

# The SKILL Card

## An Acuity Test of Reduced Luminance and Contrast

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**Purpose.** To design and evaluate a new vision test that combines low contrast and reduced illumination to stress the visual system and be sensitive to subtle alterations in function.

**Methods.** A simple new clinical test, the Smith-Kettlewell Institute Low Luminance (SKILL) Card, is designed to measure spatial vision under conditions of reduced contrast and luminance using normal office lighting. The SKILL Card consists of two near acuity charts mounted back to back. One side has a chart with black letters on a dark gray background designed to simulate reduced contrast and luminance conditions. The other side has a high-contrast, black-on-white letter chart. The SKILL score is the acuity loss (number of letters) between the light and dark sides.

**Results.** Age norms for a large normal population have been established and show that test scores increase with age, particularly after age 50. Repeatability is as good as that of standard Snellen acuity. The SKILL score is affected minimally by blur, but it is affected by large variations in light level. SKILL scores are sensitive to the presence of visual disease such as "recovered" optic neuritis.

**Conclusions.** The SKILL card allows quick, reliable measurement of the effect of reduced luminance and contrast on acuity. SKILL scores are not correlated with other vision measures in patients with optic neuritis, which shows that the SKILL card measures a different dimension of vision function than existing clinical tests. *Invest Ophthalmol Vis Sci.* 1997;38:207–218.

The Smith-Kettlewell Institute Low Luminance (SKILL) Card was developed to provide a simple, rapid, and inexpensive method for measuring vision function at reduced contrast and luminance. The combination of low contrast and reduced luminance is expected to increase sensitivity to vision changes caused by age and disease compared to standard high- and low-contrast acuity measures and simulates conditions under which people most often report real-world task performance problems.

The familiar black-on-white letter chart, originally

used for refractive error determination, has become the standard clinical technique for assessing visual function. The use of high-contrast visual acuity as the gold standard measure of vision function continues, despite the large number of studies showing that visual acuity is a poor predictor of performance on visually guided tasks, such as reading<sup>1–5</sup> and driving,<sup>6</sup> and that high-contrast acuity is relatively insensitive to pathologic changes in the visual system.<sup>7</sup> The exclusive use of high-contrast acuity in clinical settings may result in a discrepancy between the clinician's findings and the patient's self-reported visual function because, as pointed out long ago by Luckiesh,<sup>8</sup> most daily tasks involve visual conditions far removed from the well-illuminated white test chart with black letters. Though the limitations of acuity and the need for more appropriate tests are well recognized in clinical vision research, the ideas have not been transferred completely to clinical practice. To achieve widespread acceptance, a measure must not only provide sufficient additional information to be worthwhile, it must be easy, quick to use, and reliable.

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## BACKGROUND

### Low-Contrast and Contrast-Sensitivity Testing

The visual world is composed of targets varying enormously in size (spatial frequency) and contrast, so that contrast sensitivity testing more closely measures the operation of the visual system in the world (see Regan<sup>7</sup> for review and discussion). Clinical interest in contrast-sensitivity testing stems from its improved sensitivity (compared to standard high-contrast visual acuity) at detecting subtle deficits. Contrast sensitivity losses in the presence of normal acuity have been found, for example, in retinitis pigmentosa,<sup>9</sup> optic neuritis,<sup>10</sup> multiple sclerosis,<sup>11</sup> and amblyopia.<sup>12,13</sup>

Charts with sine-wave grating targets bring laboratory techniques into clinical settings (e.g., The Vistech test system,<sup>14</sup> Arden Gratings<sup>15</sup>). However, the sine-wave grating target is unfamiliar to most patients, and this perhaps contributes to the demonstrated lower reliability for gratings.<sup>16,17</sup> Optotype (letter) charts that measure contrast sensitivity<sup>18,19</sup> circumvent the problem of familiarity, have higher reliability, and have as an added advantage the fact that they use a recognition task rather than a detection task.

### Low-Luminance Testing

The sensitivity of high- and low-contrast acuity and contrast-sensitivity tests to disease- and age-related changes in vision function is increased by testing under conditions of reduced illumination.<sup>8,20-23</sup> Luckiesh<sup>8</sup> argued that the combination of low-contrast and low-luminance—worst-case conditions that tax the visual system's capabilities—greatly enhances the ability of a test to detect visual defects. In fact, Luckiesh designed a chart with decreasing luminance and contrast for the United States Air Force. Pilots were to test their vision on the chart; when they had trouble seeing the black letters on a dark background, they were instructed to use oxygen. More recent reports<sup>24-28</sup> support the clinical wisdom<sup>29</sup> that patients with visual disease experience disproportionately severe deficits under conditions of poor illumination.

Despite its advantages, low-luminance testing often is not performed because of the practical problem of adequately varying and controlling light level in clinical settings. The low reflectance of the low-contrast chart of the SKILL Card is an attempt to solve this problem. The reduced reflectance of the chart effectively reduces the background illumination without the need to alter room lighting. Of course, similar conditions can be generated by using neutral density filters held in front of the eyes while viewing a low-contrast chart, but it is difficult to hold a filter without light leakage from the sides, and low-contrast charts are not always available.

This article describes the SKILL Card and provides age norms and data regarding repeatability as well as robustness to optical blur. In addition, data addressing the sensitivity of the test at detecting disease-related visual deficits are provided.

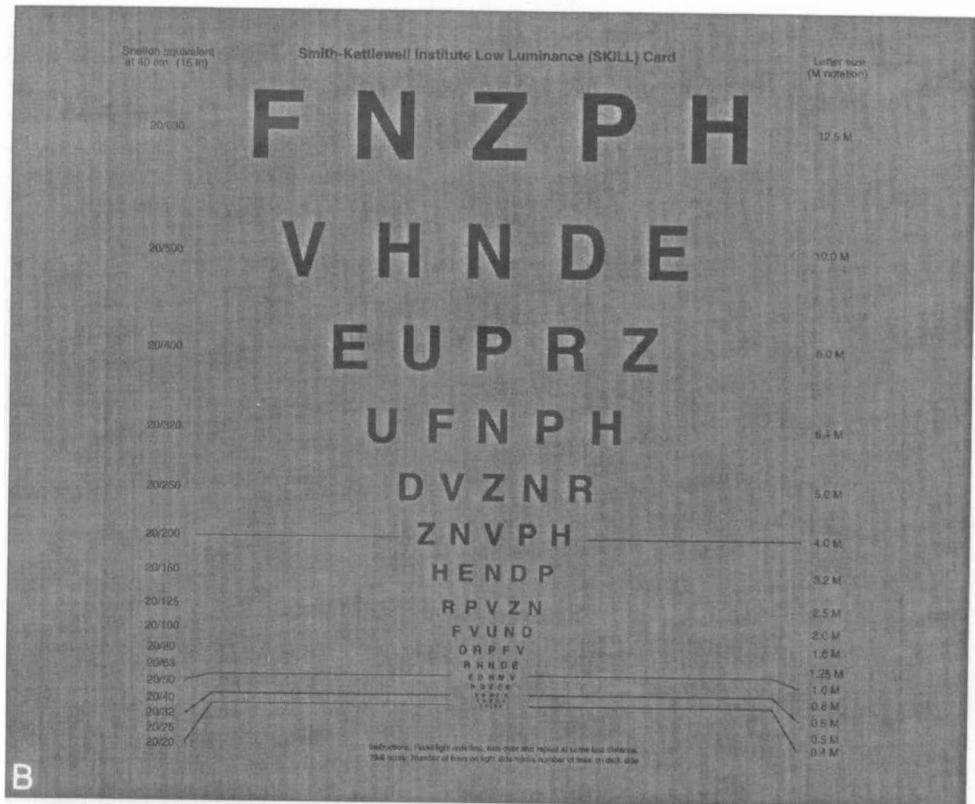
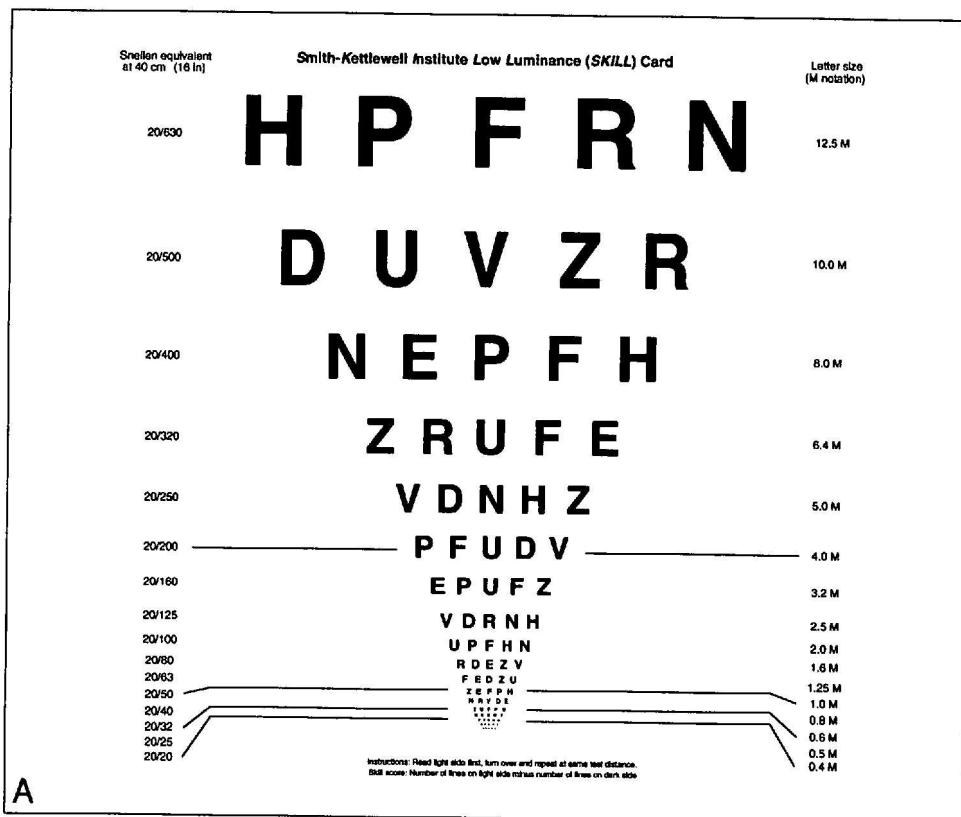
## METHODS

### The SKILL Card

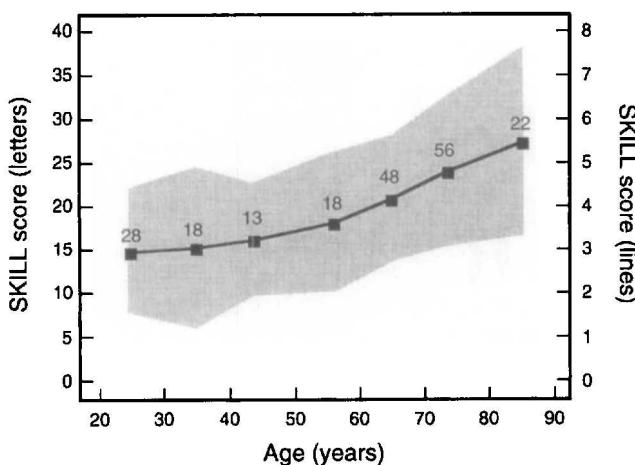
The SKILL Card (Fig. 1) consists of two letter charts mounted back-to-back. One is a low-contrast (14%) chart comprised of black letters on a dark gray (10% of the reflectance of white paper) background designed to simulate a reduced luminance condition. On the other side is a high-contrast (>90%) black-on-white letter chart with a different letter order. In use, the high-contrast side is presented at a viewing distance of 16 inches (40 cm), and near acuity is measured; the card is flipped over, and the black-on-gray side is tested at the same viewing distance. The SKILL score is taken as the difference in performance on the low-contrast dark versus the high-contrast light side. The preferred scoring for each chart is letter-by-letter, but line-by-line scoring also can be used. In this article, the details of data collection and scoring differ for each of the component sections (age norms study, reliability study, luminance study, blur study, and optic neuritis study) and are given individually for each section. In all cases, the subjects were required to read all five letters correctly on their starting line for each chart (light and dark) and continue to read (or guess) until three letters were read incorrectly on a line. A score sheet was used for recording which was labeled in reduced Snellen notation (with the specified test distance of 40 cm or 16 inches) M notation, log minimum angle of resolution (logMAR) notation, and visual acuity rating notation (see below).

### Physical Design and Fabrication Methods

A photographic process was developed in which matte-surfaced photographic paper is preexposed with uniform light for a predetermined time to produce the dark gray background before exposing it to a negative produced from a black-on-white original. The paper is chosen to be especially matte, with no specular reflections, and the result is an even, diffuse, dark gray background. A letter pattern produced on a high-resolution, Linotronic-type printer is used as the master for photographic reproduction. The method provides good consistency at low cost (approximately \$5, including mounting). The surface of the photographic paper is vulnerable to fingerprints and scratches; however, it has proven adequately serviceable when protected by a cardboard mount and border. Photometric



**FIGURE 1.** Representation of the SKILL Card light (**A**) and dark (**B**) charts. This figure is for purposes of illustration only; the dark chart is not accurately rendered.



**FIGURE 2.** Normative data for SKILL score across age. SKILL score is computed as the difference in number of letters read correctly on the light and dark charts. Plotted points are the mean scores for persons grouped by decade.

tolerances for contrast ( $\pm 1\%$ ) and luminance ( $\sim 0.1$  log unit) have been established. Each card measures  $8 \times 10$  inches exclusive of border.

The background reflectance selected, approximately 8% to 9%, is the lowest level that allows the desired optotype contrast without exceeding the dynamic range of reproduction methods. This reflectance results in a luminance factor of approximately 10 ( $\sim 1$  log unit) below that of the white background of the high-contrast, black-on-white chart. The contrast level of the dark chart,  $\sim 14\%$  Weber contrast, is slightly lower than the contrast of the gray-on-white Bailey-Lovie low-contrast distance acuity chart.<sup>30</sup> Preliminary studies indicated that higher contrast levels reduce test sensitivity.

Letter series using  $4 \times 5$  format letters were generated. Letter sizes are used on the dark chart that allow measurement of Snellen equivalents from 20/20 (logMAR 0) up to 20/630 (logMAR 1.5). This range of sizes is five lines larger than most charts that have 20/200 as the worst measurable acuity. The light chart, on which performance is better, contains two additional lines, permitting measurement of acuity as fine as the Snellen equivalent of 20/12.5 (logMAR  $-0.20$ ).

The procedures used in this study conformed to the tenets of the Declaration of Helsinki; written informed consent was obtained from all observers, and all study protocols were approved by the Joint Council on Human Research at California Pacific Medical Center.

## RESULTS

### Age Norms

Figure 2 summarizes the SKILL scores obtained from 203 normal observers, 20 years of age or older, seen

for routine eye examination in our affiliated clinics or coming to the laboratory for vision studies. Testing was conducted in the clinic or in the laboratory. These data were collected under the room lighting present in each test location, resulting in luminances of the light chart between 100 and 150 cd/m<sup>2</sup> (and between 10 and 15 cd/m<sup>2</sup> for the dark chart). Light levels in this range should be used because higher light levels may reduce the SKILL score, and lower light levels inflate it (see Fig. 5). Scoring was performed letter by letter. According to history, vision function measures, ocular examination, or some combination of these, observers were free of obvious ocular and systemic disease. Observers underwent eye examination and/or participated in a battery of vision function tests that included contrast sensitivity, glare sensitivity, color vision, and visual fields, and they completed an extensive questionnaire regarding vision and ocular health. High-contrast acuity had to be better than 20/25 for all observers up to 75 years of age and better than 20/30 for observers older than 75 years. In fact, the high-contrast acuities were better than these levels for the vast majority of observers. Presbyopic observers were corrected appropriately for the 40 cm test distance using either their own glasses (if correct) or additional lenses.

Figure 2 shows SKILL score (difference in number of letters read correctly on the high-contrast light chart and the low-contrast dark chart) as a function of age. Plotted points represent mean data for persons grouped by decade (20 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 69, 70 to 79, and 80+ years). At least 13 people were tested in each decade. Numbers above the data points indicate the number of persons tested in each age group. Because interindividual variability on many measures is known to increase with age, the older age groups were oversampled. The shaded area represents  $\pm 2$  SD. The SKILL score shows little or no change with age for the youngest age groups. Beyond age 50, SKILL score increases with age. The increase in SKILL score is not attributable to the known change in high-contrast acuity with age.<sup>31-33</sup> Because the SKILL score is a difference score, this age-related change in high-contrast acuity is taken into account.

### Test-Retest Reliability

Two sets of data were collected to assess the test-retest reliability of the SKILL score. One set of measures was obtained from 22 patients seen in the eye clinic as part of a study of vision changes in ocular hypertension, glaucoma, or suspected glaucoma.

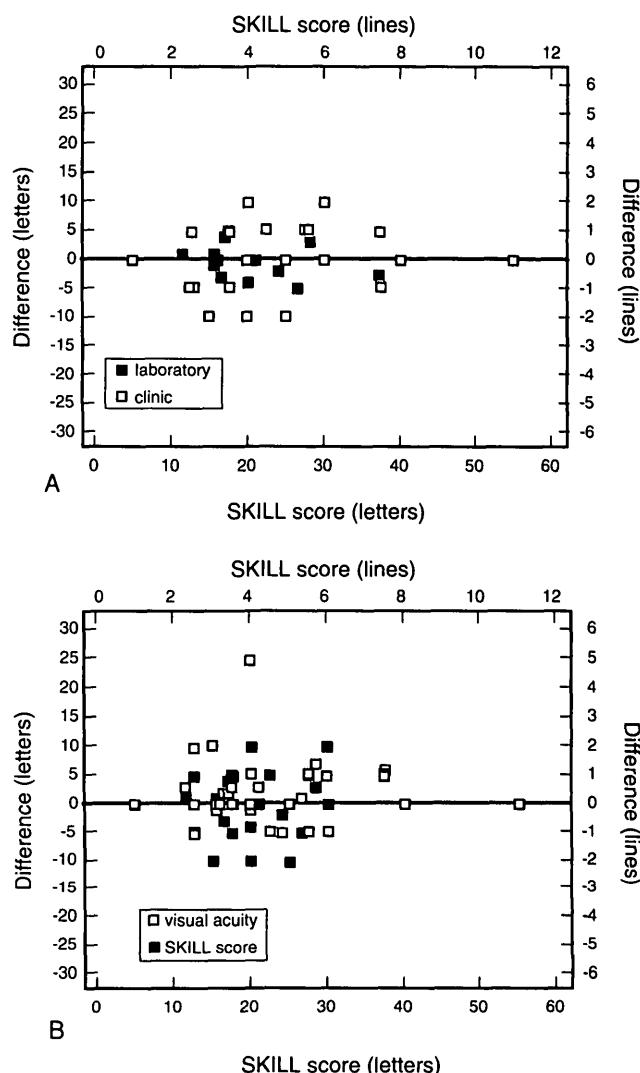
The mean age was 60 years (range, 28 to 81 years). Acuity measured monocularly ranged from 20/15 to 20/60 (mean, 20/25-2; logMAR 0.14). Subjects wore appropriate near correction lenses. Luminance on the

light chart was  $120 \text{ cd/m}^2$ , and the test distance was 40 cm. The SKILL card was administered by a medical resident on two successive patient visits to the eye clinic. Both the light and the dark charts were scored line by line; credit was given for an entire line (five letters) if three or more letters were identified correctly; no credit was given for any letters on a line on which two or fewer letters were read correctly. Scoring was performed line by line because this is the usual manner in which acuity charts are scored clinically. The SKILL score was then computed from the resultant light and dark chart acuities in the usual way.

The other data set was collected in the laboratory. Light and dark charts were scored letter by letter, and SKILL scores were calculated in the usual manner. The subject was forced to guess until three or more letters were read incorrectly on a line. The 14 observers, who were not screened in any way, ranged in age from 17 to 60 years (mean age, 43.8 years) and had visual acuities of  $20/12.5$  ( $-0.20 \text{ logMAR}$ ) to  $20/25.1$  ( $0.12 \text{ logMAR}$ ); mean =  $20/15.1$  ( $-0.08 \text{ logMAR}$ ). Each person was tested twice at approximately 1- or 2-week intervals under the same conditions. Light chart luminance was  $150 \text{ cd/m}^2$ . Subjects wore appropriate near correction, if needed, for the 40-cm test distance, and testing was conducted monocularly.

Reliability measures results are presented in Figure 3a, which shows, for the right eyes (laboratory measures) or left eyes (clinic measures) the difference between the SKILL score obtained on the first and second visits as a function of the person's average SKILL score for the two visits. Open symbols represent data obtained from the patients in the clinical setting. Solid symbols represent laboratory measures. For both data sets, the agreement between the first and second measure does not vary systematically with overall SKILL score; reliability is as good for persons with large (poor) SKILL scores as for persons with low SKILL scores. For each data set, the difference in SKILL score on the two visits is 0.5 letter on average. This indicates that there is no practice effect. All persons tested in the laboratory varied by one line or less (five letters) between measures. Clinic data, scored line by line, were slightly less consistent. None of the clinic-tested subjects showed a difference of more than two lines between SKILL score measures, and the majority (77%) of SKILL scores for this group were within one line on repeated measures.

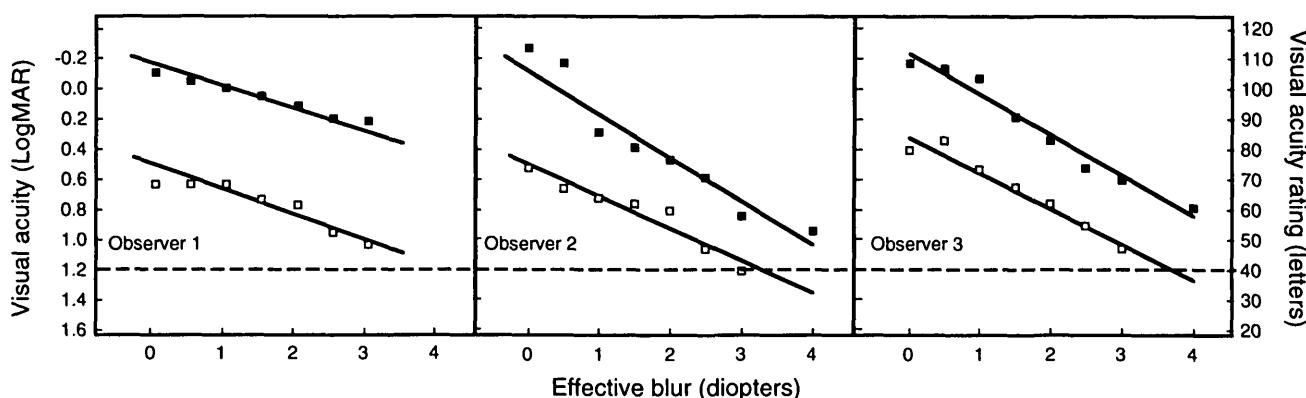
Figure 3b compares the reliability of the SKILL score to that of high-contrast visual acuity, as assessed with the light chart of the SKILL card, for both sets of subjects ( $N = 36$ ). The difference between visits for the SKILL score (solid symbols) and high-contrast acuity (open symbols) is plotted against the average of the person's SKILL scores for the two sessions. SKILL



**FIGURE 3.** Repeatability of the SKILL score measure. (A) The difference between first and second measures of SKILL score is plotted against the mean of the two SKILL scores for measurements in the laboratory, with each chart scored letter by letter (closed symbols) and measurements in the clinic with each chart scored line by line (open symbols). (B) Comparison of the difference between the two SKILL score measures (closed symbols) and the difference between the two high-contrast acuity measures (open symbols) obtained from the same persons.

score reliability is as good as or better than that of standard high-contrast acuity. The average difference in SKILL score is 0.5 letter, whereas the average difference for high-contrast visual acuity is two letters. Absolute differences (ignoring direction of change) are the same for SKILL score and high-contrast visual acuity (3.8 versus 3.5 letters).

Correlation coefficients for repeatability for high-contrast acuity, dark chart acuity, and SKILL score for clinic and laboratory samples are shown in Table 1. Standard deviations of the differences between test



**FIGURE 4.** Effect of blur on performance on the light (filled symbols) and dark (open symbols) charts of the SKILL card for three normal observers. In each case, the number of letters correctly identified is plotted against effective blur in diopters. The acuity is also specified in logMAR. Solid lines are best-fitting linear regressions. Dashed horizontal line at VAR = 40 (log MAR 1.2) indicates the limit of performance measurable with the SKILL Card dark chart at this test distance, imposed by the size of the largest letters on the chart.

and retest values are slightly lower for the SKILL score than for high-contrast visual acuity. These results indicate that SKILL score reliability is as good as or slightly better than that of high-contrast visual acuity.

### Effect of Blur on SKILL Score

The fact that the SKILL card is used at a 16-inch (40-cm) test distance raises the issue of optical defocus, particularly for presbyopic observers. To address this issue, SKILL score was determined with varying degrees of optical defocus produced by convex lenses inserted in a trial frame. Three observers, free of ocular disease and with Snellen acuity correctable to 20/20 or better, were tested after cycloplegia was induced (1% cydopentolate after 0.5% proparacaine hydrochloride) with a 2-mm artificial pupil. The purpose of this control experiment was to determine the effects of blur alone uncontaminated by any change in pupil size or by any ocular-retinal disorder, which is why young, healthy observers participated, accommodation was paralyzed, and artificial pupils were used. To avoid ceiling effects on the high-contrast chart, which might lead to an underestimation of the effect of blur, testing was performed at 1 m. Figure 4 shows the performance on the light (closed symbols) and dark (open symbols) charts of the SKILL

card plotted against effective blur. Effective blur is derived from the dioptric power of the lens, taking into account any uncorrected refractive error and the (1 D) viewing distance. The ordinate shows visual acuity plotted in logMAR and in visual acuity rating in letters. A visual acuity rating of 100 letters corresponds to 20/20 (logMAR = 0), a rating of 50 corresponds to 20/200 (logMAR = 1). A change of five letters represents one line (logMAR 0.1). High-contrast acuity and low-contrast, low-luminance acuity decrease linearly with increasing blur. The best-fitting linear regression lines are shown and provide a good fit to the data. The SKILL score is the difference between the two regression lines.

For observers 1 and 3, the lines are nearly parallel, indicating that SKILL score does not change significantly with even large amounts (2 to 3 D) of blur. In fact, these two observers show only a 2.3-letter increase and a 4-letter decrease in SKILL score, respectively, for 2.5 D of blur. Observer 2 shows a larger decrease in SKILL score with increasing dioptric blur; 2.5 D of effective blur reduces SKILL score by 10 letters compared to no blur. Most presbyopic observers have some near correction—a reasonable error in near correction is 1 D; this level of blur produces on average a 1.5-letter change in SKILL score compared to full correction. A large amount of refractive blur may produce an underestimate of SKILL score. This may result in a failure to detect small abnormalities, reducing the sensitivity of the test; blur will not result in falsely abnormal test results. To maximize the validity of the measured SKILL score, appropriate (near) correction should be used.

### Effect of Luminance on SKILL Score

Room lighting can vary considerably between locations. To determine the influence of luminance on

**TABLE 1.** Repeatability Coefficients for the SKILL Card

Repeatability Coefficients	Clinic Sample (n = 22)	Laboratory Sample (n = 14)
High contrast acuity	0.74	0.75
Dark chart acuity	0.85	0.94
SKILL score	0.77	0.91

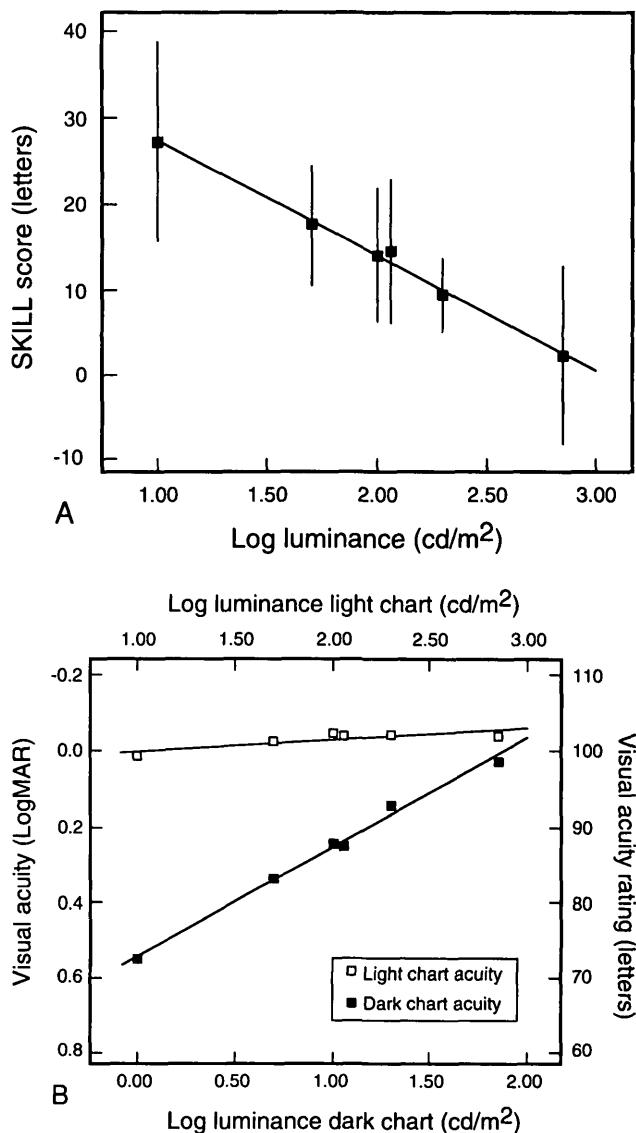
SKILL score, two groups of young observers (all in their twenties) were tested. SKILL scores were measured in the first group of eight observers at widely spaced light levels: 10, 115, and 800 cd/m<sup>2</sup>. A second group of nine observers was tested at 50, 100, and 200 cd/m<sup>2</sup> to verify the apparently linear relationship obtained between SKILL score and log luminance and to assess the effects of light level within ranges more likely to be encountered in the clinic. Scoring was performed letter by letter, and the subject was required to guess until three letters were read incorrectly on a line. Results for both groups are shown in Figure 5a, which shows SKILL score versus log luminance of the light chart. The error bars show  $\pm 2$  SD. A linear relationship between log luminance and SKILL score is evident. The least-squares regression line is a good fit to the data ( $r^2 = 0.99$ ). The average difference in SKILL score at 80 cd/m<sup>2</sup> versus 200 cd/m<sup>2</sup>, the range of light levels likely to be encountered under room illumination in the clinic or elsewhere, was approximately five letters (one line). These results indicate that although care should be taken to retest patients under the same illumination conditions each time, SKILL score is relatively unaffected by small variations in ambient illumination.

Figure 5b shows separately high-contrast (light chart) visual acuity and dark chart (low-contrast, low-luminance) acuity as functions of luminance of the light chart (on the upper abscissa) or dark chart (on the lower abscissa). The dependence of SKILL score on luminance is caused primarily by the decrease in low-contrast, dark chart acuity because high-contrast acuity shows little change over this range of light levels. The linear change in acuity with log luminance fails at higher light levels at which acuity becomes independent of luminance for light and dark charts. At such high light levels ( $>1000$  cd/m<sup>2</sup>), the low-contrast and high-contrast acuity functions are expected to merge, resulting in a SKILL score of zero.

## SKILL CARD IN OCULAR DISEASE

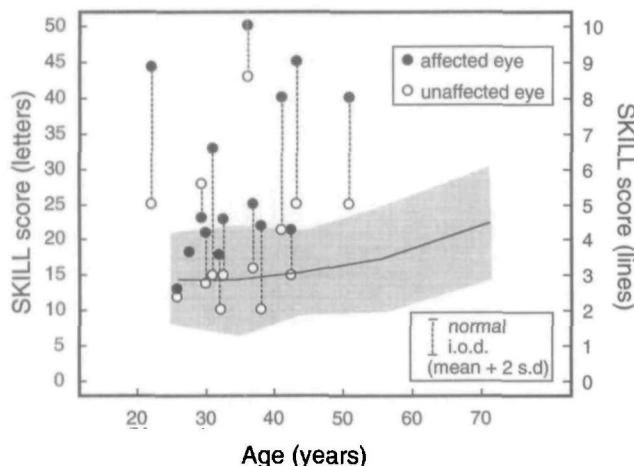
### Optic Neuritis

The sensitivity of the SKILL card to visual abnormalities was assessed in a group of patients with optic neuritis.<sup>34,35</sup> Fifteen patients (nine women, six men; mean age, 34.6 years) were seen an average of 6.25 months (range, 1 to 36 months) after the initial or most recent attack of acute demyelinating optic neuritis. The SKILL card was used as one of a battery of tests of spatial and color vision. The luminance of the white chart was 150 cd/m<sup>2</sup>, and scoring was performed letter by letter. Two of the authors performed the measurements. Figure 6 shows the SKILL score of the affected (closed symbols) and unaffected



**FIGURE 5.** Effect of luminance on performance on the SKILL Card. (A) Mean SKILL score plotted against luminance measured in a group of young normals. Vertical lines through the data points represent  $\pm 2$  SD. (B) Performance on the light (open symbols) and dark (closed symbols) charts of the SKILL card plotted against luminance (cd/m<sup>2</sup>) of the light chart (upper abscissa). The corresponding luminance of the dark chart, which is 1 log unit less, is indicated on the lower abscissa. Performance on each chart is given in logMAR and VAR, in which 1 unit is one letter read correctly, and a VAR of 100 is equivalent to 20/20 acuity.

(open symbols) eyes of the patients with optic neuritis. Despite the fact that all subjects' acuities had recovered to 20/40 or better at the time of testing (mean 20/25), 73.3% of the affected eyes had SKILL scores 2 SD or more above (poorer than) the normal mean for their age. Fifty percent of those with 20/20 or better high-contrast acuity had abnormal SKILL scores. Six of the 15 patients showed wildly abnormal SKILL scores in the



**FIGURE 6.** SKILL score is plotted against the ages of 15 patients with recovered acute demyelinating optic neuritis. SKILL scores for the affected (*closed symbols*) and unaffected (*open symbols*) eyes are plotted. Vertical broken lines connect data for each eye of persons. Solid line and shaded region represent the mean  $\pm$  2 SD for normal observers. The interocular difference obtained from a group of normal observers (mean  $\pm$  2 SD) is given for comparison.

affected eye. For example, one patient with 20/20 Snellen acuity had a dark chart acuity of 20/220 and lost more than 10 lines when contrast and luminance were reduced. Many (40%) of the unaffected eyes were abnormal, many markedly so. The finding of abnormal vision function in the unaffected eyes of patients with optic neuritis is not unique to the SKILL score or to this study.<sup>36,37</sup>

The high- and low-contrast distance acuity (Bainbridge-Lovie charts at 3 m test distance), contrast sensitivity (Pelli-Robson chart at 3 m), color vision (Adams' desaturated D-15<sup>38</sup>), short-wavelength- and middle-wavelength-sensitive cone increment thresholds were determined for each patient. The SKILL score was not significantly correlated with performance on any of these other measures, indicating that it measures a different aspect of visual performance. For example, the correlation coefficient between SKILL score and Pelli-Robson contrast sensitivity for the affected eyes was  $r = 0.09$ , indicating no relationship between these two measures. Even though nine of the affected eyes (60%) and two of the unaffected eyes (13%) had abnormal Pelli-Robson scores according to the age norms developed by Elliot and Whitaker,<sup>39</sup> some of those with abnormal Pelli-Robson scores had normal SKILL scores and vice versa, indicating that the two tests provide nonredundant information about vision function.

## DISCUSSION

### Age Changes

The average SKILL score changes little in persons between 20 and 50 years of age, but it increases linearly

beyond age 50. A linear correlation between age and SKILL score yields a correlation coefficient of 0.69 (slope = 0.21). A bilinear fit gives a slightly higher correlation coefficient of 0.72, but the bilinear fit is not statistically different from the linear fit. The bilinear fit gives a cross point of 46 years, with a slope of 0.008 before 46 years and a slope of 0.33 after 46 years. Theoretically, it is possible that ceiling effects might contribute to the lack of change in SKILL score in persons between the ages of 20 and 50. If the high-contrast acuity is better than the smallest line on the light chart, the SKILL score could be artificially small. Younger observers are expected to have better acuity than older observers, potentially making the SKILL score more susceptible to ceiling effects in young observers.

The change in SKILL score with age is not attributable to the well-known change in acuity<sup>31-33</sup> because SKILL score is a difference score that takes acuity into account. There are many age-related changes in the ocular media and later in the visual system that may contribute to the observed age-related change in SKILL score. The low reflectance of the dark side of the SKILL chart minimizes intraocular light scattering by the ocular media, known to be greater in older eyes. It is unlikely that the increased scatter of the aging lens is a major cause of the age-related changes in SKILL score. It is possible that scatter within the eye and retina will reduce the contrast of the retinal image and contribute somewhat to the increase in SKILL score with age. However, age-related changes in other optical factors, such as pupil size or light transmission through the ocular media, are more likely to affect SKILL score significantly.

Pupil size decreases with age in a luminance-dependent manner; the largest differences are evident at low light levels.<sup>40,41</sup> Some of the change in SKILL score may be caused by reduced retinal illuminance resulting from age-related decreases in pupil size. On the assumption that the only difference between a young and an old visual system is the smaller pupil of the older eye, one can calculate the expected SKILL score for the older group from the acuity versus luminance functions from younger observers. Using the pupil data of Winn et al.,<sup>41</sup> the estimated decrease in retinal illuminance is 0.2 log units between ages 50 and 80. Taub and Sturr<sup>42</sup> measured high- and low-contrast acuity in young and older observers as a function of luminance over the same range of absolute light levels spanned by the SKILL card in our study. Using their data, we calculated the expected change in acuity from a 0.2 log unit decrease in retinal illuminance. These calculations indicate that pupil size changes account for virtually none of the observed change in SKILL score with age. Our own direct mea-

surement of the effect of luminance in young observers (Fig. 5) predicts a somewhat larger change in SKILL score. A 0.2 log unit change in retinal illuminance produced a three-letter change in SKILL score. The observed average change with age is nine letters. In sum, at most one third of the observed increase in SKILL score with age is attributable to age-related pupillary miosis.

The transmission of light through the ocular media, particularly the lens, shows a spectrally dependent decline with age.<sup>43–47</sup> Short-wavelength light is significantly attenuated, whereas the mid-spectral wavelengths are less affected. The SKILL Card data described in this article were collected under broad-spectrum (white) light. We estimate that the reduction in effective photopic luminance produced by the increased lens density is approximately 0.2 log units, contributing an additional three letters to the observed increase in SKILL score between ages 50 and 80.

The estimated 0.4 log unit decrease in retinal illuminance between ages 50 and 80 produced by the combined change in pupil size and media density can account for six letters of the observed nine-letter change in SKILL score. Thus, most (two thirds) of the SKILL score change observed beyond age 50 can be accounted for by preretinal factors. The remaining age-related drop in SKILL card performance most likely reflects changes in the subsequent visual pathway, including sometimes-reported changes in cone foveal pigment density,<sup>48</sup> changes in macular cone numbers,<sup>49(cit50)</sup> or changes in the number or connections or integrity of units in the neural pathway (see ref. 51 for review).

### Repeatability

The repeatability of SKILL score measures was found to be comparable to that of high-contrast acuity measured in the same observers under the same conditions. SKILL score repeatability was somewhat better when assessed in the laboratory than when measured in the clinic, but it was good in both groups. The differences in repeatability for the two sets of measures may be related to a number of factors, including the grading scale (letter by letter versus line by line<sup>52,53</sup>) or the characteristics of the observer samples.

Interocular SKILL score differences in visually normal persons are small. The 95% confidence limits for interocular differences is less than one line determined by measurements of SKILL score for the two eyes for the group of 14 observers tested in the laboratory repeatability study. Interocular differences larger than five letters are indicative of disease in one eye. Abnormal interocular differences were observed in 11 of the 15 'recovered' patients with optic neuritis we

examined, including some for whom the SKILL score of each eye was within normal limits. Interocular SKILL score differences are an additional and frequently more sensitive index of eye health status than comparison to age norms.

Although true interobserver differences undoubtedly contributed to the large variability in the age norms in Figure 2, other factors include light level variation ( $\sim 50 \text{ cd/m}^2$ ) among test locations. Therefore, it is advised that age norms be collected under their own testing conditions by individual investigators using the SKILL card to maximize the ability to detect abnormalities in clinical populations.

### Blur

Because the SKILL card is intended for a viewing distance of 40 cm, blur is a potential contaminating factor. Blur affected the high-contrast acuity of one observer slightly more than the low-contrast, low-luminance acuity, resulting in a small decrease in SKILL score with increasing blur. The lesser effect of blur on the performance of the dark chart can be explained by the fact that acuity is reduced on this chart compared to the other. As a result, at the acuity limit, the letters on the dark chart are larger, and larger (lower spatial frequency) objects are less affected by blur. We conclude that the impact of blur on SKILL score is minimal for small amounts of blur but may lead to an underestimate of the SKILL score when significant ( $>2 \text{ D}$ ) amounts of blur are present. This would lead to a failure to detect small abnormalities, but false-positive results (i.e., misclassifications of normal conditions as abnormal) would not result.

### Luminance

The increase in SKILL score with large changes in luminance is caused primarily by the known higher sensitivity of low-contrast targets to the effects of luminance because the shape of the contrast sensitivity function changes with luminance.<sup>54</sup> High-contrast acuity is relatively unaffected over these same light level ranges. From a practical point of view, small variations in illumination, commonly encountered when going from one examination room to another, are not likely to introduce appreciable variability. However, when using the SKILL Card to track subtle changes in a person over time, care should be taken to retest under the same illumination.

### Ocular Disease

The SKILL card showed dramatically abnormal results in most of the presumably recovered patients with optic neuritis seen, on average, 6 months after the acute attack. In addition, many unaffected eyes were abnormal. We attribute the sensitivity of the SKILL

card to the reduced luminance of the card because low-contrast, high-luminance acuity was not significantly impaired in these patients. These results are in accord with clinical reports,<sup>29</sup> as well as a self-report from the Optic Neuritis Treatment Trial.<sup>55</sup>

The dramatic effect that the small change in luminance has on resolution of low-contrast letters in the patients with optic neuritis suggests an abnormality in the steady state adaptation of the contrast-detection mechanism. The vision function of the patients with optic neuritis at moderate photopic levels of illumination appears to be similar to that of visually normal observers at illumination levels 100 times dimmer. At moderate light levels (e.g. 150 cd/m<sup>2</sup>), a 1 log unit decrease in luminance does not affect high-contrast acuity and minimally affects low-contrast acuity in normal observers.<sup>56</sup> However, at much dimmer light levels near 1 cd/m<sup>2</sup>, a 1 log unit drop in mean luminance reduces low-contrast acuity by approximately 0.5 log unit.<sup>56</sup> Such a drop would produce a SKILL score of 25 letters; the mean SKILL score was 29 letters in the affected eyes. The notion that patients with optic neuritis are functioning at an effectively reduced luminance level is suggested further by the presence of an afferent pupillary defect,<sup>36</sup> increased perceptual latency,<sup>57</sup> and increased latency of visual-evoked potential signals,<sup>58–60</sup> decreased CFF,<sup>61</sup> and reduced color vision.

To date, our own clinical application of the SKILL card has focused largely on conditions affecting the optic nerve. A limited data set indicates that the SKILL score is markedly abnormal in persons with age-related maculopathy, suggesting it as a tool for assessing retinal disease. A recent publication by Leguire et al<sup>62</sup> indicates that the SKILL card is sensitive to cortical abnormalities. These authors showed that SKILL score is abnormally small in the affected eyes of persons with unilateral amblyopia compared to the unaffected eyes and to the results for age-matched children tested by the same authors. These findings corroborate the well-known clinical observation that the resolution deficit of amblyopic eyes is less severe under reduced illumination.<sup>63–65</sup> If a patient has unexplained reduction in visual acuity in one eye, use of the SKILL card may contribute to determination of the cause of the visual loss in a way similar to that of a 3 log unit neutral density filter test. Disorders of the retina and optic nerve will lead to increases in SKILL score, whereas amblyopia will result in a decreased SKILL score compared to the patient's normal eye.

In this article, we have discussed the effects of age, blur, luminance, and ocular disease on the SKILL score, which is a difference score. Of course, the acuity on the dark side of the chart can be used by itself as a measure of vision function, which is particularly

appropriate when relating vision function to performance. In the visually normal persons we tested, dark chart acuity alone is responsible for 75% of the variance in the SKILL score, whereas high-contrast acuity contributes approximately 25% of the variance. This is not surprising because all participants had good acuity; therefore, the range of high-contrast acuity values is limited. In patients with variation in high-contrast acuity and with ocular disease, the amount of variance in the SKILL score accounted for by dark chart acuity alone is expected to be less. In fact, preliminary data from the Optic Neuritis Treatment Trial's use of the SKILL card in follow-up of more than 150 patients show that less than 25% of the variance of the SKILL score can be accounted for by the dark chart acuity. The SKILL score can provide different information than the dark chart acuity alone and can yield information about mechanisms that are involved in adapting to low contrast and low luminance.

#### Key Words

adaptation, contrast sensitivity, optic neuropathy, psychophysics, visual acuity charts

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