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NEW VISUAL ACUITY CHARTS FOR CLINICAL RESEARCH

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Three new visual acuity charts facilitate quantitative use of visual acuity test results. The charts have high-contrast lettering on washable white polystyrene. Each line has five Sloan letters; the lines are of equal difficulty, and there is a geometric progression in letter size from line to line. This provides a similar task for each line on the chart with the letter size being the only variable. Charts with different letter sequences are used for testing right and left eyes.

In clinical trials or other clinical studies in which changes in visual acuity are measured over time, or in which the measurements are made by more than one examiner, perhaps in different locations, standardization of the measurements is particularly important. We have designed visual acuity charts to facilitate such standardization. The design is based on a chart created by Bailey and Lovie,[1] but incorporates recommendations of the Committee on Vision of the National Academy of Sciences-National Research Council (NAS-NRC).[2] Using the charts during the first phase of the Early Treatment Diabetic Retinopathy Study[3] and the Visual Acuity Impairment Study demonstrated their advantages. We believe that these charts will prove useful to others engaged in vision research.

Deficiencies of current charts — One widely used visual acuity chart (Fig. 1) is clearly useful for determining an individual's general level of visual acuity, but the shortcomings of it and similar charts are apparent when one tries to quantify visual acuity, especially changes in visual acuity over a period of time.

In the past, the smallest line on the chart that the individual could read was used to quantify his or her visual acuity; one or two mistakes per line were often allowed. Changes in visual acuity over time were generally reported in units of "number of lines gained or lost." In clini-

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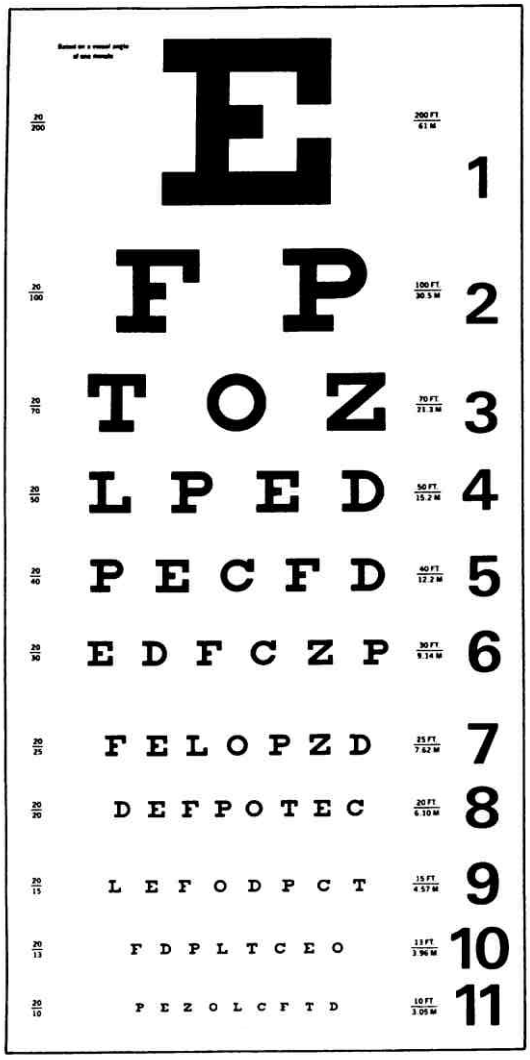

Fig. 1 (Ferris and associates). The Snellen visual acuity chart.

cal research, this type of measurement has some important limitations.

Many commonly used visual acuity charts have a different number of letters on each line (Fig. 1). Allowing one mistake per line, therefore, has a different meaning at different levels of visual acuity. To have a visual acuity of 6/6 (20/20) with this chart, one must correctly identify seven of eight letters (89%) on that line, but a visual acuity of 6/30 (20/100) requires the correct identification of only one of two letters (50%). The line for a visual acuity of 6/60 (20/200) consists of only one letter. Thus, as one reads progressively smaller lines, the task becomes more difficult not only because the letters are smaller, but also because more letters must be identified correctly. Using the same number of letters on each line eliminates this difficulty.

Most charts do not have a regular progression in letter size from the easiest to the most difficult lines. On the chart shown in Figure 1, a two-line loss from 6/21 to 6/60 (20/70 to 20/200) is almost a tripling of the visual angle, but the two-line loss from 6/6 to 6/9 (20/20 to 20/30) is less than a doubling of the visual angle. This irregular progression makes it difficult to interpret a change in visual acuity measured in "number of lines gained or lost." Using a regular progression of letter size eliminates this problem.

Snellen letters vary widely in difficulty. The letters "A" and "L," for example, are relatively easy, whereas "E" is relatively difficult. Thus, the recorded visual acuity depends on the difficulty of the letters. Choosing letters of approximately equal difficulty and ensuring that each line has approximately the same overall difficulty eliminates this problem.

New visual acuity charts — We designed three visual acuity charts (Fig. 2) that included modifications intended to resolve these problems.*

Spacing and size — Although the NAS-NRC Committee on Vision recommended using ten letters per line,[2] we used five letters per line. (This was the only deviation from the Committee's recommenda-

* Available from Precision Vision, Inc., 944 First St., La Salle, IL 61301, Phone 1-815-223-2022 Fax 1-815-223-2224 email: precisionvision@mindspring.com Web Page: precision-vision.com

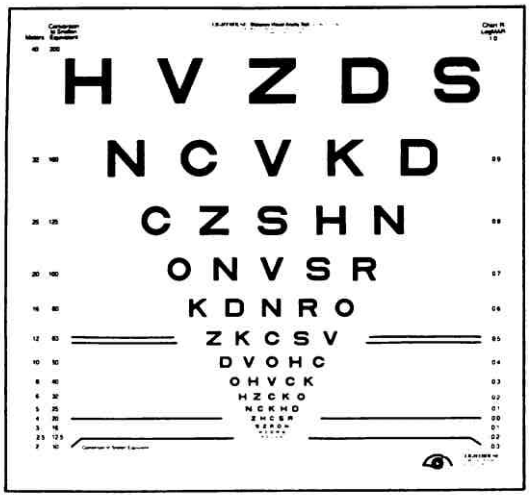

Fig. 2 (Ferris and associates). The three new visual acuity charts. Top left, Chart R. Top right, Chart 1. Bottom left, Chart 2.

Precision Vision "ETDRS" Charts
Chart "R" Cat. No. 2110
Chart "1" Cat. No. 2111
Chart "2" Cat. No. 2112

tions.) The space between letters is one letter wide and the space between lines is equal in height to the letters of the next lower line.

The letter sizes range from 58.18 to 2.92 mm, providing a visual acuity equivalent of 4/40 to 4/2 (6/60 to 6/3 [20/200 to 20/10]) at a distance of 4 m.

The progression of letter height from line to line is geometric. The letters on each line are 1.2589 times the height of the letters on the next lower line. This multiplier is the tenth root of ten, or 0.1 log unit. A three-line worsening of visual acuity is equivalent to a doubling of the visual angle regardless of the initial visual acuity used.

Letter and line difficulties — We used the ten Sloan letters (Fig. 3) on these charts. Each Sloan letter can be assigned a difficulty score based on how often that letter is read correctly at the visual acuity threshold (Table 1).[4] These letter difficulties are approximately equal to each other and to a Landolt Ring.[4] For each of the 252 combinations of five letters that can be created from the ten Sloan letters, we determined the line-difficulty score by summing the five letter-difficulty scores. We selected 28 lines of intermediate dif-

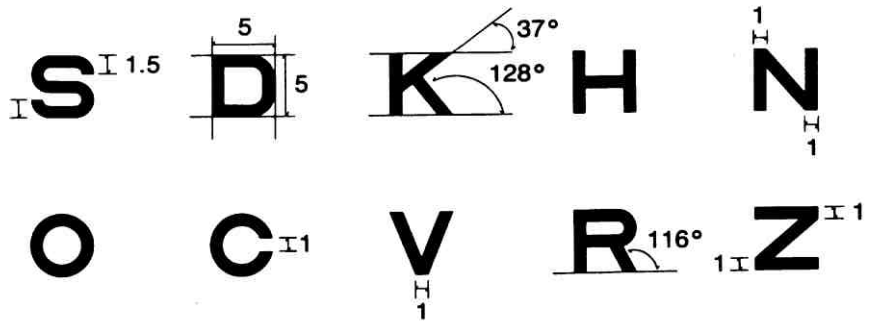

Fig. 3 (Ferris and associates). Specifications for the Snellen letters.

ficulty for inclusion in charts 1 and 2 (Table 2) of the Early Treatment Diabetic Retinopathy Study. The maximum difference in difficulty scores between lines is less than 1%.

The letters in each line were arranged so that no words or acronyms were spelled out.

Testing distances — The charts are designed for use at 4 m. This distance is consistent with the current change to the metric system in the United States, and makes it easier to use the charts in small examining rooms. The Snellen fraction at this distance is easily converted to the 20-foot equivalent by multiplying by 5/5. Example 4/5 X 5/5 = 20/25. Subtracting 0.25 diopter from the 4-m refraction yields the equivalent refraction for infinity. Maximum visual acuity and minimum dispersion of visual acuity scores are obtained at a test distance close to 4 m.[5]

The geometric progresssion of letter sizes from line to line simplifies testing at other distances. If distances are chosen in the same 0.1 log unit intervals used for the letter sizes on the visual acuity chart, then each time the testing distance is decreased by one step it should be possible to read one additional line. The resulting testing distances, in meters, are 4, 3.2, 2.5, 2.0, 1.6, 1.3, and 1.

Physical characteristics of the chart — The charts are 64.8 cm wide and 62.2 cm high (25.5 by 24.5 inches). The letters are silk-screened onto nonreflective, white, high-impact polystyrene, which can be

TABLE 1

DEGREE OF DIFFICULTY OF SLOAN LETTERS

Sloan Letter	% Correct at Threshold
S	70.6
O	71.0
C	71.4
D	79.5
K	82.1
V	84.6
R	86.3
H	89.3
N	91.6
Z	94.0

TABLE 2

DIFFICULTY SCORES FOR CHARTS 1 AND 2

Chart 1	Difficulty Score	Chart 2	Difficulty Score
NCKZO	410.1	DSRKN	410.1
RHSDK	407.8	CKZOH	407.8
DOVHR	410.7	ONRKD	410.5
CZRHS	411.6	KZUDC	411.6
ONHRC	409.6	VSHZO	409.5
DKSNV	408.4	HDKCR	408.6
ZSOKN	409.3	CSRHN	409.2
CKDNR	410.9	SVZDK	410.8
SRZKD	412.5	NCVOZ	412.6
HZOVC	410.3	RHSDV	410.3
NVDOK	408.8	SNROH	408.8
VHCNO	407.9	ODHKR	408.2
SVHCZ	409.9	ZKCSN	409.7
OZDVK	411.2	CRHDV	411.1

washed with mild detergent to maintain high contrast between the black letters and the white chart. A light box accommodates the charts and produces standardized illumination.[6]

Using the charts — The charts are installed in the standard light box. A complete refraction is performed before visual acuity is measured. This can be done at any convenient testing distance with chart R (Fig. 2, top left) or any other visual acuity chart. If the distance is other than 4 m, an overrefraction with plus or minus spheres, or both, is carried out at 4 m with chart R before visual acuity testing. The patient should not see charts 1 and 2 (Fig. 2, top right and bottom left) before the test.

To measure visual acuity in the right eye, the left eye is covered and chart 1 is then uncovered in the light box. The subject reads down the chart slowly, letter by letter, beginning with first letter on the top row. When a letter is read correctly, the examiner circles this letter on a score sheet with a layout identical to that of the chart. Only one reading of each letter is allowed, so it is most important to emphasize careful reading. When the subject has difficulty reading a letter, he or she is encouraged to guess. If visual acuity is poor, the test distance is reduced to 1 m; visual acuities as low as 1/40 (6/240 [20/800]) can be measured. After the right eye is tested, it is covered and the left eye tested in a similar fashion with chart 2. Visual acuity can be recorded as the smallest line read by each eye, with a notation such as +1 or −2 added to specify the visual acuity more accurately.

Visual acuity can be specified with several different scales. Two commonly used scales are the decimal visual acuity and the logarithm of the minimal angle of resolution (LogMAR) (Table 3). Decimal visual acuity is obtained by dividing the numerator of the Snellen fraction by the denominator. The logarithm of the reciprocal of this decimal visual acuity approximates the logarithm of the minimal angle of resolution.[1,2] Table 3 shows that the decimal visual acuity is nonlinear, whereas the LogMAR score is linear, decreasing by 0.1 unit for each lower line on the chart.

Since there is a 0.1 LogMAR unit difference between lines on these charts and

TABLE 3

EQUIVALENT VISUAL ACUITY MEASUREMENTS

Snellen Visual Acuities			Decimal Fraction	LogMAR
4 Meters	6 Meters	20 Feet		
4/40	6/60	20/200	0.10	+1.0
4/32	6/48	20/160	0.125	+0.9
4/25	6/38	20/125	0.16	+0.8
4/20	6/30	20/100	0.20	+0.7
4/16	6/24	20/80	0.25	+0.6
4/12.6	6/20	20/63	0.32	+0.5
4/10	6/15	20/50	0.40	+0.4
4/8	6/12	20/40	0.50	+0.3
4/6.3	6/10	20/32	0.63	+0.2
4/5	6/7.5	20/25	0.80	+0.1
4/4	6/6	20/20	1.00	0.0
4/3.2	6/5	20/16	1.25	−0.1
4/2.5	6/3.75	20/12.5	1.60	−0.2
4/2	6/3	20/10	2.00	−0.3

each line has five letters, an interpolated LogMAR score can be created by assigning 0.02 LogMAR units for each letter read correctly on this chart. For example, if all the letters down to and including the 4/5 (6/7.5 [20/25]) line (LogMAR +0.1) are correctly read, and three letters on the 4/4 (6/6 [20/20]) line (LogMAR 0.0) are correctly read, an interpolated LogMAR score of -0.04 (that is, +0.1 -[3 x 0.02]) can be used to represent the visual acuity. (Note that the lower the score the better the visual acuity , so 0.02 units are subtracted for each correct letter.) This principle can be extended to situations in which some letters on several lines are missed. By scoring 0.02 for each letter read correctly on the entire chart and adding these scores, a visual acuity score can be created that is a single number and is a reasonable estimate of the LogMAR score for the eye at that test. Changes in this visual acuity score over time can be easily tested statistically. Such testing is difficult with most currently used charts.

Evaluating the charts -- The visual acuity charts were evaluated in a study involving 112 individuals, all of whom had good visual acuities (6/4.5 to 6/9 [20/15 to 20/30]) One eye of each individual was tested on charts 1 and 2 after refraction. in the initial series of test, 66 subjects read chart 1 first and the other 66 read chart 2 first. The test were repeated one to 24 hours later. The same eye was refracted again, but charts 1 and 2 were read in reverse order.

Arepeated-measure analysis of variance found no significant difference between chart 1 and chart 2. Although retesting yielded a statistically significant improvement in visual acuity scores (P = .05) , the average difference in scores was less than 0.5 letter. Thus, there seems to be a satistically significant but clinically unimportant improvement in visual acuity score after repeated use of the charts .

Measurements of visual acuity using these charts provide reproducible visual acuity information in a format that facilitates quantitative data analysis.

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ARVO Abstract 1986

RELATIVE LETTER DIFFICULTY AND POSITION DIFFICULTY FOR SLOAN LETTERS USED ON THE ETDRS VISUAL ACUITY CHARTS.

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Louise Sloan originally chose ten letters which were roughly equal to each other and to a Landolt ring in difficulty. The Landolt ring was chosen as the reference standard against which letters would be compared. The ten Sloan letters were arranged in groups of five per line on the modified Bailey-Lovie visual acuity charts used in the Early Treatment Diabetic Retinopathy Study (ETDRS).

This study has recruited 3928 patients. Data from visual acuity examinations performed at the initial study visit for both eyes of patients in this study were used to replicate Louise Sloan's original letter difficulty assessment. The percent of time the Sloan letters were correctly identified at "threshold" in the ETDRS was as follows: C = 46.8%, O = 53.0%, S = 60.2%, D = 61.6%, K = 65.3%, R = 67.7%, V = 68.5%, H = 73.2%, N = 80.3%, Z = 86.6%. The order of letter difficulty and relative degree of difficulty were only slightly different from the earlier study. In addition, our data allowed us to test letter position difficulty. It has been reported that letters at the beginning and end of a line have different difficulties than letters in the body of the line because there is less contour interaction at the ends of a line. Data will be presented from our study which are not consistent with this hypothesis. Alternative rationales for the position difficulty differences we find will be discussed.

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VISUAL ACUITY CHART ILLUMINATION.

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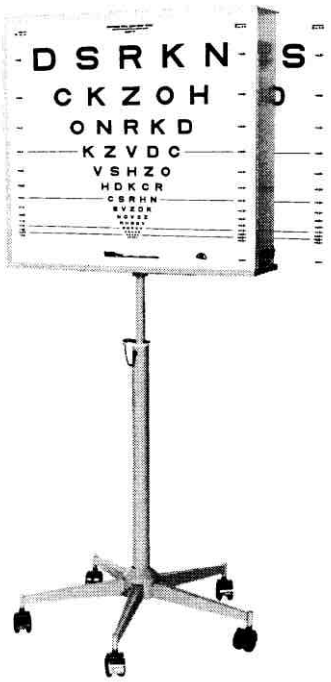
Standards for visual acuity testing were set by the first major clinical trial in ophthalmology, the Diabetic Retinopathy Study (DRS). These front-illuminated charts were large, bulky, and difficult for clinics to manage. The illumination specifications on the retroilluminated charts from the New York Lighthouse for the Blind were matched to those of the DRS. We compared visual acuity measurements using those two different methods of chart illumination.

A total of 200 patients with diabetic retinopathy, with and without macular edema, age-related macular degeneration, cataract, or uveitis and a visual acuity of 20/200 or better and normal controls were studied at the Eye Clinic of the National Eye Institute. Each patient/control received a manifest refraction performed by an ophthalmic technician according to the Early Treatment Diabetic Retinopathy Study (ETDRS) protocol. Two visual acuity examiners then measured the acuity of each patient or control. Both the order in which the charts were used and the order of the examiners was selected at random. Each examiner was masked as to the result obtained by the other examiner.

To date no statistically significant differences have been seen using the different chart illumination methods. The majority of patients have only had two or fewer letters difference on replicate VA measurement. Multivariate analysis of the results will be presented.



ETDRS Illuminator Cabinet Cat. No. 2425 shown with optional Caster Base Cat. No. 2426

New ETDRS Charts

Relative letter difficulties evaluated in ETDRS study were used for developing new ETDRS charts. Using the ten Sloan letters, we generated a list of 252 possible different 5 letter lines (two lines are not considered different if they have the same letters but in different order). As a letter score we used the percent of correct readings of the letter at threshold estimated in this study. Namely, the letter scores 84.4, 77.4, 68.8, 63.6, 62.2, 60.9, 55.6, 51.6, 47.1 and 39.3 are assigned to Z, N, H, V, R, K, D, S, O, and C respectively. For each of the 252 lines, a line score was calculated equal to the sum of the scores of the letters in the line. Then the 252 lines were sorted by the ascending line score. The middle 28 line (113 through 140) in the list of the sorted 252 lines were shuffled and then splitted between Chart 1 and Chart 2. Additional Chart 3 was made up using the neighbor lines (106 through 112 and 141 through 147). Since the lines with the score close to the median one were used to make up the charts, each of the new charts has lines quite homogeneous in difficuly. The relative difference between the maximum and minimum line score is 2.2, 2.2, and 3.2 percent in Chart 1, Chart 2, and Chart 3 respectively. The three charts are quite similar in difficulty: the mean line score is 305.4, 305.5, and 305.45 in Chart 1, Chart 2 and Chart 3 respectively. The three charts are balanced so that in each chart each letter is represented in each position at least once.

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Relative Letter and Position Difficulty on Visual Acuity Charts From the Early Treatment Diabetic Retinopathy Study

Frederick L. Ferris III, M.D., Valeria Freidlin, Ph.D., Aaron Kassoff, M.D., Sylvan B. Green, M.D., and Roy C. Milton, Ph.D.

Ten Sloan letters were used in the visual acuity charts developed for use in the Early Treatment Diabetic Retinopathy Study. We used the data from the 3,710 Early Treatment Diabetic Retinopathy Study subjects to investigate the relative difficulty of the ten Sloan letters and to evaluate whether the position of a letter on a line affected its relative difficulty. In general, our findings were consistent with those of the previous study. The four letters with curved contours (C, O, S, and D) were more difficult to discern at threshold than the six letters (Z, N, H, V, R, and K) composed of straight lines. Our data demonstrate that under these test conditions, letters at the end of a line are more likely to be read incorrectly than letters at the beginning of the line. This finding indicates that these data are probably not useful for evaluating possible crowding phenomena.

In 1952 Sloan, Rowland, and Altman[1] proposed ten letters for use in visual acuity testing. They found that these letters were of similar difficulty, but that the four letters with curved contours were somewhat more difficult to discern at threshold than the six letters composed of straight lines. These ten Sloan letters were used in the visual acuity charts developed for use in the Early Treatment Diabetic Retinopathy Study.[2]

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We used the data from the Early Treatment Diabetic Retinopathy Study to investigate further the relative difficulty of the ten Sloan letters and to evaluate whether the position of a letter on a line affected its relative difficulty.

Patients and Methods

To estimate letter and position difficulty, we used the data from the best-corrected visual acuity examination of 3,710 Early Treatment Diabetic Retinopathy Study subjects (7,420 eyes) performed at the study-qualifying visit (one study patient did not have complete information and is not included in these analyses). Procedures for refraction and visual acuity testing were previously reported.[3,4] All patients in this study were asked to read each letter on the chart starting at the upper left-hand letter and to proceed by row until they could no longer read letters. They were urged to continue to guess at letters until they missed all letters on a line.

Figures 1 and 2 show the two Early Treatment Diabetic Retinopathy Study charts (chart 1 for right eyes and chart 2 for left eyes) that were used during each examination. Lines on both Early Treatment Diabetic Retinopathy Study charts have five Sloan letters and are separated by logarithmic intervals as previously described.[2] The number of letters on a line that are correctly identified is the score for that line. Lines with a score of 5 or 0 provide no discrimination of letter difficulty because all letters were either read correctly or missed. Lines with some letters correctly read and some missed do provide information on relative letter difficulty. These lines on the chart are defined as discriminant lines.

Letter difficulty was estimated on the basis of

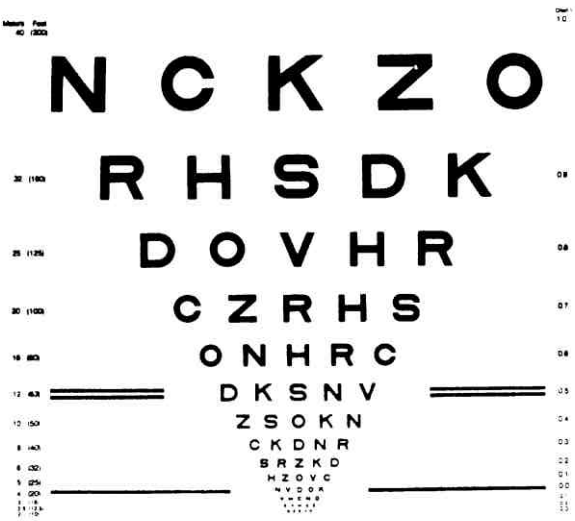

Fig. 1 (Ferris and associates). Chart 1, the Early Treatment Diabetic Retinopathy Study visual acuity chart for right eyes.

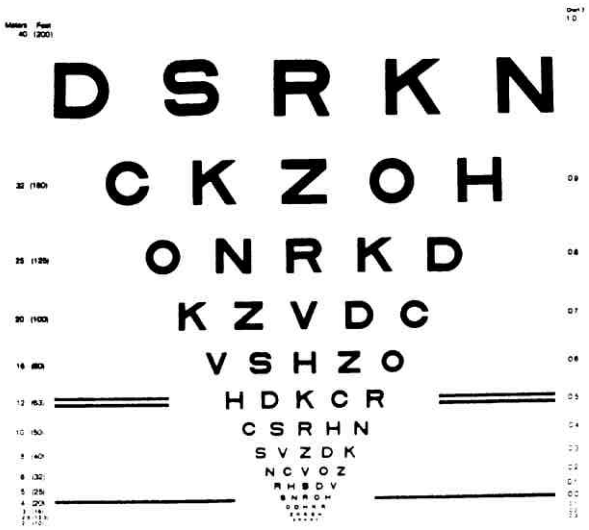

Fig. 2 (Ferris and associates). Chart 2, the Early Treatment Diabetic Retinopathy Study visual acuity chart for left eyes.

all discriminant lines for all study patients. The proportion of incorrect letters was calculated for each letter by dividing the total number of times that letter was read incorrectly on discriminant lines by the total number of times that letter appeared on discriminant lines.

Three categories were used for the position of a letter in a line as follows: first, middle (that is, positions 2, 3, and 4 pooled together), and last position. The three middle positions on a line were combined because not all letters were well represented at every position. By pooling the middle positions, each letter was adequately represented in the first, middle, and end positions; this allows adjustment for letter difficulty when determining position difficulty and allows for testing of whether the beginning of the line is more or less difficult than the middle or end of the line, and whether crowding or surrounding distracters make the middle letters on a line more difficult to discern than the letters at the beginning or end of a line.

Position difficulty was estimated by dividing the number of times letters were incorrectly read at each of these three letter positions (first, middle, last) on a discriminant line by the total number of times that position was read on those discriminant lines.

Analyses of single 2 × 2 tables were performed to estimate the unadjusted relative odds of incorrectly reading different letters or different letter positions.[5] The Mantel-Haenszel procedure for a series of 2 × 2 tables was used to calculate the adjusted relative odds. The χ^2 test was used to test for homogeneity of letter or position difficulties.[5]

We used data for two charts (both eyes) combined because the combination provides better representation of each letter in various positions on various lines. Similarly, for each position, various letters of various sizes are represented better in two charts combined than in only one. However, because of the possible effect of correlation between eyes on the level of statistical significance, we also performed separate analyses of position and letter difficulties using right eyes only.

Results

The total number of discriminant lines for two eyes combined was 11,753. Figure 3 shows the number of times each line was a discriminant line. Because most of the patients in the Early Treatment Diabetic Retinopathy Study had good visual acuity at baseline, approximately three quarters of the information comes from the ten lines corresponding to visual acuities of 20/12.5 through 20/32 on these two charts.

Figure 4 shows the percent of incorrect readings on discriminant lines for each of the ten Sloan letters. Relative odds of incorrectly reading the ten Sloan letters on discriminant lines can be calculated by using 2 × 2 tables as

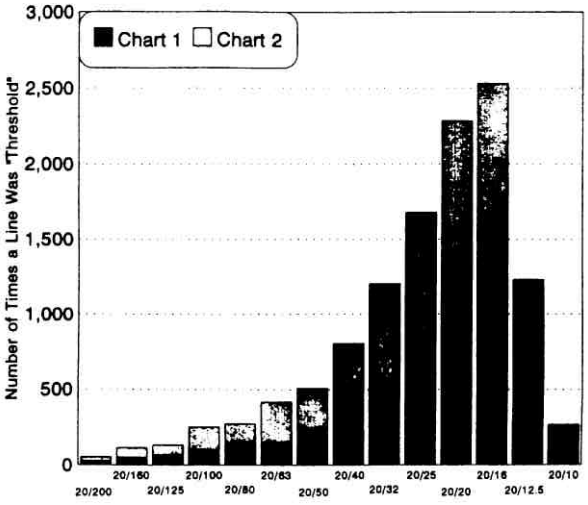

Fig. 3 (Ferris and associates). The number of times each line on the Early Treatment Diabetic Retinopathy Study (ETDRS) visual acuity charts was a discriminant line.

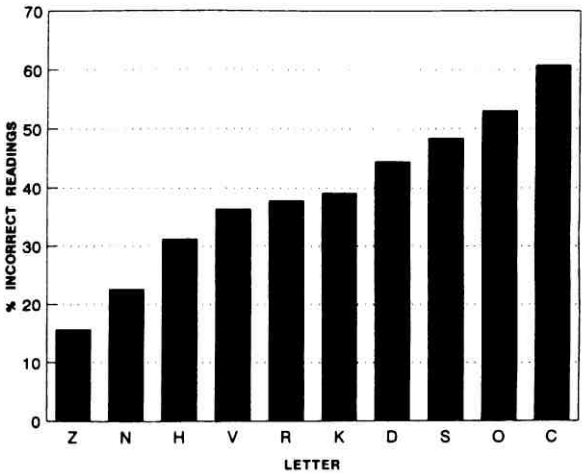

Fig. 4 (Ferris and associates). The letter difficulties on discriminant lines using the Early Treatment Diabetic Retinopathy Study data.

shown in Table 1. The results of analyses of all 2 × 2 tables comparing the letter difficulties on discriminant lines are shown in Table 2. The relative odds of an incorrect response on a discriminant line, calculated by comparing each letter separately with "Z," the easiest letter, ranged from 1.6 (letter "N") to 8.4 (letter "C"). Position-adjusted relative odds of incorrect reading for letters were similar to the unadjusted ones.

The overall χ^2 test for homogeneity of letter difficulties was significant with $P < .0001$. The Mantel-Haenszel test adjusting for position was used to test whether particular pairs of letter difficulties differed significantly. Only three pairs of letters did not differ significantly in difficulty: K, R; K, V; and R, V. All other letter pairs differed significantly in relative difficulty ($P = .02$ for "S" and "O," and $P < .0001$ for all other pairs of letters).

Table 3 shows the percent of incorrect readings on discriminant lines for each of three positions and relative odds of incorrect reading for middle letters or last letter vs first letter. As seen in Table 3, the letters at the end of the line were more likely to be missed than letters at the beginning of the line (reading left to right). The Mantel-Haenszel test adjusting for letter showed that all three pairs of positions were significantly different in percent incorrect answers ($P < .0001$).

Analyses using only the right eye did not differ appreciably from those described previously.

TABLE 1
ODDS OF INCORRECT READING ON DISCRIMINANT LINE FOR LETTERS C AND Z

LETTER	NO. OF CORRECT READINGS ON DISCRIMINANT LINES (%)	NO. OF INCORRECT READINGS ON DISCRIMINANT LINES (%)	ODDS OF INCORRECT READING*	TOTAL
Z	3,785 (84.4)	699 (15.6)	0.1847	4,484
C	2,216 (39.3)	3,429 (60.7)	1.5474	5,645

*Relative odds (odds ratio) of incorrect reading for C and Z: 1.5474/0.1847 = 8.38.

Discussion

The ten letters chosen by Sloan, Rowland, and Altman[1] for visual acuity testing in 1952 have been widely used for measuring visual acuity in the last four decades. In their original report, Sloan, Rowland, and Altman[1] reported on the differences in legibility at threshold for these ten letters as assessed in 234 eyes with varying degrees and types of ametropia. They defined threshold as the lowest line of ten letters on which seven or more were read correctly.

TABLE 2
RELATIVE ODDS OF INCORRECT READING ON DISCRIMINANT LINE, EACH LETTER VS LETTER Z*

LETTER	TOTAL NO. OF READINGS ON DISCRIMINANT LINES (N = 58,765)	NO. OF INCORRECT READINGS ON DISCRIMINANT LINES (%) (N = 23,070)	UNADJUSTED ODDS RATIO (95% CONFIDENCE INVERVAL)	ADJUSTED FOR POSITION ODDS RATIO (95% CONFIDENCE INTERVAL)
Z	4,484	699 (15.6)	1.00 —	1.00 —
N	6,301	1,427 (22.6)	1.58 (1.43–1.75)	1.68 (1.52–1.87)
H	6,979	2,177 (31.2)	2.45 (2.23–2.70)	2.39 (2.17–2.64)
V	6,590	2,400 (36.4)	3.10 (2.82–3.41)	3.22 (2.92–3.55)
R	5,177	1,955 (37.8)	3.28 (2.98–3.62)	3.21 (2.91–3.55)
K	5,728	2,241 (39.1)	3.48 (3.16–3.83)	3.30 (2.98–3.65)
D	5,742	2,548 (44.4)	4.32 (3.92–4.76)	4.55 (4.10–5.05)
S	4,931	2,388 (48.4)	5.08 (4.61–5.61)	5.69 (5.09–6.36)
O	7,188	3,806 (53.0)	6.09 (5.55–6.69)	6.41 (5.82–7.05)
C	5,645	3,429 (60.7)	8.38 (7.60–9.23)	8.80 (7.97–9.72)

*χ^2 test of homogeneity: $P < .0001$.

Because the Early Treatment Diabetic Retinopathy Study charts have only five letters per line, the threshold definition used by Sloan, Rowland, and Altman[1] was not possible with this data set. Table 4 shows the letter difficulties on discriminant lines by using Early Treatment Diabetic Retinopathy Study data compared with the letter difficulties at threshold originally reported by Sloan, Rowland, and Altman.[1] In general, the results of the two studies are similar. The percent incorrect is higher in the data from the Early Treatment Diabetic Retinopathy Study. This finding is not surprising because Sloan, Rowland, and Altman[1] only used threshold lines with no more than 30% incorrect responses, whereas our definition of discriminant lines allowed up to 80% incorrect responses on a line. Consistent with the analysis of Sloan, Rowland, and Altman,[1] the four letters with curved contours (C, O, S, and D) are more difficult to discern than letters composed of straight lines. The order of increasing difficulty was also similar in both studies. The exceptions were that Sloan, Rowland, and Altman[1] reported that "S" was the most difficult letter, whereas our study showed both "O" and "C" to be more difficult.

Our finding that "C" is one of the most difficult letters is consistent with the findings of Sloan, Rowland, and Altman[1] and Sheedy, Bailey, and Raasch,[6] which shows that visual acuities measured with Landolt rings are somewhat lower than visual acuities measured with letters.

Although the ten Sloan letters were chosen for approximately equal difficulty, our data

TABLE 3
RELATIVE ODDS OF INCORRECT READING ON DISCRIMINANT LINE, MIDDLE LETTERS OR LAST LETTER VS FIRST LETTER*

POSITION	TOTAL NO. OF READINGS ON DISCRIMINANT LINES (N = 58,765)	NO. OF INCORRECT READINGS ON DISCRIMINANT LINES (%) (N = 23,070)	UNADJUSTED ODDS RATIO (95% CONFIDENCE INTERVAL)	ADJUSTED FOR LETTER ODDS RATIO (95% CONFIDENCE INTERVAL)
First	11,753	4,029 (34.3)	1.00 —	1.00 —
Middle	35,259	14,117 (40.0)	1.28 (1.23–1.34)	1.30 (1.24–1.37)
Last	11,753	4,924 (41.9)	1.38 (1.31–1.46)	1.55 (1.46–1.66)

*χ^2 test of homogeneity: $P < .0001$.

TABLE 4
COMPARISON OF THE RELATIVE DIFFICULTY OF LETTERS BETWEEN THE EARLY TREATMENT DIABETIC RETINOPATHY STUDY AND SLOAN, ROWLAND, AND ALTMAN[1]

	INCORRECT READINGS ON DISCRIMINANT LINES*	
LETTER	EARLY TREATMENT DIABETIC RETINOPATHY STUDY, % (N = 7,420 EYES†)	SLOAN, ROWLAND, AND ALTMAN[1], % (N = 234 EYES)
Z	15.6	6.0
N	22.6	8.4
H	31.2	10.7
V	36.4	15.4
R	37.8	13.7
K	39.1	17.9
D	44.4	20.5
S	48.4	29.4
O	53.0	29.0
C	60.7	28.6

*The definitions of discriminant lines in the two studies are not the same.

†Exact number of eyes not available from this study.

show that the odds of missing a "C" on discriminant lines are approximately eight times that of missing a "Z" on these lines.

Hypotheses related to letter crowding or surrounding distracters might have suggested that the middle letters in a line would be more difficult to discern than the letters at the beginning or end of a line. Our data do not show this. It is likely that our results are related to the patients reading from the left to right on the chart. Despite a protocol requirement that each letter on a line was to be read with full effort, it seems likely that, after several attempts to read virtually illegible letters on a line, the patient's effort decreased despite encouragement by the examiner. This decreased effort is a possible explanation for our finding of increasing position difficulty as one reads from left to right on a line.

Data from the Early Treatment Diabetic Retinopathy Study support previous findings of Sloan, Rowland, and Altman[1] concerning the relative difficulty of the ten letters used on many visual acuity charts. The Early Treatment Diabetic Retinopathy Study database provides a much more extensive evaluation of these relative letter difficulties and modifies the original conclusions to a small degree.

Based on the relative difficulties found by Sloan, Rowland, and Altman[1] the Early Treatment Diabetic Retinopathy Study chart was designed to minimize the difference in the degree of difficulty between lines on the chart.[2] By using this same method but based on the new relative letter difficulties, new sets of lines can be created. Table 5 provides suggested letter sequences for a new chart that would further minimize the difference in relative difficulty between lines on the chart. Using the new relative letter difficulties found in the Early Treatment Diabetic Retinopathy Study analysis, the revised chart lines in Table 5 differ by

TABLE 5
SUGGESTED LETTER SEQUENCES FOR REVISED EARLY TREATMENT DIABETIC RETINOPATHY STUDY CHARTS AND LINE-DIFFICULTY SCORES*

METERS	(FEET)	CHART 1	LINE DIFFICULTY SCORE	CHART 2	LINE DIFFICULTY SCORE
40	(200)	C O H Z V	303.2	Z R K D C	302.4
32	(160)	S Z N D C	308.3	D N C H V	304.7
25	(125)	V K C N R	303.4	C D H N R	303.3
20	(100)	K C R H N	308.6	R V Z O S	308.9
16	(80)	Z K D V C	303.8	O S D V Z	302.3
12	(63)	H V O R K	302.6	N O Z C D	303.8
10	(50)	R H S O N	307.1	R D N S K	307.7
8	(40)	K S V R H	307.1	O K S V Z	307.6
6	(32)	H N K C D	302.0	K S N H O	305.8
5	(25)	N D V K O	304.6	H O V S N	308.5
4	(20)	D H O S Z	307.5	V C S Z H	307.7
3	(16)	V R N D O	305.9	C Z D R V	305.1
2.5	(12½)	C Z H K S	305.0	S H R Z C	306.3
2	(10)	O R Z S K	306.2	D N O K R	303.2

*Line-difficulty score is the sum of % correct for the five letters on the line.

2%. Using the new letter difficulties the lines on the current Early Treatment Diabetic Retinopathy Study chart differ in relative difficulty by 11%; they differ by only 1% based on the original Sloan letter difficulties. Both the current Early Treatment Diabetic Retinopathy Study charts and revised charts have only small differences in line difficulties and are useful for clinical research purposes.

Data from this study provide little information concerning position difficulty because it seems likely that these results are most likely to relate to patient and examiner effort rather than true differences associated with letter position.

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Meters	Feet	CHART 1					Score	CHART 2					Score
40	(200)	C	O	H	Z	V	303.2	Z	R	K	D	C	302.4
32	(160)	S	Z	N	D	C	308.3	D	N	C	H	V	304.7
25	(125)	V	K	C	N	R	303.4	C	D	H	N	R	303.3
20	(100)	K	C	R	H	N	308.6	R	V	Z	O	S	308.9
16	(80)	Z	K	D	V	C	303.8	O	S	D	V	Z	302.3
12	(63)	H	V	O	R	K	302.6	N	O	Z	C	D	303.8
10	(50)	R	H	S	O	N	307.1	R	D	N	S	K	307.7
8	(40)	K	S	V	R	H	307.1	O	K	S	V	Z	307.6
6	(32)	H	N	K	C	D	302.0	K	S	N	H	O	305.8
5	(25)	N	D	V	K	O	304.6	H	O	V	S	N	308.5
4	(20)	D	H	O	S	Z	307.5	V	C	S	Z	H	307.7
3	(16)	V	R	N	D	O	305.9	C	Z	D	R	V	305.1
2.5	(12.5)	C	Z	H	K	S	305.0	S	H	R	Z	C	306.3
2	(10)	O	R	Z	S	K	306.2	D	N	O	K	R	303.2

PRECISION VISION
CHART 1
CAT. NO. 2121

PRECISION VISION
CHART 2
CAT. NO. 2122

ETDRS REVISED CHARTS

Meters	Feet	CHART 3					Score
40	(200)	R	N	O	V	S	301.9
32	(160)	Z	C	R	D	H	310.3
25	(125)	N	V	S	O	K	300.6
20	(100)	D	R	Z	K	O	310.2
16	(80)	S	N	H	C	V	300.7
12	(63)	C	R	V	S	Z	301.1
10	(50)	V	K	C	N	H	310.0
8	(40)	S	V	K	D	N	309.1
6	(32)	K	D	H	Z	C	309.0
5	(25)	H	Z	C	O	R	301.8
4	(20)	O	K	D	H	N	309.8
3	(16)	Z	O	N	K	C	309.1
2.5	(12.5)	R	H	S	V	D	301.8
2	(10)	D	S	O	R	Z	300.9

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CHART 3
CAT. NO. 2123

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