tests have been incomplete so that the overreferral rates are not established.

Practical information concerning some of the home vision tests that have come to the author's attention is given in Table II. All but one utilizes the E optotype in the form of a chart or as an isolated symbol, but there is no agreement with respect to testing distance or standards for referral.

COMPARATIVE STUDIES

The purpose of this discussion is not to review exhaustively all the comparative studies reported to date but rather to survey the relevant, more recent articles. For example, the excellent study by Borg and Sundmark[100] will not be considered because it evaluates the Sjogren hand, Bostrom-Marquez square, and a hand figure designed by the authors. Of these three optotypes, only the Sjogren hand is widely used in the United States.

In 1958 Jonkers[138] reported a comparative study in which the visual acuities of 173 children, ranging in age from three to over eight years, were obtained with five different optotypes: letters with serifs, numerals, pictures of the author's design, Landolt rings, and E symbols with the middle stroke shorter than the two side strokes. Standard deviations of acuity scores were highest for the picture chart and lowest for the letter chart. Agreement was closest between the E symbols and letters. The reliability of the picture chart was considered the poorest of the methods used. Conversion formulas and a table with comparative acuities are provided. The manner in which the tests were administered and scored is not explicitly stated nor does the author provide details regarding testability. Apparently none of the children was professionally examined.

In 1964 Savitz[106] reported the results of an ambitious project in which eight types of screening tests (21 specific tests) were given by the author to 94 children in their homes. The ages of the children ranged from 31 to 54 months, the median age 39 months. Fifty-three white and 41 nonwhite children were screened. The families visited were socioeconomically depressed and resided in a low-cost housing project in Massachusetts. Not all tests were given to each child and the order of presentation varied. There was no set number of times for reintroduction of tests which were initially failed. Testing, interspersed with physical activity, continued for at least two hours.

The findings were largely limited to testability. The STYCAR miniature toys — originally developed by Sheridan for severely handicapped children[96] — were found most generally useful. This test consists of matching or naming 10 small toys held 10 feet from the child. Although testability was highest with this test, the author notes that the test is not capable of accurate standardization; calculation of Snellen equivalents is also not possible. The test is designed to provide qualitative information concerning vision and also to detect differences in acuity between the two eyes, but reliability and validity have never been established; hence it is uncertain what is being measured. The STYCAR letters and E-Test were both found to be relatively unsatisfactory because of poor testability.

The results of this study are difficult to interpret because of the large number of variables involved. Not only were not all tests administered to each child, but the test equipment was at times

unavailable and occasionally tests were inadvertently omitted. The author's previous experience in administering such tests is not stated, but there were difficulties with cover test interpretations. There was virtually no professional examination of referrals or of normals so that overreferral and underreferral rates were not established; nor is there any information on reliability or validity of test results.

The manner in which the study was conducted, the young ages of the subjects, their educational deprivation, the unusual and variable testing environments, as well as the lack of parental cooperation in obtaining professional follow-up appointments, make the findings nongeneralizable to other preschool populations tested by more conventional methods.

In 1967 Taubenhaus and Jackson[93] compared the visual acuity of a large number of 3- to 6-year-old children obtained with the E-Test, Sjogren hand, Titmus Screener, and Allen picture cards. Cover tests were performed at distance and at near fixation.

Trained volunteers screened the preschool children. All children were initially screened with two different, randomly selected visual acuity tests. Children who failed any of the tests, children who were considered to have a visual or ocular abnormality on the basis of teacher or screener observation, and 20% of the normal children were referred for rescreening. On rescreening, children were given all four acuity tests and the cover tests. All the children who were rescreened were referred for ophthalmologic examinations. Two ophthalmologists examined each referred child independently.

Age adjusted visual acuity criteria were used for making pass-fail decisions. The tests were compared with themselves (reliability) and with each other.

The authors found that all four visual acuity tests are satisfactory and for practical purposes equivalent. The cover test was found to be unreliable. A private recent communication with one of the authors[139] revealed that the Titmus Screener is no longer being used because it is thought to be less satisfactory than the other methods.

Because the persons doing the testing were not highly experienced, because different screeners administered different tests to individual children under nonrigorous conditions, and because of the low failure rates found with all four acuity tests, it is hardly surprising that marked differences were not found between the acuity tests administered. In the reliability analysis, pass-fail

dichotomies were used rather than raw scores; much potentially useful information was thereby sacrificed. No statements regarding statistically significant differences between tests were offered. Objective examination findings were not used as a basis of validity judgments.

The authors make the point that as long as a test is reliable and valid, the selection and training of the persons who do the screening are more important than the choice of test(s); a philosophy which the author of the present report wholeheartedly endorses. In this age of instant obsolescence and seeming urgency to introduce new testing methods, empathy, competency, and attention to testing technique tend to be neglected.

Lippmann in 1969[113] reported a two-part study. In phase one 879 comparative tests were given to 338 preschool children in nine day-care centers by a college graduate. The tests administered were: The American Optical Company picture chart, Good-Lite illiterate E chart, Allen pictures, STYCAR letter wall chart, and STYCAR toys. All testing was performed at 20 feet. The children were divided into small groups and given test A first followed by test B. Another group received test B followed by test A. "Simpler" tests were given when a child could not complete his assigned test. The STYCAR toys were found to be unworkable because children became upset when they had to give them up. The Allen pictures were limited in that acuities better than 20/30 could not be measured. The American Optical Company picture chart was difficult to use and had the highest rate of untestability in the group. The Illiterate E chart and STYCAR letter charts had equal testability but the Illiterate E chart was "less reliable" than the STYCAR letters, particularly in the younger children. The most striking advantage of the STYCAR letters was the speed with which they could be taught.

The Good-Lite illiterate E test at 20 feet, the Good-Lite illiterate E test at 10 feet, and the Titmus Vision Tester with illiterate E symbols were given to 75 children. Difficulty was experienced with the Titmus Vision Tester. Testability ratios were the same with the illiterate E tests at 10 and 20 feet but acuities were slightly higher at 10 feet.

Forty-six children were given both whole-line and individual optotype exposures to the Good-Lite illiterate E chart at 20 feet. Both testability and acuity were slightly better with single optotype presentations.

To explore the relationship between acuity and intersymbol distance, two specially designed crowded STYCAR letter charts as well as the conventional STYCAR letter chart were presented to 33 children. Differences in visual acuity between charts with different intersymbol distances never amounted to more than one line on the chart. Only one 3-year-old child could pass this test with whole-line exposure, whereas nine additional 3-year-old children could master the test when single symbols were exposed.

In phase two of this study a different preschool population was used. A registered nurse gave the Michigan Preschool Test in the Titmus Vision Tester to 77 children, the illiterate E test at 20 feet to 76 children, the illiterate E test at 10 feet to 106 children, and the STYCAR letters at 20 feet to 88 children. Untestable children received the same test a second time; if they were still untestable they received the STYCAR letters. Testing time with the illiterate E test was shorter at 10 feet than at 20 feet. Untestability was highest for the Michigan Preschool Test and equal for children taking the illiterate E test at 10 feet and the STYCAR letter test at 20 feet. Untestability was lowest after the second test for the group that was initially tested with STYCAR letters.

All children showed improved acuity with advancing age independently of the test method, but best acuity scores were obtained with the STYCAR letter test at 20 feet, and testing times were shortest with this method.

The conclusions reached by the author are not based on statistical analyses of the data but rather on comparisons of means and percentages. There are no tests for significance. The experience and training of the persons who did the screening is not given. The exact testing methods used are not stated. In phase 2 of the study the comparability of the groups receiving each different test is not established. Reliability was not determined since the children received each test only once, if they were testable. Apparently none of the children received a professional examination so the underreferral and overreferral rates are not known.

Keith, Diamond and Stansfield[121] in 1972 reported the results of a study carried out by two qualified orthoptists working separately in two hospitals. Thirty-five children were tested at one center and 39 at the other. The children were three to six-and-a-half years old; many had eye abnormalities. The tests used were Snellen's test type, Beale Collins and Clement Clarke pictures, Landolt rings, Sjogren hand, STYCAR letters, E-Test and Ffooks test. One group

was tested by means of an E chart, the other by isolated E optotypes. One group received Beale Collins pictures, the other Clement Clarke pictures. With these two exceptions, the same tests were given to the children in both groups. The results with Snellen's types and the Landolt rings were so poor that they were eliminated. Data collection was limited to testability evaluations and acuity scores. Testability and acuity scores were highest for the STYCAR letters (seven were used). Variation in acuity results obtained in individual children using different tests was considerable. Nearly half the children showed a difference of two or three lines with the Snellen test type, Landolt rings and Clement Clarke picture tests excluded.

The critical remarks made in reference to Lippmann's study apply with equal validity to this study and therefore need not be repeated.

The two preschool vision acuity tests which seem to emerge from these comparative studies as the most suitable and productive are the E-Test and the STYCAR letters. The third section of this report describes a clinical study in which the E-Test and an adaptation of the STYCAR letter test were given to a group of preschool children in a comparative yet randomized manner so that their relative strengths and weaknesses might become apparent.

PART III

INTRODUCTION

The purpose of this study was to explore the relative advantages and disadvantages of two visual acuity tests suitable for the preschool child. The tests selected were the popular Snellen E-Test and a version of the recently introduced STYCAR test. Some reports suggest that the Letter-Matching-Test may be more satisfactory than the E-Test for visual acuity testing of young children. A higher proportion of testable children[96,107,113,121,122,140] and greater reliability[107,113,140] have been claimed. The major variables measured and compared were testability, learning time (group and individual), testing time, reliability, and validity.

PROJECT DEVELOPMENT

The Prevention of Blindness Society of Metropolitan Washington has conducted annual eye screening tests for the children enrolled in the D.C. Department of Recreation's preschool program for the past several years. Preliminary discussions with both the Preven-

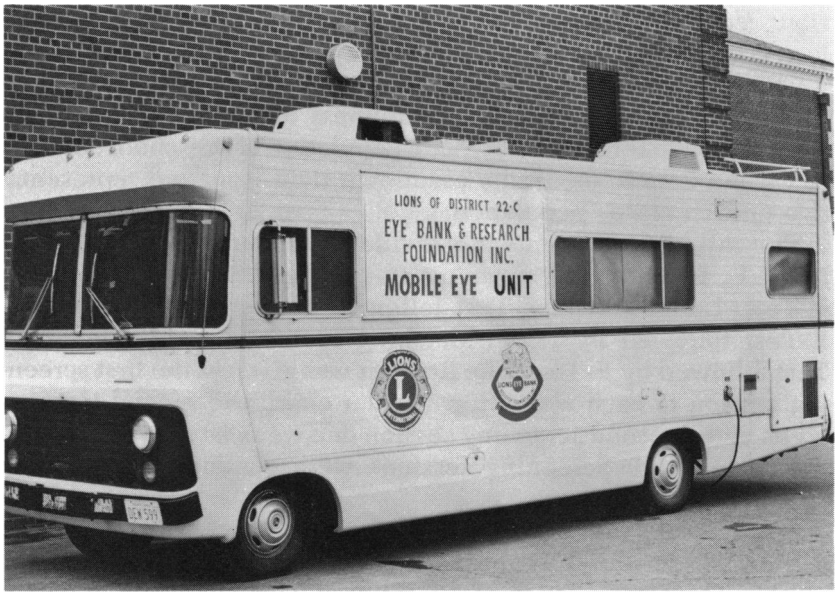


FIGURE 4
Mobile eye van used for the medical examinations.

tion of Blindness Society of Metropolitan Washington and the Cooperative Play Program of the D.C. Department of Recreation revealed considerable interest in conducting a research project designed to evaluate the relative merits of the two visual acuity tests.

During the early summer of 1975 arrangements were made with Mrs. Marlyn P. Hinkle, Director of the Cooperative Play Program of the D.C. Department of Recreation to begin the project in the late fall of 1975, in as many of the 55 preschool centers as possible. It was recognized that for administrative reasons the project could not be extended beyond the end of the school year in May of 1976.

Detailed protocol planning began in the spring of 1975 and continued until the fall of that year. The principal investigators involved with and responsible for the experimental design and conduct of the project were the author; Mrs. Margaret B. Kenealy, Director of the Pre-School Vision Screening Program of the Prevention of Blindness Society of Metropolitan Washington; and Dr. William Schafer, Associate Professor, Department of Measurement and Statistics, College of Education, University of Maryland. Mrs. Kenealy functioned as program coordinator. She organized all ses-

sions (screening and medical), made out the schedules, and collected and retained the data.

The basic concept of the project was to use experienced personnel from the Prevention of Blindness Society of Metropolitan Washington to screen an adequate population of preschool children *twice* and then to medically examine a significant and representative portion of this population.

The children were randomly divided into four groups designated EE, LL, EL, and LE, meaning respectively E-Test followed by E-Test, Letter-Matching-Test followed by Letter-Matching-Test, E-Test followed by Letter-Matching-Test, and Letter-Matching-Test followed by E-Test. The first test was given at the first screening session to each eye of a particular child; the second test was given at the second screening session one week later to each eye of the same child. Screening sessions were conducted within the preschool centers.

Approximately one week after the second screening session the author, accompanied by three assistants, performed complete eye examinations on a portion of the children who had completed both screening sessions. The mobile eye care van of the Lions of District 22-C, Eye Bank and Research Foundation, Inc. (Figure 4) was made available to the project to facilitate the medical eye examinations. It was parked on the playing fields of preschool centers as close as possible to the children's classroom. The ten-foot testing lane, examining chair and supporting diagnostic equipment inside the van greatly simplified the logistics of performing the medical eye examinations. Because of scheduling conflicts and mechanical problems, the van was not consistently available. Indeed, one-third of the medical examinations had to be conducted within the preschool centers.

VISUAL ACUITY TESTING MATERIALS

Visual acuity charts designed for testing at ten feet were obtained from the Good-Lite Company*. This company manufactures an E chart is based on the STYCAR letters popularized by Sheridan.[96] rections for use by Otto Lippmann, M.D. The Letter-Matching-Test chart is based on the STYCAR letters popularized by Sheridan (96). The charts are so designed that they are exactly comparable in terms of symbol size and placement. For each of the four possible

*7426 West Madison Street, Forest Park, Illinois 60130

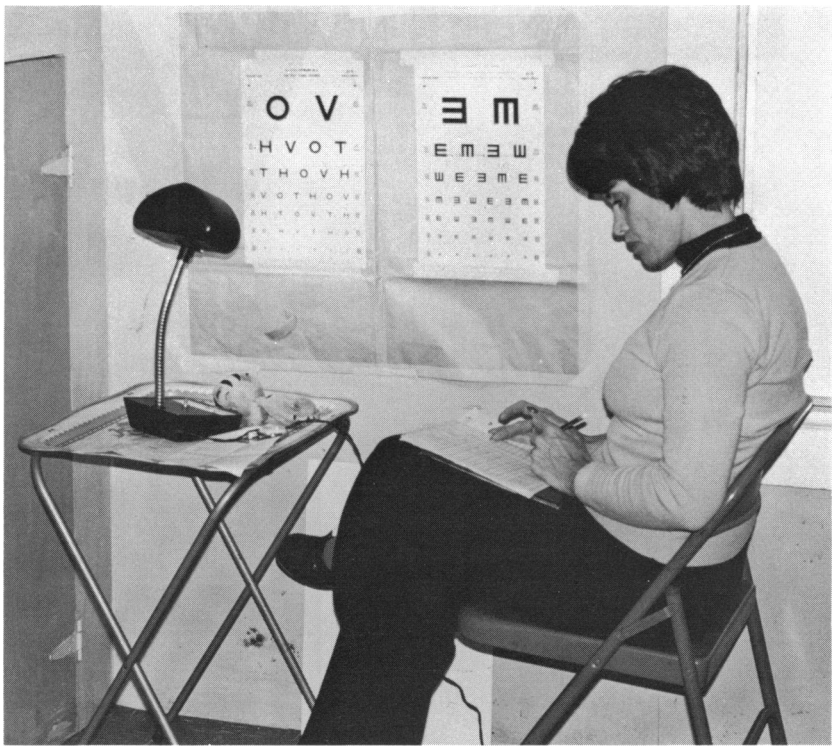


FIGURE 5
The two dissimilar acuity charts are mounted on a wall. The light is moved so as to illuminate one or the other chart.

orientations of the letter E, one of the H, T, O, or V letters may be substituted. If, for example, the symbol ∃ is consistently replaced by the letter O, ⩋ by V, ∃ by H, and ⩋ by T, the letter sequence of the letter chart can be exactly reconstituted.

Two optotypes are located on the 10/100 line, four on the 10/50 line, five on the 10/35 line, and six on each of the subsequent lines (10/25, 10/20, 10/15, and 10/10). The letters are block style sans serif. They are black against a white dull matte nonreflective finish. The rectangular charts are composed of washable vinyl plastic and measure 9 × 14 inches.

Individual optotypes were presented through a square aperture in the center of a white cardboard mask sufficiently large to occlude the entire chart. The masks supplied by the Good-Lite Company were found to be too small to cover adequately the acuity charts.

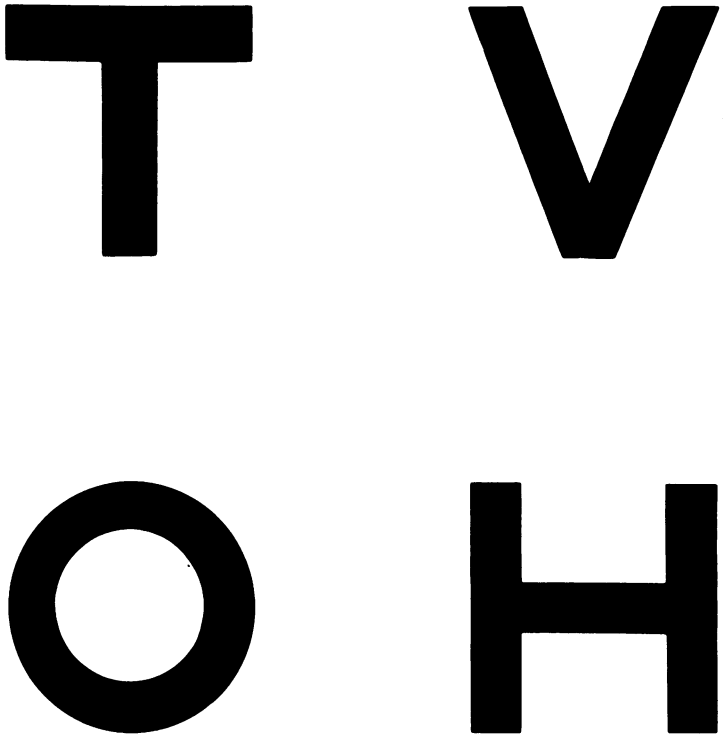


FIGURE 6
The Letter-Matching-Test response panel.

Therefore, larger masks had to be constructed out of white cardboard.

Charts were wall-mounted by means of several pieces of double-stick tape. The mask, with its central aperture, was manipulated by one of the persons participating in the testing procedure.

The center of each chart was located approximately at eye level of the standing average preschool child. The chart worker stationed at the 10 foot testing distance generally found it more convenient to manipulate the masking card from a sitting position.

A gooseneck lamp with a 100 watt frosted bulb was positioned on a portable tray-stand approximately two feet from the chart on the side opposite to that of the chart worker. It was adjusted to evenly illuminate the entire chart without highlights or glare. This arrangement provided approximately 50 millilamberts of luminance, which is near the middle of the comfortable reading zone.

In the preschool centers the two dissimilar acuity charts were mounted on a wall one or two feet apart. The source of illumination, directed at the particular chart to be used, could easily be moved from one chart to the other (Figure 5). Acuity testing in the mobile van was performed using a single wall-mounted chart that could be changed rapidly whenever necessary. Space in the van was inadequate to permit the simultaneous mounting of both charts.

The Letter-Matching-Test equipment supplied by the Good-Lite Company includes a "response panel." This consists of a vinyl plastic card with the four letters H, T, O, and V printed in the same style as on the 10 foot chart (Figure 6). The card was held by the examiner and presented to the child whenever a matching response was needed.

Children were instructed to identify the orientation of the E symbol by holding their finger or fingers in the same direction as the strokes of the letter E. A matching type of response was contemplated for the E-Test and a response panel was actually manufactured for this purpose. Pilot experience, however, immediately demonstrated to the satisfaction of all the professional personnel included in the study that this method would be unsatisfactory for preschool children because of the directional confusion created by the juxtaposed similar symbols. Several testers found that they themselves had considerable difficulty in identifying the appropriately oriented symbol on the response panel. Therefore, even though it was deemed preferable from a theoretical standpoint to use matching responses in both tests, it was thought impractical to do so. A second objection to the use of the E-response panel was that the test is not customarily conducted in this manner. This fact would severely limit the generalizability of any conclusions reached.

THE STUDY POPULATION

In 1975-1976 the District of Columbia Department of Recreation operated a preschool program for approximately 700 children through 48 preschool centers in nine administrative areas, with 10 to 25 children attending each center. The purposes of the program are to provide education and supervised play activities at a nominal charge for appropriately aged residents of the city. Participating children are between two and one-half and six years of age. The majority are between the ages of three and five years. They are mostly black inner-city children from middle and lower socioeco-

nomic families. A map showing the locations of the facilities of the D.C. Department of Recreation indicates that these facilities are fairly evenly distributed throughout the Metropolitan area.

A group of upper-middle-class white children from a private school in Northwest Washington, D.C. were also included in the study, (Abingdon Montessori School). With this single exception, all of the children in the study population were enrolled in the Cooperative Play Program of the D.C. Department of Recreation.

DETAILED PLANNING

It was recognized at the outset that it would be essential for data analysis purposes that similar acuity testing methods be used by each screening team and by the author during the medical examinations. The nine persons involved in the screening portion of the study had had significant prior experience. Seven were assigned to the staff of the Prevention of Blindness Society of Metropolitan Washington; two project participants were part-time volunteers.

The two screening sessions were conducted about one week apart. Most of the time the same screening team was present at each of the two sessions. One particular team member (the examiner) attended the child and held the occluder over the eye not being tested. A second staffer (the chart worker) presented the optotypes, while a third person (the recorder) timed the events and recorded the results. The examiner remained constant at each particular center. At the smaller centers it was possible to combine the latter two chores so that only two persons were needed. By design, assignments and team members frequently changed between different centers, but not within any given center.[141] There were only four exceptions to this plan. On two occasions a team member (not the examiner) was unable to attend the second session and a substitute staffer was used. On two other occasions a team member (not the examiner) present at the first session was unable to attend the second session and a substitute was not used.

The frequent changes in team composition between different centers helped to assure standardized procedures. Uniformity of the techniques employed was further enhanced by occasional observation of screening sessions by the author.

Separate data collection sheets were designed for screening sessions and for the medical examination. The children at each center were listed alphabetically on the data sheets.

All children were divided into four cells by a systematic random sampling technique. This was accomplished in the following man-

ner. The number of children in each center available for testing was divided by four. The quotient represented the total number of like ballots that would be used in the drawing. Four dissimilar ballots were used, one for each cell. (Since there are four suits of cards in a deck, it was convenient to use each suit for a different cell (EE, LL, EL, and LE)). By randomly drawing individual shuffled ballots, one per child, each child, taken in alphabetical order, was assigned a particular cell. Children remaining unassigned (if any) after this drawing and those who enrolled after initial assignment were given cell designations by random drawing from four dissimilar shuffled ballots.

The cell assignments were made prior to the screening sessions. Children absent from one or both screening sessions were not counted. This is the primary reason for the unequal cell populations. If a child was screened twice he or she was considered to have entered the study and was assigned a case number. Also, if a child was screened twice, he or she was counted whether or not a medical examination was scheduled, scheduled and conducted, or scheduled and for any reason not conducted.

The eye to be tested first at the first screening session was selected by reference to random tables. Consecutive even and odd numbers were utilized to indicate right and left eyes. Whichever eye was tested first at the first screening session would be tested first at the second screening session.

The following information was available on the data sheets prior to the commencement of the first screening session: patient's name (listed in alphabetical order), presence or absence of medical consent form, sex, birth date, group (cell) assignment, eye to be tested first, and test used. The last item although redundant was included to assure performance of the correct acuity test.

A four-page instructional brochure was composed and distributed to the screening personnel specifying the modus operandi.

Each child to be screened or medically examined was given a tag with name and assignment for the purpose of rapid identification and as a double check on the correctness of the acuity test to be administered.

The children were divided into E and Letter-Matching groups according to their assignments on the data sheets prior to both screening sessions. Each child received group instruction before being tested. No prior instruction by parents or teachers was permitted, and acuity test assignments were not known to them. Ten to

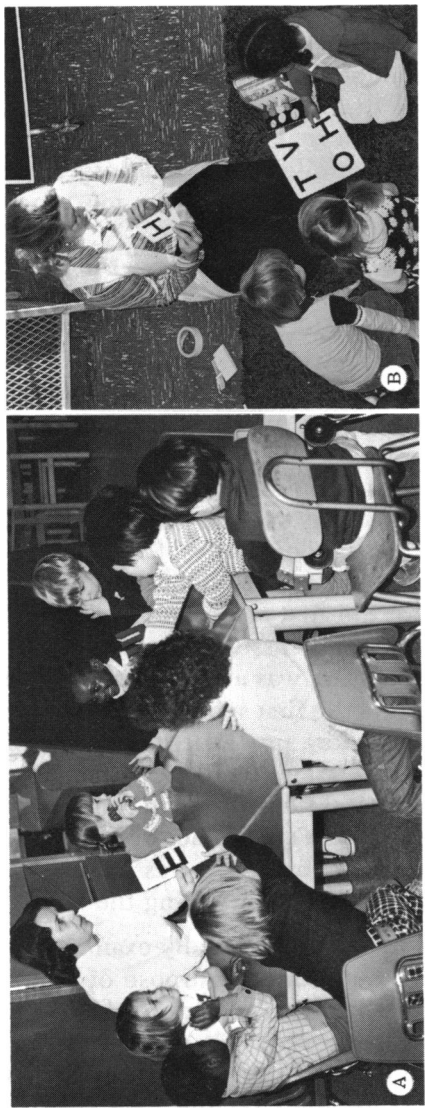


FIGURE 7
Group instructional sessions for E-Test (A) and for Letter-Matching-Test (B).

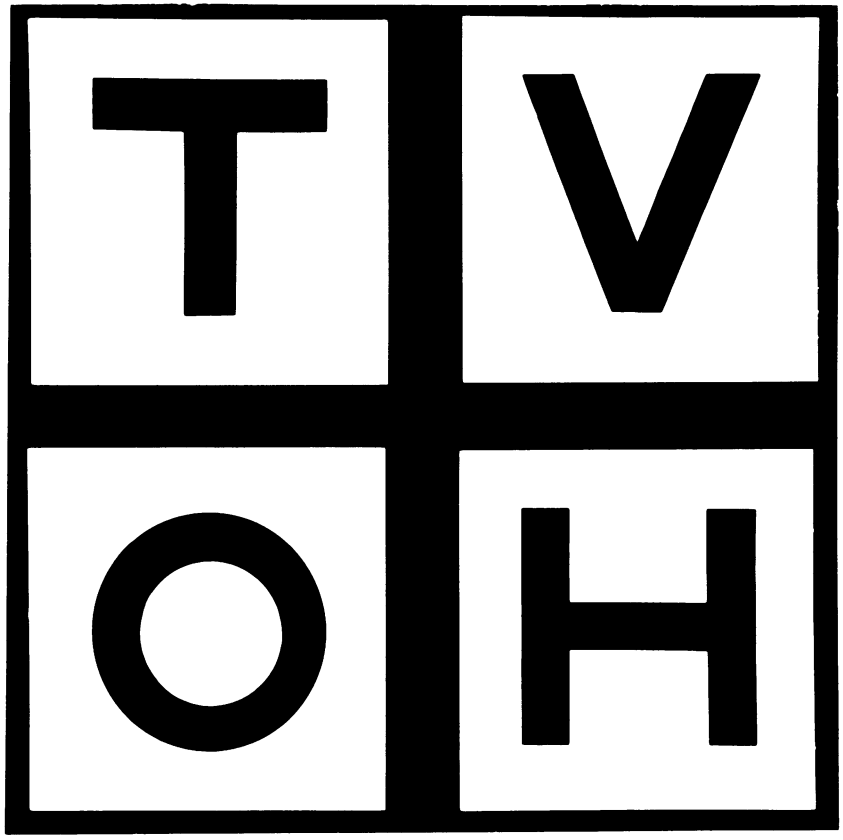


FIGURE 8
Single letters used to teach the Letter-Matching-Test.

15 minutes were spent in explaining the tests to both groups. Both instructional sessions were conducted simultaneously in separate areas within a center by different screening personnel (Figure 7). Individual instruction within a group was given after the majority of children within the group had mastered the technique. This individual instruction, however, could not extend the total group instruction time beyond the 15 minute limit. All children were requested to stay for the entire session (but this was not enforced for those children who mastered the test quickly and showed signs of impatience, thereby threatening to distract the slower learners).

A single 20/200 size letter E on a white background was used for instruction on the E-Test. If a child could not learn to indicate with

fingers or hands the direction of the strokes of the letter E in up, down, left, and right orientation, a three-dimensional "toy" E was employed as a last resort. This figure was held by the child who was told to orient it to match the four different directions of the letter E presented by the teacher.

Letter-Matching instruction was given using the same response panel as would be used in the actual testing procedure. Children were taught to point to the letter on the response panel that matched single letters (H, T, O, or V) presented by the teacher (Figure 8). These detached letters were obtained from the Good-Lite Company.

Ambient room illuminance was measured by Gossen Luna-PRO electronic exposure meters. The spherical diffuser was centered over the meter's round window, in the incident light-measuring mode, and the tester faced the position to be occupied by the child with her back to the illuminated chart. The scale of the meter was used which provided the more nearly central meter scale reading (the meter has two scales for low and high light levels). All four meters used during the project were checked by the author prior to distribution for zero scale reading in darkness, for inter- and intra-instrument consistency when held toward a source of light, and for battery condition. Since the same meter was used at each of the two screening sessions held at particular centers, the very slight interinstrument variation (of the order of one-half scale reading or 10 foot-candles) was not considered significant.

The light meter reading was recorded at both screening sessions. The reading obtained at the first screening session was placed on the data sheets for guidance at the second screening session. The screening personnel were requested to obtain the same level of illumination at the second screening session (i.e., the same meter reading) in a given center by adjusting blinds, shades, overhead lights, etc.

Individual screening began immediately after group instruction. Children were screened by the team in alphabetical order, one at a time.

Group learning time was defined as the length of time within the 15 minute time limit required to bring all of the children in the group up to criterion performance. This might include individual instruction of slower students. Results were recorded on the data sheets at each session.

When the child arrived at the screening position, timing of individual learning began. All children, regardless of their performance in the group instructional session, were individually examined for testability prior to acuity testing. The criterion performance for testability was defined as properly identifying by hand or finger pointing, or by matching four out of four, five out of six, or six out of eight consecutive E or letter cards within the 120 second time period allotted. These testability criteria were chosen because the probability of success by chance alone is less than .01 (less than 1 chance in 100) for each of these scores. This provides a high degree of assurance that the child understands the task to be performed.

The calculation of the value $P < .01$ is relatively simple since it is based on the binomial distribution:

$$P(x) = \frac{N!}{x!\,(N-x)!} P^x Q^{N-x} \quad \text{where}$$

$P(x)$ = Probability of exactly x successes in N trials

N = Number of trials
x = Number of successes
P = Probability of success on a single trial
Q = 1 − P = Probability of failure on a single trial

There are four ways to pass the testability criteria:
(1) 4 of the first 4
(2) 3 of the first 4 and 2 of the next 2
(3) 3 of the first 4, 1 of the next 2, and 2 of the next 2
(4) 2 of the first 4, 2 of the next 2, and 2 of the next 2.

The probability of passing by chance is the sum of probabilities of the above four events, since they are mutually exclusive.

$$P(1) = \frac{4!}{4!(4-4)!}(.25)^4(.75)^0 = .00391$$

$$P(2) = \left[\left(\frac{4!}{(4-3)!3!}\right)(.25)^3(.75)^1\right]\left[\left(\frac{2!}{(2-2)!2!}\right)(.25)^2(.75)^0\right] = .00293$$

$$P(3) = \left[\left(\frac{4!}{(4-3)!3!}\right)(.25)^3(.75)^1\right]\left[\left(\frac{2!}{(2-1)!1!}\right)(.25)^1(.75)^1\right]\left[\left(\frac{2!}{(2-2)!2!}\right)(.25)^2(.75)^0\right] = .00110$$

$$P(4) = \left[\left(\frac{4!}{(4-2)!2!}\right)(.25)^2(.75)^2\right]\left[\left(\frac{2!}{(2-2)!2!}\right)(.25)^2(.75)^0\right]\left[\left(\frac{2!}{(2-2)!2!}\right)(.25)^2(.75)^0\right] = .00082$$

The sum of $P(1) + P(2) + P(3) + P(4) = .00876$

If a less stringent testability criterion had been selected, chance factors would have permitted more children who had not understood the testing procedures to have received the visual acuity test. This would have resulted in a larger number of performance failures and in a higher overreferral rate.

A stringent testability criterion has the additional advantage of assuring more efficient time utilization. For example, if the criterion measure for testability had been set at a minimum of three successes in four trials, the probability of meeting the criterion by chance alone would be:

$$P(x) = \frac{4!}{3!\,(4-3)!}(.25)^3(.75)^1 + \frac{4!}{4!(4-4)!}(.25)^4(.75)^0 = .05078$$

This means that about one child out of 20 who did not understand the testing procedure would have been passed as testable on the basis of chance.

The time allowance (120 seconds) for the determination of testability was chosen on the basis of pilot experience. Very few children who could not perform the test within two minutes could do so after an additional minute or two.

All four orientations of the E symbol and all four letters were shown during the determination of testability. This was important because some children would be able to identify some orientations of the E symbol (usually vertical) but not others. Likewise, some children seemed to have less difficulty matching some letters than others. The order of presentation was randomized. Testability determinations were made without occlusion.

Children who did not achieve criterion within the 120 second time limit were designated learning failures. Such children were not given the acuity tests. They did, however, receive the other parts of the screening test.

A few children named the letters or verbalized the direction of the E symbol (left, right, up, or down). Although this oral response was not taught or encouraged, it was permitted. If a child could not point correctly with his finger or hand, occasional success was obtained with the solid figure E. If this device was used or if naming of symbols occurred, these facts were recorded on the data sheets under "comments."

If the child was classified as a learning failure, an attempt was made to explain the reason. Screening personnel were requested to specify: does not understand instructions, uncooperative, won't or can't fixate, etc. under "comments." The designation 120+ was

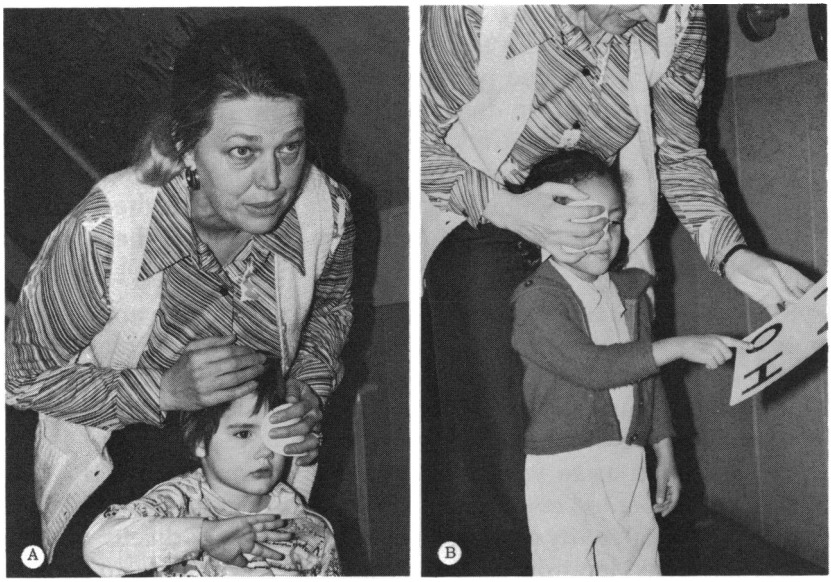


FIGURE 9
E-Test (A) and Letter-Matching-Test (B) individual acuity testing using handheld heavy paper occluder.

used in the time column for such children. This meant that the criterion measure was not achieved within the time limit.

All visual acuity testing was conducted at 10 feet. The decision to use this testing distance was based on the experience of the Prevention of Blindness workers involved in the study as well as on the reports of other investigators.[96,107] The 20 foot testing distance customarily used for adults was thought to be too remote for the young children involved in the project. The shorter testing distance provides greater immediacy thus tending to increase attention; it has the disadvantage of reducing the retinal blur of myopic eyes and increasing the accommodative requirement of emmetropic and hypermetropic eyes. It is interesting to quantitate the effect of the reduced testing distance. Rays emanating from a point of 20 feet (six meters) have a divergence of 1/6 diopter at the eye. Rays emanating from a point 10 feet distant (three meters) have a divergence of 1/3 diopter at the eye. The difference then in vergence between these two testing distances is equal to $1/3 - 1/6 = 1/6$, or .17 diopter, an amount insufficient in magnitude to make a critical difference in many instances.

The type of occluder to use during the acuity testing was also carefully considered. The author has a strong personal preference for adhesive-type opaque patches placed directly over the eye on the skin, while the screening personnel preferred hand-held-type occluders. The past experience of both parties although extensive led to different conclusions. The screening personnel felt that the greater acceptability of the hand-held devices outweighed the risk of undetected incomplete occlusion; the author had the opposite impression.

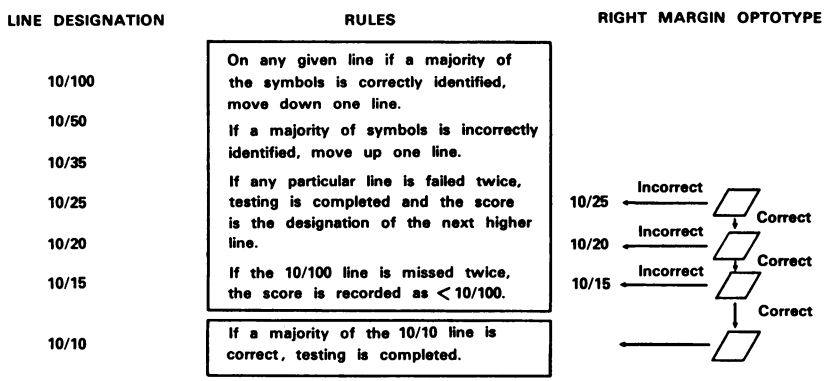
Since no information was available on which to base an informed opinion, the screening personnel used a heavy paper occluder held by the examiner stationed with the child (Figure 9); the author used an Opticlude® adhesive eye patch. Those children who normally wore glasses were tested only while wearing their glasses.

The question as to whether an entire line or individual letters should be presented centers on the "crowding phenomenon". This aspect of visual acuity testing has been previously discussed. The important consideration in this respect is that failure to present entire lines of test type risks the possibility of missing some children with amblyopia.

If the prevalence of amblyopia of 1.8% as found by Flom and Neumaier[142] is accepted, it would be reasonable to expect approximately 11 amblyopic patients to be present in the study population. If less than half of all amblyopic eyes demonstrate this phenomenon,[143] then the number of relevant patients decreases to approximately five. The major variables to be compared did not include relative success in amblyopia detection. A different population (such as an eye clinic population) would be more suitable for this purpose. As Burian has stated:[144] "The ability of an eye to recognize symbols smaller than the ones presented in a row is evidence that the eye possesses a visual resolution power which is higher than the one indicated by the line acuity. The minimum separable is by definition the criterion for visual acuity. The single E acuity is, therefore, a measure of the acuity which the eye in fact possesses and which can be brought out under optimal conditions."

Another reason for not presenting entire lines is the difficulty in maintaining a clear understanding as to which optotype at a given moment is to be interpreted by the child. Probably the most arduous aspect of preschool visual acuity testing is the maintenance of interest and attention. The simultaneous presentation of multiple symbols is confusing and distracting to the preschool child. Even

LOGIC SCHEMA FOLLOWED IN ACUITY TESTING FOR BOTH CHARTS



Testing begins with the optotype at the right margin of the 10/25 line.

A right to left arrow means that a sufficient number of optotypes are shown on that line to make a pass-fail decision.

A downward directed arrow means the optotype at the right margin of the line immediately below is presented next.

The terms "Correct" and "Incorrect" apply to the response to the adjacent optotype.

FIGURE 10
See text.

pointers and more elaborate methods of indicating separate test symbols do not eliminate the decrease in impressiveness created by background figures. When individual optotypes are not indicated, the child may interpret one or two symbols on a line of several symbols and then, inexplicably and without the awareness of the person administering the test, repeat the interpretation of these same symbols. Such performance characteristics make scoring very difficult.

The personnel from the Prevention of Blindness Society of Metropolitan Washington involved in the design of the study, as well as many other workers in this field, recognize the difficulty of line presentations, and there is general agreement[93,96,97,100,113,118,121,123,125,133,134,145-150] that children under five years of age are not good candidates for whole line presentations. Rather than introduce another variable, it was elected to test all of the children by the same single optotype method.

Much thought was given to the precise method to be used in measuring visual acuity. What was needed was a schema that would be systematic and yet appropriate for the preschool children to be tested. It was felt that the method used should be similar to

testing methods employed in the past in order to make results more meaningful in a comparative sense. The expertise of the Prevention of Blindness personnel was most helpful in designing a technique that was both rigorous and practical.

The method finally selected (after several conferences and two pilot trials) is shown in a modified flow sheet form in Figure 10.

Acuity testing began with the extreme right-hand symbol on the 10/25 line. If this symbol was correctly identified, the optotype immediately below was presented. The symbols located at the right margin of the chart continued to be presented in this manner until a mistake was made. If no mistake was made, the 10/10 line was presented symbol by symbol from right to left. If an error was made going down the right side margin, all the optotypes on that line were presented. If the majority of symbols on that line were correct, the line below was presented right to left. If the majority on that line were incorrect, the line above was again presented. If the 10/25 right margin symbol was failed, the optotypes on the 10/25 line were presented. The mask was then moved up or down depending on whether the majority were incorrect or correct respectively. Any line failed was repeated once but only once. If a particular line was failed twice, the acuity was recorded as that of the next higher line.

The screening personnel were instructed to learn the number of optotypes on each particular line of the chart so that all the symbols on each line need not necessarily be presented. The number of symbols shown was only that required to make a pass or fail decision for the particular line. For example, if 4/6, 3/5 or 3/4 symbols were correctly identified, the remaining symbols were not presented. To do so would have penalized the child unnecessarily in terms of testing time.

The decision to commence acuity testing with the line located in the center of the chart was somewhat arbitrary. This choice had the advantage of not initially stressing children with normal vision, thereby giving them a feeling of accomplishment. It provided sufficient time for reasonable measurement to the cooperative child with reduced acuity.

The right rather than left margin of the chart was selected for optotype presentation because of a peculiarity in the Letter-Matching-Test chart. The sequence of letters in this chart is such that by presenting letters starting with the symbol at the left margin of the 10/25 line and proceeding directly down to the 10/10 line and then across this line from left to right, only two letters in the 10/10

line would be missed by the astute child who perceives and follows a continuous clockwise rotation of matches on the response panel. If, on the other hand, the right margin is used, the child who follows the clockwise rotation of responses will miss 4/6 letters of the 10/10 line. In the first instance the child would pass the test at the 10/10 level; in the second instance, the child would fail the 10/10 line.

The decision to use a majority rather than higher percentage of correct responses for a pass-fail determination was based primarily on practical considerations; i.e., the number required for a majority on each line is readily determined. The 50% threshold level is also preferred by other investigators because of its relative stability.[11,12,13]

The probability of identifying the majority of symbols correctly on each line by chance alone varies, of course, according to the number of symbols on each line.

The top line of the chart (10/100 line) consists of only two figures. Therefore, the probability of identifying both figures correctly (which is the requirement to pass this line since 1/2 is not a majority) by chance is 1/16 or .06. The probability for the 10/50 line (3/4) is .0508 and for the 10/35 (3/5) is .1035. The probabilities for the 10/25, 10/20, 10/15 and 10/10 lines (4/6) are each .0376. These probabilities are calculated in the same manner as the probabilities for passing the testing requirement.

It should be noted that the probabilities for passing individual lines by chance are higher than the probabilities for passing the testability requirement by chance. The effect of the higher "hurdle" to qualify for testing and the lower "hurdle" for passing individual lines is to assure that it is likely that those who are tested understand the test $P < .01$, but having satisfied this criterion there is a greater likelihood of passing an individual line by chance. The effect of repeating a failed line once is to double the probability of a line being passed by chance alone. This creates a significant risk in the case of the 10/35 line since the probability of passing this line by chance alone rises to .21. For the critical line of 10/15 (in terms of passing the test) the probabilities remain below .10. This is still higher than optimum since about eight in 100 would be expected to pass the critical 10/15 line on this basis. It should be noted, however, that this probability is affected by the requirement to identify at least two symbols correctly before the 10/15 line is presented (the two symbols at the right margin of the 10/25, and 10/20 lines).

Therefore, the true probability of a patient with vision less than 10/25 passing the test at the 10/15 level would be the product of the probabilities of correctly guessing both of the symbols that are presented prior to this line P = 1/16 and the probabilities of correctly guessing 4/6 symbols on the 10/15 line on the first or second try (.0625 × .0376 × 2) = .00470. This has the effect of reducing the level of under-referral to $P < .01$, a similar order of magnitude as the probability level selected for testability. In other words, the likelihood of testing a child when he is untestable is similar to the likelihood of passing a child with vision less than 10/25; and both events are highly unlikely.

Acuity testing results were recorded for each eye in conventional Snellen form. The time required to reach a measurement was recorded in seconds. If the 120 seconds allotted for acuity testing for each eye were exceeded, the result was recorded as 120+ for the particular eye involved. If an acuity of less than 10/15 was measured in either eye or if more than 120 seconds of testing time was used without passing the 10/15 line, the result was considered a performance failure. Screening personnel were asked to supply information as to the apparent cause of the performance failure. Possible reasons included: instructions not understood, lack of cooperation, avoidance of occluder, apparent inability to fixate, etc.

The visual acuity of the second eye was tested in exactly the same manner as the first eye. The score obtained and the time required were recorded on the data sheet, as recorded for the first eye tested.

Observations were made regarding the presence or absence of external disease or defects, of nystagmus or abnormal ocular alignment or movements. Ocular alignment was tested by means of the conventional cover-uncover test. Manifest deviations were not measured with prisms but the type (convergent, divergent, or vertical) was specified.

Exactly the same procedures were followed at the second screening session as in the first screening session. Testers were not given information regarding prior performance. Children who failed the second screening test and were not scheduled to receive the medical eye examination were at the point of completion of the second screening test outside the confines of the study. Further acuity testing of these children was permitted. If in the judgment of the screening personnel further testing might be expected to result in improved scores, such additional testing was conducted. Parents of

children who did not receive the medical examination were notified of visual acuity problems by the Prevention of Blindness Society of Metropolitan Washington only if their children failed to pass the second screening acuity test with or without extended testing. Learning failures were not considered equivalent to performance failures. The parents of such children were informed that their children were too young or too immature to cooperate for acuity testing. The parents of children found to be normal were also notified of the findings. The parents of children who failed the test on the basis of external disease, nystagmus or abnormal ocular motility were informed of the abnormal findings and were advised to obtain professional care, as were those who failed the performance aspect of the visual acuity test. No information was sent to parents of children scheduled to receive the medical eye examination until the examination was completed.

Approximately one or two weeks after the second screening session, the medical eye examinations were conducted. The author did these examinations, assisted by Mrs. Jo Ann Walker, the certified orthopist at Children's Hospital, National Medical Center; Mr. Kevin Lincoln, the Mobile Eye Unit van driver and ophthalmic assistant employed by the Lions Eye Bank of District 22-C; and Mrs. Mary Welch, a trained technician. Mrs. Walker was responsible for patient flow. She also instilled the second set of eye drops when required. Mr. Lincoln recorded the data, and Mrs. Welch presented the optotypes at the 10 foot testing distance. She also assisted with ocular motility testing.

Children were examined in alphabetical order. Prescriptions of glasses worn were obtained by the neutralization method using trial case spherical and cylindrical lenses. Cylinder axes were determined by reference to the 180 degree scale on a conventional trial frame. Children wearing glasses were tested only with their glasses.

There was no group instruction prior to the medical eye examination. Testability was determined in exactly the same manner and within the same 120 second time limit used in the screening sessions. Only those children who satisfied the testability criterion received acuity tests. Those who did not achieve criterion were considered learning failures.

The eye to receive acuity testing first was selected in advance by random number table assignment. The test used was the test employed in the second screening session. This information was given

on the data sheets. The author did not have access to the acuity scores obtained on the first or second screening sessions at the time of the medical examination. The acuity test given at the first screening session was also not available. The time limit for visual acuity testing was increased from the 120 seconds used in the screening sessions to 180 seconds. The reason for this somewhat more generous time allocation was to make the testing procedure somewhat more deliberate, thereby resembling more closely the time frame generally available for acuity testing in the office of an eye care specialist. The method of optotype presentation and the scoring system were the same as those used in the screening sessions. A performance failure was defined as a visual acuity less than 10/15 within the three-minute time period allowed for each eye. When the time limit for acuity testing of an eye was exceeded, 180+ was recorded on the medical data sheet. Any external diseases or defects were noted. Ocular motility examination consisted of conventional cover-uncover and alternate-cover testing at distance and near fixation utilizing accommodative targets. The latter consisted of moving a small puppet held at 10 feet; the former consisted of "wiggle" pictures or small models of animals held at 13 inches. Phorias and tropias were measured by means of the simultaneous or alternate prism-cover tests at distance and/or near.[151,152] Ocular rotations were inspected in the nine diagnostic positions of gaze, and under- or over-actions of extraocular muscles were recorded.

The author instilled 2% Cyclopentolate eye drops in both eyes upon completion of the ocular motility portion of the examination. Children with darkly pigmented irides received a second drop of the same medication in both eyes approximately five to ten minutes after the initial instillation. Five black children received a third instillation of the drops one-half hour after the initial instillation. Sensitivity or dose-related toxic effects were not encountered and children were not retinoscoped without adequate cycloplegia. Specially prepared packets of hard candy were awarded to all children after initial drop instillation.

Streak retinoscopy was performed under subdued illumination by means of a Copeland instrument and hand-held wide aperture lenses. A trial frame was used to determine cylinder axis. Because of the young age and generally poor cooperation of the children, it was necessary to request each child to fixate the retinoscope light rather than a more remote object. Distance fixation is difficult to obtain and maintain with such young subjects. The disadvantage of

stimulating residual accommodation is more than offset by the improved control over fixation and by being able to refract directly on the patient's visual axis. Sphere and cylinder combinations were held before the eye under study. Lens power was adjusted until neutralization was obtained at the 67 cm working distance used.

Monocular indirect ophthalmoscopy was performed after retinoscopy. An Oculus rechargeable flashlight with a right-angle prism and a +20 diopter Nikon lens were used. Children with less than normal visual acuities and children who were learning failures were, in addition, studied by means of a conventional direct ophthalmoscope. The maculas and optic discs of both eyes were visualized on each child who received the medical eye examination. All abnormalities were recorded.

The families of children who failed the medical eye examination because of reduced acuities, abnormal refractions, external disease or defects, ocular motility abnormalities, or fundus pathology were notified of the findings by mail. The parents were instructed to telephone the author so that the significance of the abnormalities could be explained and an eye health care plan established.

ETHICAL AND FINANCIAL CONSIDERATIONS

Conferences were held with the preschool leaders of the target centers after permission to conduct the study was obtained from the Research Committee of the Hospital and from the Cooperative Play Program of D.C. Department of Recreation. The leaders were informed of the nature of the project by Prevention of Blindness Society representatives. Virtually all the preschool leaders were enthusiastically helpful in the organization and operation of the screening sessions and medical eye examinations.

Resistance to the project was encountered from a few parents who misunderstood or were suspicious of the reasons for the study. There was a distinct feeling on the part of a few parents that their children were being subjected to abusive or potentially dangerous procedures. These suspicions were largely dispelled by five community meetings held in different regions of the city attended by the author, representatives from Prevention of Blindness of Metropolitan Washington, preschool leaders, and concerned parents. At these evening meetings the protocol was explained in considerable detail and parental questions were fully answered. The sessions were generally fruitful in assuaging the anxieties of the parents — although not all parents were persuaded to permit their

children to be medically examined, and one preschool center refused to participate.

A three-page cover letter was devised in order to present the project to the parents in the clearest and most comprehensive manner possible. The letter explained the rationale and procedural aspects in nontechnical language. It listed the more common adverse reactions to the eye drops used in the medical eye examinations.

Each prospective family was given an informed consent and a written questionnaire in addition to the cover letter. Children could not receive the medical eye examination without a signed informed consent. However, signed consents were not required or requested for children scheduled to receive only screening tests.

The families of all participating children were informed by mail of the eye findings. The information was conveyed in simple English. When abnormalities were discovered in the medical eye examination, parents were instructed to telephone the author for a detailed explanation of the findings and for advice regarding management. This would include a prescription for glasses when indicated.

The area of greatest concern to many parents was the anticipated discomfort and possible adverse reactions associated with the eye drops. Some parents expressed a strong desire to be with their children during the medical eye examination. This was always permitted but was mildly discouraged because of space limitations. Experience indicated that the presence of parents made no significant difference in terms of the cooperation of their children.

In order to avoid the possibility of economic gain from the project, the author informed parents that their children could not become his private patients after the medical eye examination. The Prevention of Blindness Society of Metropolitan Washington elected not to accept any parental reimbursement for screening services included in the study.

The project was funded by two grants from The Children's Eye Care Foundation and from Children's Hospital sources derived from the private practice income of the author. The screening personnel from the Prevention of Blindness Society were paid on an hours worked basis. The same arrangement applied to the nonprofessional assistant involved in the medical eye examinations. The orthoptist, van driver, and author received no additional in-

come for their participation. Statistical services were obtained on a contractual basis.

DATA PROCESSING

Information contained on the raw data sheets, was transferred by the author onto IBM FORTRAN Coding Forms. A total of 85 variables utilizing 147 columns were needed for each subject included. A programmer prepared 633 computer cards from the FORTRAN Coding Forms. These cards constituted the input data for a UNIVAC 1108 Computer located at the University of Maryland. Dr. William Schafer obtained the computer programs from "Statistical Package for the Social Sciences Manual"[153] and conducted the analyses required. Fifty-seven pages of computer printout were obtained. Only a small portion of this voluminous material has been incorporated in this report.

FINDINGS

Children Screened and Medically Examined

Forty-seven preschool centers of the D.C. Department of Recreation and one private preschool were visited by the screening teams. Children from 35 of these preschool centers were scheduled for medical examination. Three centers had so few participating pupils that it was more convenient to examine them medically at other centers, and one center declined to enter the study. Five children were not present for the medical eye examination at the scheduled time and were later transported to other preschool centers for this examination. A total of 633 children comprising 442 (70%) blacks, 184 (29%) whites, and seven (1%) orientals were included in the study. Of these, 225 (36%) received only the screening tests and 408 (64%) received both the screening tests and medical examination.

Screening sessions and medical examinations were for the most part performed in one administrative area at a time. This approach simplified dissemination of procedural information and collection of consent forms and questionnaires. It also made scheduling easier.

Factors such as vacations, competing duties, and obligations of members of the screening and medical teams affected personnel availability. Schedules were nevertheless composed several weeks in advance. Whenever projections indicated insufficient time to

examine medically all the preschool children within a given area without delaying the screening teams, particular centers within the area were selected for screening tests only. Such decisions were made on a random basis by the program coordinator well before screening sessions were started.

Thirty children in the Abingdon Montessori School were screened only and 36 children received both screening and medical eye examinations. Assignments were made largely on the basis of parental desires and consent. Some of the parents of this upper-middle-class school already had their children under professional eye care and for that reason declined the medical eye examination.

Absenteeism was a significant problem in the conduct of this study. Sixty-four children were absent at the time of the first screening session and 68 were absent from the second screening session. Fifty-nine children were absent from both screening sessions. None of these children, of course, could be included in the study. Twenty-five children who had attended both screening sessions and for whom permission had been obtained for the medical eye examination failed to attend the medical eye examination. These children were included in the study and were added to the other children who had completed both screening sessions but

TABLE III. EXTERNAL EYE DISORDERS FOUND IN THE CHILDREN RECEIVING MEDICAL EXAMINATIONS

Subject Number	Type of Abnormality	Noted in Screening Sessions	Noted in Medical Examination
222	Eyelid Nevus		X
223	Eyelid Edema	X	
228	Eyelid Melanocytosis		X
287	Oculocutaneous Albinism	X	X
307	Anisocoria		X
311	Conjunctivitis		X
348	Blepharoptosis		X
350	Eyelid Edema	X	X
364	Eyebrow Scar		X
376	Unilateral Corneal Enlargement	X	X
422	Eyelid Scar		X
425	Blepharitis	X	X
436	Sector Iris Nevus		X
446	Corneal Opacity		X
458	Blepharitis		X
469	Blepharoptosis		X
483	Conjunctival Surgical Scars		X
494	Anisocoria		X
601	Epiphora		X

TABLE IV. PHORIAS AND TROPIAS ACCORDING TO FIXATION DISTANCE FOUND IN THE CHILDREN RECEIVING MEDICAL EXAMINATIONS

Subject Number	Type of Abnormality	Noted in Screening Sessions	Noted in Medical Examinations
267	Brown's Syndrome		X
535	Esophoria at Near		X
240	Esotropia at Near	X	X
189	Esotropia at Distance and Near	X	X
287	Esotropia at Distance and Near	X	X
480	Esotropia at Distance and Near	X	X
482	Esotropia at Distance and Near	X	X
604	Esotropia at Distance and Near	X	
613	Esotropia at Distance and Near	X	X
190	Exophoria at Near		X
251	Exophoria at Near		X
265	Exophoria at Near		X
269	Exophoria at Near		X
285	Exophoria at Near	X	X
305	Exophoria at Near	X	X
351	Exophoria at Near		X
352	Exophoria at Near		X
436	Exophoria at Near		X
442	Exophoria at Near		X
544	Exophoria at Near		X
582	Exophoria at Near	X	
619	Exophoria at Near		X
624	Exophoria at Near		X
429	Exophoria at Distance and Near		X
376	Exotropia at Distance	X	X

were not scheduled to receive the medical eye examination (161 children) or who did not qualify for the examination because of parental failure or unwillingness to sign the consent form (39 children).

EXTERNAL DISORDERS

Table III lists the external defects that were noted in the 408 children who received both the screening tests and the medical examination. Although the emphasis of the study was on visual acuity testing, it is interesting to observe that several (mostly minor) abnormalities were not described by the screening teams.

Ocular Alignment and Motility Disorders

Table IV lists the alignment disorders that were found in the 408

TABLE V. FUNDUS ABNORMALITIES FOUND IN THE CHILDREN RECEIVING MEDICAL EXAMINATIONS

Subject Number	Type of Abnormality
287	Albinotic fundi, absent foveal reflexes
376	Asymmetric disc cupping
426	Myopic type fundus changes OD
442	Bilateral pigment epithelium irregularity
530	Localized pigment epithelium hypertrophy OS

children who received both the screening tests and medical examination. Seven children were found to have esotropia by the screening teams. Six of these seven cases were identified by the author. There was disagreement on only one child. The single child with exotropia was noted by both screening personnel and the author. There was substantial disagreement with respect to children with phorias. However, most of these deviations were small exophorias at near; all but one were 10 prism diopters or less.

Only one child was found to have nystagmus. This was Subject 287 who had oculocutaneous albinism.

Fundus Disorders

The fundus abnormalities found during the medical examinations are listed in Table V. Subject 287 had the typical ocular features of oculocutaneous albinism including prominent choroidal patterns and absent foveal reflexes. Subject 376 had suspected unilateral glaucoma with ipsilateral corneal enlargement and increased cup/disc ratio. Children with symmetric, moderate myopia and compatible fundus findings were not included in the table, but Subject 426 was included because of the unilateral nature of the defect. Subject 442 had an obscure type of pigment epithelial irregularity affecting both eyes with normal central acuity. An extramacular, sharply circumscribed area of pigment epithelial hypertrophy was found in Subject 530.

Questionnaire Results

Thirty-two children were thought to have an eye problem by their parents. Of these, 15 were found to have an abnormality and 17 were found to be normal at the medical examination. The defects noted are listed in Table VI. Refractive errors included in the table exceed the criteria for failure due to refractive error.

Thirty-three children were found at the medical examination to have a cycloplegic refractive error in minus cylinder in one or both

TABLE VI. CHILDREN THOUGHT BY THEIR PARENTS TO HAVE EYE ABNORMALITIES AND SUBSEQUENTLY FOUND TO HAVE EYE ABNORMLAITIES AT THE MEDICAL EXAMINATION

Subject Number	Abnormality Found at Medical Examination
190	Exophoria at Near
215	Myopic Refractive Error
222	Eyelid Nevus
228	Eyelid Melanocytosis and Astigmatic Refractive Error
267	Brown's Syndrome and Myopic Refractive Error
279	Astigmatic Refractive Error
287	Oculocutaneous Albinism, Nystagmus, Esotropia, Astigmatic Refractive Error and Absent Foveal Reflexes
294	Astigmatic Refractive Error
307	Anisocoria
350	Eyelid Edema and Myopic Refractive Error
376	Unilateral Corneal Enlargement, Asymmetric Cupping, Suspected Unilateral Glaucoma, and Exotropia
480	Esotropia
482	Esotropia and Myopic Refractive Error
551	Myopic Refractive Error
613	Esotropia and Myopic Refractive Error

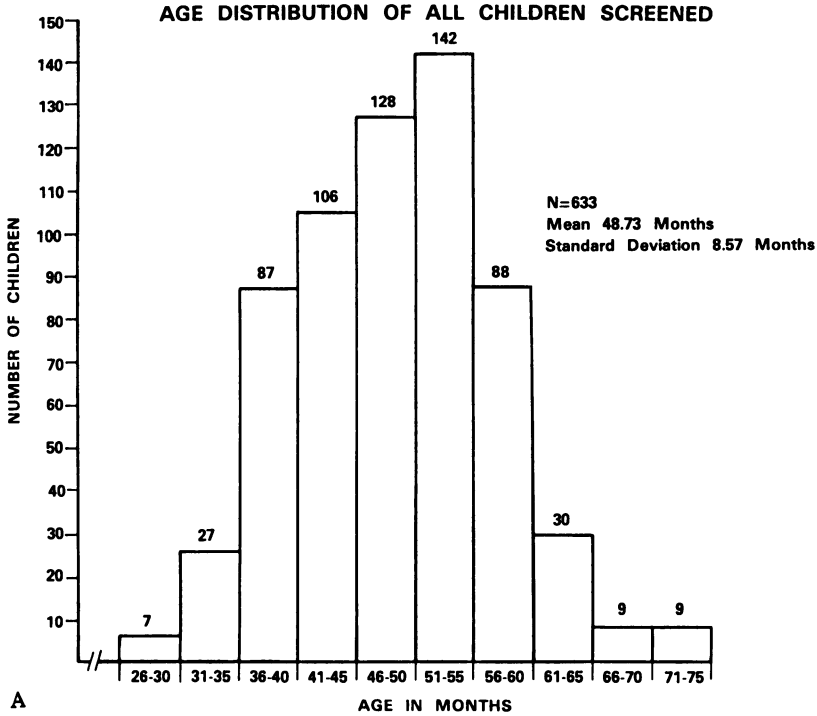
eyes, exceeding −1.75 sphere and/or −1.50 cylinder. Of these children only eight were thought to have an eye problem by their parents and one-half of these (four children) had strabismus as well as a refractive error.

Of the eight children found to have strabismus at the medical examination, five were receiving professional eye care at the time of the medical examination and the parents of a sixth child were aware of the defect. Thus in six of the eight children with strabismus the parents were aware of a defect. This is in marked contrast to the much smaller ratio of children with refractive errors thought to have an abnormality by their parents, as previously stated.

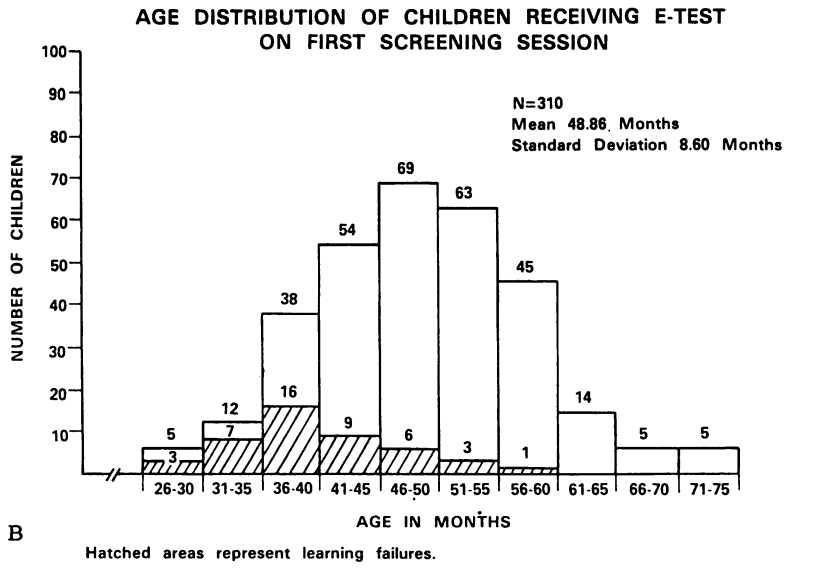
Five children were wearing glasses when medically examined. Three of these children had strabismus: two had single vision lenses for correction of myopic and compound myopic refractive errors, and one had bifocals for a high AC/A ratio. The other two children had astigmatic refractive errors.

TESTABILITY

The age distribution of all children screened is shown in Figure 11A. The negative skewness of the histogram is probably explainable on the basis of the effect of school matriculation which produces a steeper incline for the older children than does the admission minimal age requirement of two and one-half years for the younger children. The age distribution of children who received the E-Test and Letter-Matching-Test on the first screening session is shown in Figures 11B and 12A. The similarity of the populations



A

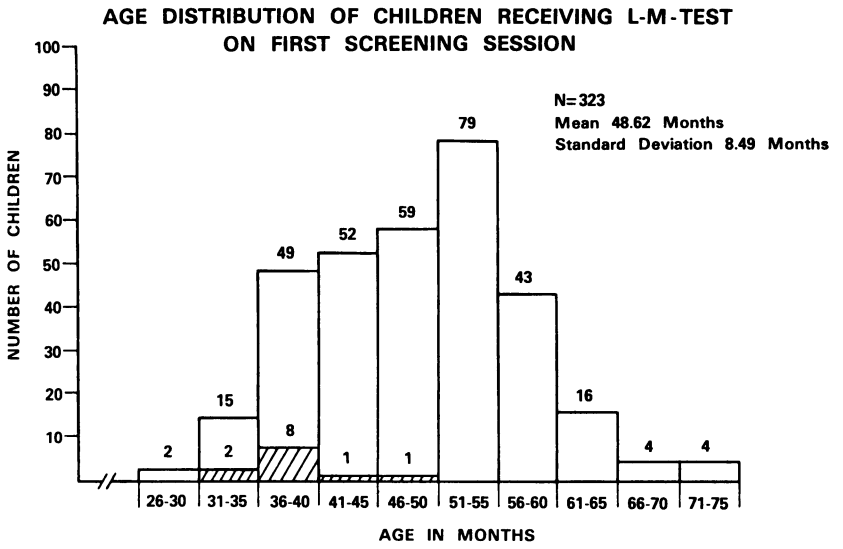


B

Hatched areas represent learning failures.

FIGURE 11

A: Histogram showing the number of children in each age group screened. B: Histogram showing the number of children in each age group receiving the E-Test on the first screening session.



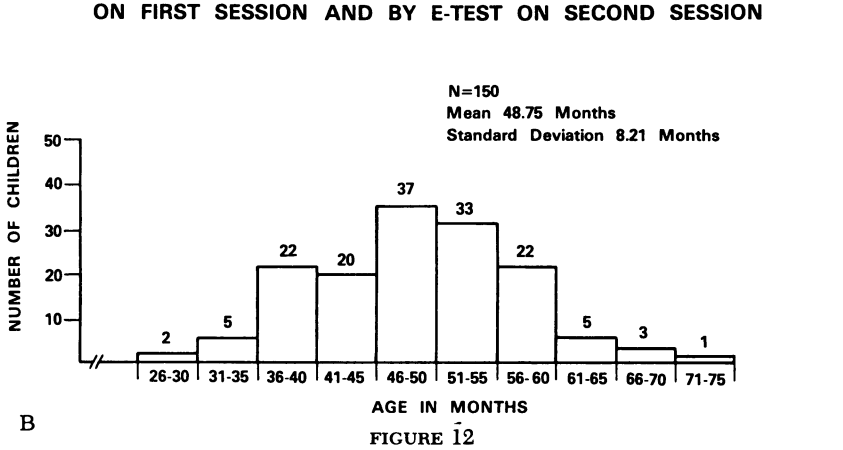


FIGURE 12

A: Histogram showing the number children in each age group receiving the L-M-Test on the first screening session. B: Histogram showing the number of children in each age group receiving the E-Test on the first screening session and the E-Test on the second screening session.

in terms of subject numbers, means, and standard deviations is evident. These parameters remain relatively constant in the four subgroups in Figures 12B, 13A, B, and C.

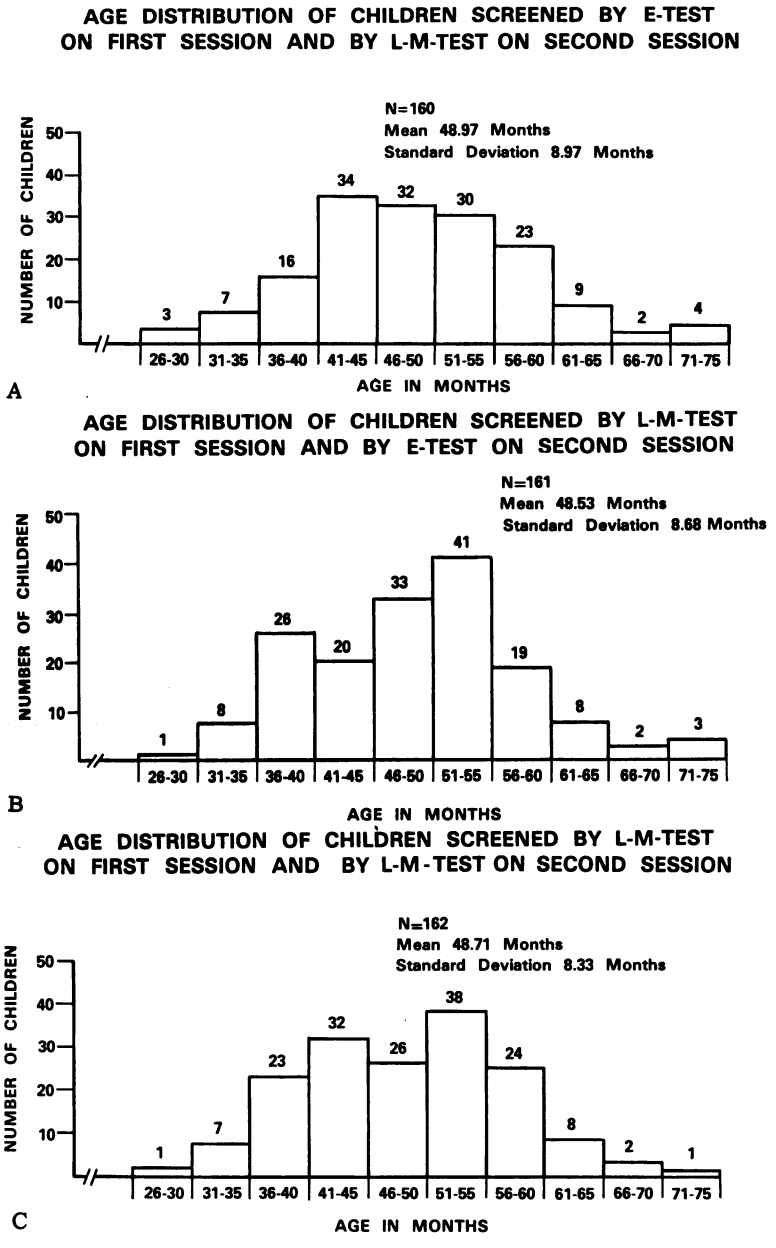


FIGURE 13

A: Histogram showing the number of children in each age group receiving the E-Test on the first screening session and the L-M-Test on the second screening session. B: Histogram showing the number of children in each age group receiving the L-M-Test on the first screening session and the E-Test on the second screening session. C: Histogram showing the number of children in each age group receiving the L-M-Test on the first screening session and the L-M-Test on the second screening session.

Testability was defined as learning failure, i.e., inability to reach criterion within the two-minute time period allotted. The numbers of children in each age group who were untestable at the time of the first screening session are represented by the hatched areas in Figures 11B and 12A. The same information is presented in percentage form in Table VII. The relationship between testability and age is clearly evident for the E-Test but the sparsity of learning failures with the Letter-Matching-Test permits no definite conclusion regarding an age dependent relationship, although the data suggest such a relationship.

The chi-square value with correction for discontinuity for the ratios of testable children on the first screening session by the E-Test (265/310=85.5%) and by the Letter-Matching-Test (311/323=96.3%) is 21.22, indicating that the differences between the ratios is significant ($P < .001$). In other words, the Letter-Matching-Test was learned by a significantly higher proportion of children than the E-Test on the first screening session.

The chi-square value with correction for discontinuity was also computed for the chidren below 48 months of age at the time of the first screening session. This analysis was performed because of the fact that approximately 20% of the older children but very few of the subjects below 48 months of age had been exposed during the previous year to the E-Test but not exposed to the Letter-Matching-Test. The ratios for testability were: E-Test 106/143 = 74.1% and Letter-Matching-Test 137/149 = 91.9%. Chi-square = 15.34, indicating that the difference between the ratios is also significant ($P < .05$) for the younger children.

TABLE VII. THE NUMBER OF CHILDREN IN EACH AGE GROUP RECEIVING THE E-TEST OR L-M-TEST AT THE FIRST SCREENING SESSION TOGETHER WITH THE NUMBER AND PERCENT OF CHILDREN IN EACH AGE GROUP FOUND TO BE UNTESTABLE ACCORDING TO TEST ADMINISTERED

Age Group In Months	Number of Subjects		Number of Subjects Untestable		Percent Untestable	
	E-Test	L-M-Test	E-Test	L-M-Test	E-Test	L-M-Test
26-30	5	2	3	0	60	0
31-35	12	15	7	2	58	13
36-40	38	49	16	8	42	16
41-45	54	52	9	1	17	2
46-50	69	59	6	1	9	2
51-55	63	79	3	0	5	0
56-60	44	43	1	0	2	0
61-65	14	16	0	0	0	0
66-70	5	4	0	0	0	0
71-75	5	4	0	0	0	0

TABLE VIII. NUMBER OF GROUPS, MEAN AND STANDARD DEVIATION OF GROUP INSTRUCTION TIME IN MINUTES AT THE FIRST SCREENING SESSION ACCORDING TO TEST ADMINISTERED

	Number of Groups	Mean	Standard Deviation
E-Test	49	12.49	2.16
L-M-Test	49	10.57	1.44
With 48 Degrees of Freedom t=40.09			

A statement of the time in minutes required to teach the children within each of the two separate instructional groups at the first screening session is presented in Table VIII. The difference between means is significant at the .05 level of probability by the related-samples t-test. It can therefore be stated that the Letter-Matching-Test was learned in the group instructional sessions significantly more rapidly than the E-Test.

The time in seconds required to instruct individual children at the first screening session immediately prior to acuity testing is shown in Table IX. In order to permit computation, children with scores over 120 seconds were excluded from calculations of means and standard deviations. These children comprised the learning failures. The difference between means is again significant at the .05 level of probability by the two-sample t-test for all children and for children less than 48 months of age. This indicates that individual instruction also was significantly shorter with the Letter-Matching-Test than with the E-Test.

The time in seconds required to perform acuity tests on both eyes of individual subjects at the first screening session is shown in

TABLE IX. NUMBER OF CHILDREN, MEAN AND STANDARD DEVIATION OF INDIVIDUAL INSTRUCTION TIME IN SECONDS AT THE FIRST SCREENING SESSION ACCORDING TO TEST ADMINISTERED AND AGE

All Subjects			
	Number of Subjects	Mean	Standard Deviation
E-Test	265	20.65	21.28
L-M-Test	311	14.91	10.39
With 574 Degrees of Freedom t=4.20			
Subjects Less Than 48 Months of Age			
	Number of Subjects	Mean	Standard Deviation
E-Test	106	30.79	26.32
L-M-Test	137	17.55	14.08
With 241 Degrees of Freedom t =5.03			

TABLE X. NUMBER OF CHILDREN, MEAN AND STANDARD DEVIATION OF TESTING TIME IN SECONDS AT THE FIRST SCREENING SESSION ACCORDING TO TEST ADMINISTERED AND AGE

All Subjects			
	Number of Subjects	Mean	Standard Deviation
E-Test	245	93.85	46.62
L-M-Test	290	75.51	41.91
With 533 Degrees of Freedom t=4.79			
Subjects Less Than 48 Months of Age			
	Number of Subjects	Mean	Standard Deviation
E-Test	93	104.92	43.62
L-M-Test	121	84.21	43.77
With 212 Degrees of Freedom t=3.44			

Table X. Testing times that exceeded the allotted 120 seconds for each eye were not included in the calculation of the mean or standard deviation. Once again the Letter-Matching-Test was significantly faster (at the .05 level of probability) as determined by the difference between means by the two-sample t-test for all children and for children less than 48 months of age.

To address the question of consistency of testability determinations between the first and second screening sessions the four separate subgroups (E-E, E-L, L-E, and L-L) were compared (Table XI). The phi coefficients shown are simply the familiar Pearson product-moment correlation rho for two-by-two tables with dichotomous categories. Possible values of phi therefore range from -1.00 to $+1.00$. The value zero would indicate a total lack of correlation, whereas -1.00 would indicate a perfect negative corre-

TABLE XI. TESTABILITY COMPARISONS IN TERMS OF PHI COEFFICIENTS OF CHILDREN AT THE FIRST AND SECOND SCREENING SESSIONS ACCORDING TO TEST ADMINISTERED

GROUP E-E			GROUP E-L			GROUP L-E			GROUP L-L		
	Screen 1			Screen 1			Screen 1			Screen 1	
	Yes	No		Yes	No		Yes	No		Yes	No
Screen 2 Yes	130	13	Screen 2 Yes	134	19	Screen 2 Yes	143	1	Screen 2 Yes	156	1
Screen 2 No	1	6	Screen 2 No	0	7	Screen 2 No	12	5	Screen 2 No	0	5
Φ=.486			Φ=.496			Φ=.466			Φ=.910		

lation and +1.00 would indicate a perfect positive correlation. The formula for ϕ is:

$$\frac{ab-bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

where a,b,c, and d apply to the values indicated in Table XII.

The comparative testability data of Table XI permit several interesting observations. In group E-E, 13 children were untestable in the first screening session and testable in the second screening session, whereas only one child was untestable on the second screening session and testable on the first screening session. Six children were untestable at both sessions. This demonstrates a learning tendency whereby many children who could not perform the test on the first attempt could do so on the second attempt.

Consideration of the testability data for groups E-L and L-E clearly indicates the higher testability with the Letter-Matching-Test compared to the E-Test regardless of the order of presentation.

Although there are two few subjects for a statement of significance, the children comprising group L-L appeared to show the greatest consistency in testability. Five children in this group were untestable on both occasions and only one was untestable on one session (the first) and not on the other (the second).

The conclusions from the above analysis of testability considerations are that under the experimental conditions imposed, the Letter-Matching-Test was significantly superior to the E-Test in terms of proportions testable, group and individual instruction time, individual acuity testing time, and possibly also superior in testability consistency.

Reliability

Reliability is defined as consistency. It is a measure of the ability to obtain the same numerical value or score on different occasions.

TABLE XII. DESIGNATION OF CELLS IN A TWO-BY-TWO CONTINGENCY TABLE

		SCREEN 1	
		Yes	No
Screen 2	Yes	a	b
	No	c	d

TABLE XIII. NUMBER OF RIGHT AND LEFT EYES AND CORRELATION COEFFICIENTS (RHO) OF ACUITY SCORES WITH STANDARD SCORE TRANSFORMATION FOR THE E-E AND L-L GROUPS FOR ALL CHILDREN AND FOR CHILDREN LESS THAN 48 MONTHS OF AGE

	All Subjects				
	E-E Group		L-L Group		Standard Score by
	N	rho	N	rho	rho to z Transformation
Right Eye	125	.627	145	.160	4.66
Left Eye	124	.670	146	.111	5.67
	Subjects Less Than 48 Months of Age				
	E-E Group		L-L Group		Standard Score by
	N	rho	N	rho	rho to z Transformation
Right Eye	47	.515	60	.120	2.23
Left Eye	48	.673	60	.004	4.07

The precise visual acuity actually obtained for each eye at the two different screening sessions could be used to estimate reliability or, in a coarser way, one could simply utilize the pass-fail criterion employed in the study which was 10/15 or better representing a pass and 10/20 or worse representing a failure. The former would be expected to provide a more meaningful appraisal since it makes use of more information than does the simple dichotomy.

Table XIII presents the reliability data from groups E-E and L-L, treating the acuity values obtained as a continuous variable. The entire population studied and children under 48 months of age are presented separately. Scores less than 10/100 were not considered in this computation. Nontestable children were also excluded. The differences between the rho coefficients for the two tests for both right and left eyes of all children and of younger children are significant at the .05 level of probability by the z-test based on Fisher's rho to Z transformation. All z (standard score) test results greater than 1.96 are significant at the .05 level of probability.

These results clearly demonstrate the superiority of the E-Test in terms of reliability under the test conditions employed.

Validity

For reasons previously enumerated, a standard of 10/15 or better was utilized in this study as normal acuity regardless of age. Children with 10/10 acuity in one eye and 10/15 acuity in the other or with 10/10 or 10/15 in both eyes were considered to have passed the acuity test.

Criterion validity is defined as the ability of a test to measure a variable according to a standard. The rationale for the standards

used in the study is explained in the following section. It is sufficient to state at this point that two sets of refraction criteria were utilized as standards. Children with cycloplegic errors greater than Peters's modified criteria for 10/15 acuity were classified as failures. They were subdivided into two groups. First were those children who had cycloplegic refractive errors in minus cylinders exceeding −1.75 sphere and/or −1.50 cylinder in any meridian and second were those children who had intermediate refractive errors, i.e., whose errors exceeded Peters's modified criteria but not the −1.75 sphere and/or −1.50 cylinder standard. The first subgroup consisting of 33 children is referred to as F2 and the second consisting of 32 children as F1. Three children in the F1 subgroup were learning failures on the first screening session. It was found that only one patient with reduced acuity due to an observable cause would have been overlooked if only refractive criteria had been utilized. This single exception was Subject 480 who had insignificant refractive errors in both eyes and esotropia. Visual acuity was found to be 10/15 in the right eye and 10/20 in the left eye at the medical examination; slight amblyopia could not be ruled out. All other strabismic and anisometropic patients, as well as those with

TABLE XIV. POINT-BISERIAL CORRELATION COEFFICIENTS (ETA) OF E-TEST AND L-M-TEST RESULTS AT THE FIRST SCREENING SESSION WITH REFRACTION STATUS FOR ALL CHILDREN AND FOR CHILDREN LESS THAN 48 MONTHS OF AGE

All Subjects Receiving E-Test on First Screen

REFRACTION	Pass	Fail
Pass	134	11
Fail 1	6	7
Fail 2	2	18

eta=.685

All Subjects Receiving L-M-Test on First Screen

REFRACTION	Pass	Fail
Pass	153	18
Fail 1	10	6
Fail 2	6	7

eta=.343

Subjects Below 48 Months Receiving E-Test on First Screen

REFRACTION	Pass	Fail
Pass	44	7
Fail 1	3	5
Fail 2	1	10

eta=.641

Subjects Below 48 Months Receiving L-M-Test on First Screen

REFRACTION	Pass	Fail
Pass	58	16
Fail 1	3	3
Fail 2	2	1

eta=.134

TABLE XV. TOTAL NUMBER OF CHILDREN AND STANDARD SCORE TRANSFORMATION OF THE ETA COEFFICIENTS FOR THE FOUR TWO-BY-THREE TABLES SHOWN IN TABLE XIV

All Subjects First Screen Pass-Fail Correlated with Refraction Pass-Fail				
E-Test		L-M-Test		Standard Score by
N	eta	N	eta	eta to z Transformation
178	.685	200	.343	4.63

Subjects Less Than 48 Months of Age First Screen Pass-Fail Correlated With Refraction Pass-Fail				
E-Test		L-M-Test		Standard Score by
N	eta	N	eta	eta to z Transformation
70	.641	83	.134	3.77

nystagmus and fundus abnormalities that failed visual acuity testing, would have been classified as failures on the basis of refractive criteria alone.

The validity data from the first screen are shown in Table XIV. The eta coefficients are point-biserial correlations which in the present case measure the association between passing or failing the acuity test and the refraction, scored zero for pass, one for fail 1, and two for fail 2. Point-biserial correlation coefficients are Pearson product-moment correlation coefficients applied to data which are such that one of the two variables is dichotomous (pass-fail acuity test) and the other is continuous (refraction score). The data are

TABLE XVI. SENSITIVITY, SPECIFICITY, OVERREFERRAL AND UNDERREFERRAL RATES OF CHILDREN SCREENED AND MEDICALLY EXAMINED. BASED ON ACUITY TEST RESULTS AT THE FIRST SCREENING SESSION AND THE REFRACTIVE ERRORS FOUND

All Subjects		
	Receiving E-Test on First Screen	Receiving L-M-Test on First Screen
Sensitivity	25/33 (76%)	13/29 (45%)
Specificity	134/145 (92%)	153/171 (89%)
Overreferral Rate	11/36 (31%)	18/31 (58%)
Underreferral Rate	8/142 (5.6%)	16/169 (9.5%)

Subjects Less Than 48 Months of Age		
	Receiving E-Test on First Screen	Receiving L-M-Test on First Screen
Sensitivity	15/19 (79%)	4/9 (44%)
Specificity	44/51 (86%)	58/74 (78%)
Overreferral Rate	7/22 (32%)	16/20 (80%)
Underreferral Rate	4/48 (8.3%)	5/63 (7.9%)

organized according to test performed and age group. Children who exceeded the refractive standards with one or both eyes were considered failures. The differences between the eta coefficients for the two acuity tests of children in similar age groups are significant at the .05 level of probability (Table XV).

Sensitivity, specificity, overreferral and underreferral rates are given in Table XVI. Of interest is the effect of the second screen on the numbers of under- and overreferrals. Children in groups E-E and L-L were considered. A total of nine children in group E-E should have failed both screening sessions according to refractive criteria F2. Of these, none passed the first screening session, but two passed the second screening session. Hence the second screening session increased the number underreferred by two. A total of six children in group L-L should have failed both screening sessions according to the refraction criteria F2. Of these, four passed the first screening session and five passed the second screening session. The second screening session increased the number underreferred by one.

A total of eight children in group E-E were overreferred from either or both screening sessions in the sense that they had insignificant refractive errors (less than F1 errors). Of these, two failed both screening sessions, three passed the first and failed the second, and three failed the first and passed the second. The second session had no net effect on the number of overreferrals. A total of 10 children in group L-L were overreferred from either or both screening sessions in that they had refractive errors less than F1. Of these, four failed both screening sessions, none passed the first and failed the second, and six failed the first and passed the second. The second screening session reduced the number of overreferrals by six.

The usual effect of a second screening session is suggested by this study; to wit, the number of underreferrals was increased and the number of overreferrals, with a single exception, was decreased.

DISCUSSION

Because of absenteeism, the unwillingness of some parents to have their children medically examined, and the racial and socioeconomic characteristics of the study group, no generalizations to a larger urban preschool population can be made without severe reservations. Thus, prevalence rates for external and internal eye defects, strabismus, refractive errors, etc. would have little or no

meaning and will not be given. The children in this study were largely black (70%) and were drawn from a wide area of Washington, D.C.

Screening personnel of the Prevention of Blindness Society of Metropolitan Washington are primarily taught to detect defects that might contribute to decreased vision. This fact helps to explain the excellent performance observed in detecting strabismus but the relatively poor detection rate for minor external defects and phorias.

Parental observations regarding eye abnormalities are notoriously inaccurate. Nevertheless, six of the eight children found to have strabismus were in fact thought to have an eye abnormality by their parents; indeed, five of the eight were already receiving professional eye care. This high proportion of suspected cases to total cases of strabismus is in marked contrast to the low rate of parental awareness of vision defects due to refractive errors. Thus, of the 33 children with refractive errors exceeding −1.75 sphere and/or −1.50 cylinder in one or both eyes, only eight were thought to have an eye problem by their parents and four of these children had strabismus. Three children were found to have anisometropia equal to or greater than 1.50 diopters of spherical equivalent difference between their two eyes. Only one of these children (#604) passed the cycloplegic refraction. This child had a +1.00 error in the right eye and a +3.00 error in the left eye. Both screening tests and also the acuity assessment in the medical examination were passed. The other two children, Subjects 376 and 426, failed the refraction. Subject 376 failed all three visual acuity tests while Subject 426 passed two of the three visual acuity assessments (see below). Of these three children, only Subject 376 was thought to have an eye problem by a parent. The "quiet" nature of refractive errors is, of course, widely known and constitutes an important reason for conducting preschool vision screening. Young children with very large refractive errors commonly assume that their status is normal, even when both eyes are affected.

The data from this study clearly show that the type of Letter-Matching-Test used was superior to the type of E-Test used from the standpoint of testability. Not only were there fewer learning failures with the Letter-Matching-Test, but the group and individual instruction times, as well as performance times, were significantly shorter with the Letter-Matching-Test. Testability was consistently higher for the Letter-Matching-Test. The children receiv-

ing the E-Test on two consecutive occasions showed a learning effect whereas this was not observed with the Letter-Matching-Test.

The above observations were rather strikingly demonstrated in this study, but similar observations have been made by other investigators.[96,113,121] It is this evident superiority in ease of learning and ease of performance that has contributed to the popularity of this test. What has been lacking in some previous reports is data concerning reliability and validity. Without this additional information, the improved testability scores by themselves mean little.

To explore the hypothesis that the Letter-Matching-Test and E-Test scores were actually equivalent, the acuity scores of children who received both tests in the two screening sessions (the combined E-L and L-E groups) were compared. All of the children included in this analysis achieved a score on both visual acuity tests. Sandler's A-statistic[155] was employed. The probability values obtained from Sandler's A-statistic are identical with Student's *P*-values. The calculations, however, are simpler with the former. Differences between the two test scores obtained with right eyes were computed. The procedure was then repeated for scores with left eyes. Visual acuity was recorded in decimal form, ranging from 1/10 = .10 to 10/10 = 1.00. The mean difference for the 482 eyes was .0895 or 8.95% higher for the Letter-Matching-Test. This represents a difference of less than one line on conventional visual acuity charts. The

$$\text{A-statistic} = \frac{\sum D^2}{(\sum D)^2} = \frac{24.8}{1860} = .0133$$

which with 481 degrees of freedom is highly significant. This means that under the conditions of the study, the Letter-Matching-Test scores were definitely higher than the E-Test scores on the same eyes of children who received both tests. This does not necessarily mean that the tests made fundamentally unequal visual demands, because the higher scores with Letter-Matching could just as likely result from dissimilar response factors. The matching response required may be fundamentally different from the pointing response required in terms of inherent interest, avoidance of directionality problems, physical demands, speed of performance, degree to which a decision is forced, etc. The data from the study do not provide the reason for the difference in acuity scores but the difference is clear. Similar findings have been reported by others.[113,121]

TABLE XVII. INTERPRETATION OF 10/25 LINE (FOURTH LINE FROM TOP IN PHOTOGRAPH 1 AND PHOTOGRAPH 2 OF FIGURE 22) BY FIVE PREPRESBYOPIC ADULTS

	Photograph 1				Photograph 2			
	E-Test		L-M-Test		E-Test		L-M-Test	
Subject	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect
1	6	0	5	1	6	0	3	3
2	6	0	5	1	6	0	5	1
3	6	0	3	3	6	0	2	4
4	6	0	5	1	5	1	3	3
5	6	0	5	1	6	0	3	3
Totals	30	0	23	7	29	1	16	14

To shed further light on recognition vs. response differences between the two tests, an additional experiment was performed. Two arbitrarily blurred photographs were obtained by defocusing a 35mm camera directed at a point midway between evenly illuminated side-by-side charts. The photographs were mounted one meter from the preferred eye of five prepresbyopic adult volunteer subjects. Corrective lenses were worn when indicated and uniform illumination was provided by bright overhead incandescent lamps. All determinations were made under the same testing conditions. Scoring was performed by the author for all five subjects. Testing was conducted on the 10/25 line of both photographs; hits and misses were recorded and tabulated.

The results (Table XVII) show a difference in difficulty between the two tests under these admittedly arbitrary and artificial testing conditions. More errors were made on the Letter-Matching-Test than on the E-Test on both photographs by all subjects. It is possible that under different circumstances (including the presence of uncorrected astigmatism and tests which avoid oblique astigmatism) differently directed discrepancies between the two charts might be demonstrable.

Greater resolving power of the adult human visual system in the horizontal and vertical directions than in the two oblique directions has been demonstrated. Anatomic,[156] psychophysical,[157,158] neurophysical[159] and electrophysical[160] evidence point toward a cortical seat for this phenomenon. It is not clear, however, from the literature whether or not children below six years of age share this directional sensitivity.[161]

If the visual system of the children in the study population did in fact possess such differential sensitivities, the E symbols would be expected to be more easily recognized by them than the letters O and V. Orientation threshold differences may have played a role in the higher scores obtained by adults with the E-Test objects than with the letter-test objects in the photographic experiment cited above, although other factors may also have contributed to the differences found.

The observation that differential sensitivities are present in adults but possibly not in preschool children means that the greater ease in recognizing E symbols than letters by adults cannot necessarily be expected to apply to the young subjects in the study.

The combined results of this experiment and the preceding comparative analysis nevertheless suggest that the higher scores ob-

tained with the Letter-Matching-Test may be due to differences in the response techniques used rather than to differences in recognition demands. The reader will recall that the possibility of such a finding was foreseen during the planning phases of the study. It was nevertheless considered advisable to perform both tests as they are actually conducted in the field.

The reliability correlation coefficients were rather low even for the E-Test. A rho of at least .80 is desired in screening tests.[162] The correlation coefficients for the Letter-Matching-Test were extremely poor. The data suggest that the E-Test is not a particularly "good" test for the population studied but that it is a better test in terms of reliability than the Letter-Matching-Test.

The superiority of the E-Test in terms of reliability both for the study population as a whole and for the younger children calls for an explanation. Regretfully, only hypotheses can be offered.

One possibility is that the testability differences resulted in reliability differences. By this is meant that the E-Test, being inherently more difficult to learn and to perform, requires greater skills including perhaps some of the same types of abilities that result in improved reliability or validity. The inherently easier to learn and to perform Letter-Matching-Test admits to a greater extent children who lack these abilities. What might these skills be? Perhaps such attributes as interest, concentration, motivation, and intelligence — in other words, variables that affect the duration and quality of attention to the task.

Another possibility centers on the past experience and prejudices of the testers. The Letter-Matching-Test was new to the screening personnel; the E-Test was familiar. If lack of familiarity with the Letter-Matching-Test was the cause of the reliability differences, then one would also expect testing with the more recently introduced technique to require more time and result in more learning failures. In actuality, the opposite was observed. Possible bias on the part of the testers was minimized by meticulous attention to testing procedures. It does not seem likely that individual preconceptions could have caused the differences noted.

The tendency of some children to persevere in a particular rotary direction on the response panel during the matching process was noted on rare occasions by the testers and by the author at the medical examination. The design of the HOTV test chart used is such that this type of patterning of responses is encouraged on the 10/15 and 10/10 lines. This tendency is accentuated by presenting

the left-hand optotypes. It was for this reason that testing was performed using the right-hand optotypes. This technique effectively prevented a child from passing the test based on consecutive clockwise rotational type responses. To further discourage this type of sequencing, the panel was physically withdrawn from the child after each response was obtained. Despite these two precautions, the rotational type of matching responses given by some children might have contributed to the reliability and validity differences between the two tests.

It should be noted that visual acuity scores were actually somewhat higher for the Letter-Matching-Test than for the E-Test when eyes screened by both tests were compared. This suggests that the infrequently observed automatic type of rotational sequencing did not materially reduce Letter-Matching-Test scores.

Refraction criteria used in the past for referral have been somewhat arbitrary, based on community standards[163,164] or on expert opinion.[164,165] To establish a somewhat more secure foundation, the work of Peters[40] was used to provide refractive errors that would be expected to result in visual acuities less than 10/15. Peters' published level of visual acuity corresponding to various errors in refraction in children ages 5-15 years (N=2,452 eyes) based on Snellen chart acuity measurements of uncorrected eyes capable of 20/20 vision with glasses was modified to correct for the 10 foot (rather than 20 foot) testing distance. Eyes with refractive errors exceeding these limits were considered abnormal (Figure 14).

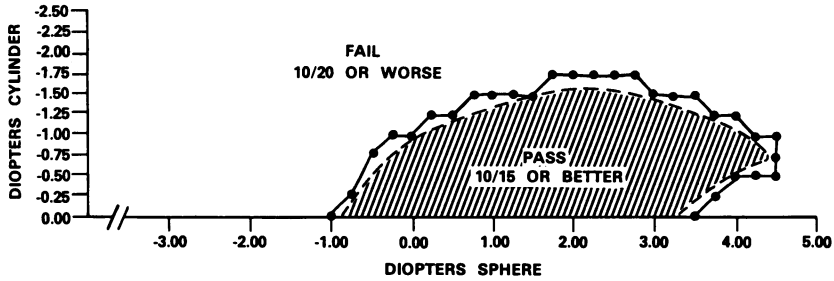


FIGURE 14

The relationship between refractive error and visual acuity based on Peters's data corrected for a 10-foot testing distance. The hatched area represents 10/15 or better visual acuity as shown by Peters.[40] The connected dots represent the actual spherical and cylindrical values used in making pass-fail decisions.

The accuracy of retinoscopy has been shown to vary according to the examiner[167] and is greater for cylindrical power than for spherical power.[167] In a previous study[168] Cyclopentolate 1% drops given to young children twice was demonstrated to uncover as much refractive error for patients with over −1.50 diopters of myopia as atropine drops or ointment given for three days prior to examination. This same study showed that hyperopic eyes and eyes with less than −1.50 diopters of myopia tended to have from one-third to one-half diopter less hyperopia under Cyclopentolate as opposed to atropine. The difference between the two groups was assumed to be due to the absence of reward for the myopic patients to accommodate on the retinoscope which was held at a working distance of 67 cm. Another interesting observation made in this study was that age, iris pigmentation, and reactivity of the pupils did not seem to cause much variation in the observed mean differences.

It should be noted that in the above study,[168] in which 30% of the children were blacks, Cyclopentolate 1% was given twice. In the present study a 2% solution was given twice. In both studies children were directed to look directly at the retinoscope held 67 cm from the subject's eye. An objection to this technique is that it encourages patients to accommodate if they have less than −1.50 diopters of myopia. Determinations of cylinder axis and power are probably more accurate with this method than with distant fixation because the refraction is performed directly on the visual axis. Since lens spheres and cylinders were used simultaneously, it was possible to neutralize both principal meridians in rapid succession. This comparative technique would be expected to result in errors of cylinder power less than about 0.50 diopter.

Retinoscopy is a fairly accurate technique but it has been demonstrated to have a slight positive bias when performed on patients without cycloplegia[167] as compared to the results of manifest refractions.

A recent study[169] suggests that the technique itself has a slight inherent inaccuracy which results in apparent hypermetropia. This is thought to be due to reflection from the retinovitreous interface rather than from the level of the outer segments of the photoreceptors.

Two levels of failure, based on the size of the refractive errors, were used. The first or F1 group were those children with intermediate refractive errors that exceeded the limits of error compatible with 10/15 acuity as determined by Peters, modified for the

10-foot testing distance used but not exceeding a higher standard of greater than −1.75 sphere and/or −1.50 cylinder. The latter group is referred to as the F2 group.

According to Peters, a simple myopic refractive error exceeding −1.00 (for a 10-foot working distance), will result in acuity less than 10/15. Because of the known inaccuracies in determining spherical errors (particularly under cycloplegia), as well as the bias found clinically, and also inherent errors in the method, it was elected to increase this value for the F2 group by −0.75 diopters; i.e., spherical errors alone would have to be equal to or greater than −2.00 diopters to be considered incompatible with 10/15 acuity.

With respect to cylindrical errors, for the F2 group it was elected to use Peters's value of greater than −1.50 since errors greater than this combined with any spherical value will result in acuities less than 10/15, according to Peters. The greater accuracy in determining cylindrical errors as opposed to spherical errors has already been mentioned.

Subjects in the F1 group were not thought to require glasses but their parents were advised that these children should have annual eye examinations. The parents of children in the F2 group were given prescriptions for glasses. This constitutes a rather arbitrary decision on the part of the author but it had the advantage of establishing a practical difference between the two groups. Thus, the F1 group was an observation group while the F2 group was a treatment group.

The overwhelming importance of refractive errors either alone or as an associated defect in patients with reduced acuity was striking in this study. Indeed, as previously stated, only one patient with reduced acuity due to an observable cause would have been overlooked if refractive criteria alone had been used as the basis for passing or failing.

The relative significance of refractive errors in accounting for reduced acuity in preschool children is well illustrated by Detroit Project 20/20:[170] a detailed analysis of vision screening of 8,276 preschool children with 84% follow-up for the 1,013 children referred for professional eye examinations. Of interest is that 90% of the low visual acuity referrals were found to have significant refractive errors. Three-fourths of the children referred for muscle imbalance also had abnormal refractions.

Nordlow and Joachimsson[91] in a study of 3,787 four-year-old Swedish children found that 228 of the 359 (64%) children profes-

sionally examined following referral from visual acuity screening had reduced vision due to refractive errors.

Hatfield,[171] surveying 145 "complete" preschool vision screening projects (including 89,461 children), reported to the National Society for the Prevention of Blindness that 87% of the referred children with specific defects found at professional examination had some type of refractive error.

In the 1973-74 national reporting statistics[79] on 861 preschool vision projects undertaken by Prevention of Blindness affiliates in 22 states (including 279,657 children), 70% of referred cases in those projects that were "complete" had abnormal refractive errors.

In 1977 Ingram[172] found that 72 ± 3% of all cases of esotropia and/or amblyopia in a sample of young children referred to two eye clinics had a refractive error of +2.00 diopter sphere or more spherical hypermetropia in the more emmetropic eye, or +1.00 diopter or more spherical or cylindrical anisometropia. The close association between refractive status and squint and/or amblyopia suggested reconsideration of refraction as a basis for screening young children for visual defects.

The numerical preponderance of refractive errors raises the question as to the necessity to measure acuity at all. A weak argument could be advanced that only refraction need be determined. Such an approach would, of course, overlook many patients with ocular motility disorders, amblyopic eyes without significant refractive errors, and also organic defects and diseases that do not affect the refractive status.

Promising studies have been performed on somewhat older children utilizing automated refraction devices.[173] The reliability and validity of such devices in preschool children has yet, however, to be demonstrated. Nevertheless, this is an approach to preschool screening that may hold promise, particularly if incorporated with external eye examinations and cover-uncover testing for strabismus. It is not inconceivable that in the not-too-distant future the preschool vision "screen" will consist of an acuity test, an external eye examination, cover-uncover testing, an automated refraction, and immediate (on premises) dispensing of optical correction, with repeat acuity testing, all performed by specially trained technicians. Only children with external defects, strabismus, or poor acuity with glasses might be referred for medical evaluation. Such an approach might have particular appeal in underdeveloped countries where few medically trained specialists are available.

The validity data in which the pass-fail acuity results obtained at the first screening session are compared with the refraction pass-fail criteria indicate the superiority of the E-Test as compared to the Letter-Matching-Test although neither test achieved high validity scores. The reasons for the more valid results obtained with the E-Test presumably include the same reasons as suggested for the greater reliability obtained with the E-Test. Tests that are less reliable also tend to be less valid. If results fluctuate from test to test (greater variance) they are not as likely to compare to a criterion measure as favorably as test results that are more constant (lesser variance), assuming both tests share the same mean value.

An additional factor that may possibly play a role in the differences in validity noted between the two tests is chart memorization. Subject #426 is particularly relevant in this regard. This child had a degree of myopia in the right eye that was incompatible with normal acuity (−7.00 diopters). This patient failed the E-Test given in the first screening session but passed the Letter-Matching-Test given in both the second screening session and in the medical examination. Peeking was not likely, at least in the latter examination, since an occlusive eye patch was worn over the relatively normal left eye while the right eye was tested. The results indicated that the child was either an extraordinarily good guesser or peeker or, more likely, had memorized those particular lines of the letter chart that he could not see with his poor right eye.

Although no conclusive evidence is available, it was the impression of several testers that responses were more easily memorized for the Letter-Matching-Test than for the E-Test. The clockwise type of sequencing on the response panel may have accentuated this difference.

Another possibility is that the E-Test is more sensitive to astigmatic refractive errors than the Letter-Matching-Test. Optotypes O and V may be easier to interpret in the presence of certain types of cylindrical errors than similarly sized E optotypes. The fact that most children have vertically and horizontally directed astigmatic principal meridians may be relevant in this regard.

The value of retesting those who originally fail an acuity test is controversial. From a theoretical standpoint, the worth of this procedure is largely a philosophical one centering on the desirability of a trade-off between an increase in the number of underreferrals and a decrease in the number of overreferrals. From a practical

standpoint, economic factors as well as public and professional considerations are also involved in making this decision.

CONCLUSIONS

Under the experimental conditions imposed, the Letter-Matching-Test used was superior to the version of the E-Test used with respect to testability, group and individual instruction time, and performance time.

On the other hand, the E-Test was consistently more reliable in terms of test-retest acuity scores and more valid in terms of agreement between pass-fail acuity results obtained at the first screening session and two levels of pass-fail refraction criteria.

These differences were observed in both the entire population studied as well as in children below 48 months of age.

On the basis of the results obtained, a recommendation cannot be made to substitute the Letter-Matching-Test used in this study for the E-Test for the routine screening of preschool children. The Letter-Matching-Test may be useful in screening those particular children unable to perform the E-Test, but its value in such situations has not been critically compared to other types of tests which might also be employed in this context, such as the Allen picture or Sjogren hand tests.

SUMMARY

The purpose of the study was to evaluate the relative merits of two screening tests used for visual acuity assessment of preschool children. The tests that were compared were the Good-Lite Company versions of the E-Test and of the STYCAR (Screening Test for Young Children and Retardates). The former is the most popular method for evaluating central acuity in young children in this nation; the STYCAR is a relatively new letter-matching-test developed in England, where it is widely employed. The E-Test poses left-right orientation problems which are eliminated by the symmetrical letters H, T, O, and V utilized in the Letter-Matching-Test.

Both visual acuity tests were administered on two separate occasions by personnel from the Prevention of Blindness Society of Metropolitan Washington to 633 preschool children in Washington, D.C. By random selection, 150 of the children received the E-Test

at both sessions, 162 children received the Letter-Matching-Test at both sessions, 160 children received the E-Test on the first session and the Letter-Matching-Test at the second session, and 161 children received the Letter-Matching-Test at the first session and the E-Test at the second session. The author medically examined the eyes of 408 of the 633 children without knowledge of which test had been initially administered.

Statistical analysis of the data obtained from the study indicated that the Letter-Matching-Test was significantly better in terms of testability rates, group and individual instruction time, and performance time. The E-Test was more reliable in terms of test-retest acuity scores and was also more valid in terms of agreement between pass-fail results obtained at the first screening session and two levels of pass-fail refraction criteria.

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