# Visual Acuities "Hand Motion" and "Counting Fingers" Can Be Quantified with the Freiburg Visual Acuity Test

*Kilian Schulze-Bonsel, Nicolas Feltgen, Hermann Burau, Lutz Hansen, and Michael Bach*

**Purpose.** The visual acuity (VA) of patients with very low vision is classified using the semiquantitative scale "counting fingers" (CF), "hand motion" (HM), "light perception" (LP), and "no light perception." More quantitative measures would be desirable, especially for clinical studies. The results of clinical VA measurements, Early Treatment Diabetic Retinopathy Study (ETDRS) charts, and the Freiburg Visual Acuity Test (FrACT) were compared. The FrACT is a computerized visual acuity test that can present very large Landolt C optotypes when necessary.

**Methods.** Examined were 100 eyes of 100 patients with various eye diseases (e.g., diabetic retinopathy, ARMD), covering a range of VAs from LP to decimal 0.32. The FrACT optotypes were presented on a 17-inch LCD monitor with random orientation. After extensive training, two ETDRS and FrACT measurements were obtained. The testing distance was 50 or 100 cm.

**Results.** ETDRS and FrACT coincided closely for VA $\geq$ 0.02 ($n$ = 80). ETDRS measures were successfully obtainable down to CF (at 30 cm; test–retest averaged over all patients, coefficient of variation $[CV]_{ETDRS}$ = 9% ± 8%), and FrACT provided reproducible measurements down to HM (test–retest $CV_{FrACT}$ =12% ± 11%). For CF ($n$ = 6), both ETDRS and FrACT resulted in a mean VA of 0.014 ± 0.003 (range, 0.01–0.02). The VA results of FrACT for HM ($n$ = 12) were 0.005 ± 0.002 (range, 0.003–0.009); the individual values were highly reproducible. No results were obtainable for LP ($n$ = 2).

**Conclusions.** The three acuity procedures concur above a VA of 0.02. The results suggest that the category CF at 30 cm can be replaced by 0.014, using ETDRS or FrACT. Using FrACT, one can even reproducibly quantify VA in the HM-range, yielding a mean VA of 0.005. (*Invest Ophthalmol Vis Sci.* 2006;47: 1236–1240) DOI:10.1167/iovs.05-0981

Visual acuity (VA) is one of the most important variables in clinical studies, and it is the most important parameter for patients. There are many different VA-tests. The Early Treatment Diabetic Retinopathy Study (ETDRS) charts[1] are used most frequently in clinical studies. Modern VA charts follow a logarithmic scale. The accepted step size is 0.1-log-unit steps, corresponding to a factor of 1.259 between the lines. Currently, VA tests do not cover the whole range of VA scale as we cannot provide accurate quantitative measurements in the lower range between the subjective measures of "counting fingers" (CF) and "no light perception" (NLP). These values below the testing range of the ETDRS charts[1] can only be roughly estimated[2,3] by using the Snellen charts, for example. One of this estimation's problems is the difference in contrast. CF at a given distance is usually converted to a Snellen equivalent by assuming that the fingers are approximately the size of the elements of a "200 letter. " But the contrast of a hand against a white coat is much lower than that of a black letter on a white background. Holladay[3] estimated a VA of 0.01 (decimal notation) for CF and 0.001 for "hand motion" (HM). His estimates suggest a difference of 1-log-unit step between CF and HM. Grover et al.[2] estimated a decimal VA of 0.0025 for CF, 0.002 for HM, 0.0016 for "light perception" (LP), and 0.0013 for NLP, which would only indicate a difference of 0.1-log-unit step between CF and HM and between HM and LP, meaning that the change from CF to HM would not be relevant, since typically a change of 3 lines (corresponding to a factor of two) or more is considered clinically significant. Clinical experience, however, suggests that this difference is noticeable by patients and can improve their spatial orientation and ultimately their quality of life. Reliable quantification of low VA levels, particularly of CF and HM, could resolve this question.

The Freiburg Visual Acuity Test (FrACT) is a computerized VA test that can present very large Landolt C optotypes when necessary (for details see below in equipment). We focused on patients with low vision and tried to find out whether VAs on the semiquantitative ordinal scale of CF, HM, and LP can be quantified by the FrACT. We also compared the FrACT results in patients with low vision with the results obtained using ETDRS charts and a standard clinical eye chart.

## Materials and Methods

### Patients

One hundred eyes of 100 patients with low vision, covering a range of VA from LP to decimal 0.32, were tested. When both eyes met these criteria, the eye with lower VA was tested. We included patients with corneal diseases, cataract, glaucoma, trauma, uveitis, diabetic retinopathy, retinal detachment, AMD, macular hole, retinal vascular occlusion with macular edema, optic nerve atrophy, high myopia, amblyopia, and nystagmus (Table 1). The tenets of the Declaration of Helsinki were followed, the study's protocol was approved by our local ethics committee, and informed consent was obtained from all participating patients.

### Nomenclature

VA is defined as the reciprocal value of the gap size (in minutes of arc) of the smallest recognized Landolt C. The gap size of the smallest recognized Landolt C (in minutes of arc) is called MAR (minimum angle of resolution) and represents the smallest angle between two points that an observer can just barely discriminate.

VA is recorded in different notations: decimal acuity, Snellen fraction, and logMAR. In the Snellen fraction (i.e., 20/80), the enumerator represents the distance between the patient and the eye chart. The denominator represents the distance at which the optotypes can be read by a person with "normal" (20/20) acuity. The decimal acuity

From the Department of Ophthalmology, University of Freiburg, Freiburg, Germany.

Presented at the annual meeting of the Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 2005.

Submitted for publication July 27, 2005; revised October 31, 2005; accepted January 9, 2006.

Disclosure: **K. Schulze-Bonsel**, None; **N. Feltgen**, None; **H. Burau**, None; **L. Hansen**, None; **M. Bach**, None

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be marked "*advertisement*" in accordance with 18 U.S.C. §1734 solely to indicate this fact.

Corresponding author: Michael Bach, Department of Ophthalmology, University of Freiburg, Killianstrasse 5, Freiburg 79106, Germany; michael.bach@uni-freiburg.de.

**TABLE 1.** Disease Category Frequencies of the 100 Subjects

| | |
|---|---|
| Corneal diseases | 11 |
| Cataract | 14 |
| Glaucoma | 14 |
| Trauma | 4 |
| Uveitis | 2 |
| Diabetic retinopathy | 21 |
| Retinal detachment | 11 |
| Age-related macular degeneration | 10 |
| Macular hole | 4 |
| Retinal vascular occlusion with macular edema | 2 |
| Optic nerve atrophy | 2 |
| High myopia | 2 |
| Amblyopia | 2 |
| Nystagmus | 1 |

Data are the number of subjects.

derives from the Snellen fraction by simply calculating the fraction. MAR is the reciprocal value of VA. As with decimal acuity, it makes sense to calculate the logarithm so that the values are approximately normally distributed: MAR = 1/VA, logMAR = log(1/VA), and logMAR = −log(decimal acuity). Visual acuities converted into different notations are shown in Table 2. In this study, all visual acuities are expressed as decimal acuity.

## Equipment

**ETDRS Charts.** The ETDRS chart (Lighthouse Low Vision Products, New York, NY) is based on the design suggested by Bailey and Lovie[4] and incorporates the recommendations of the U.S. National Academy of Sciences-National Research Council (NAS-NRC).[5] The chart has been described in detail by Ferris et al.[1] In brief, the letter stimuli are printed on a translucent panel and illuminated[6] from behind. The chart has five letters per row of the same size. The letters of the following rows become gradually smaller, the difference is 0.1 logMAR. A wide range of VA can be tested when the testing distance is changed. A logMAR between +1 and −0.3 can be reached at 4 m, from +1.6 to +0.3 logMAR at 1 m and from +1.9 to +0.6 logMAR at 0.5 m. We describe the procedure in a later section. For consistency, all logMAR results of this study were transformed to the log(decimal VA) scale.

**The Freiburg Visual Acuity Test.** The FrACT is a computerized VA test that can present very large Landolt C optotypes on a computer monitor when necessary. This test has been developed and described in detail by one of the authors[7] and runs on Macintosh (Apple Computers, Cupertino, CA), Linux (developed by Linus Torvalds; available without charge at Linux Online; http://www.linux.org), or Windows (Microsoft Corp., Redmond, WA) operating systems. It has been validated in various studies[8–10] and can be downloaded free of charge.[11] Besides a computer, a large monitor, and a keyboard, no extra equipment is needed. The FrACT can be calibrated easily to the monitor size and resolution used. In this study, the optotypes were presented on a 17-inch LCD monitor (luminance 170 cd/m$^2$, resolution 1280 × 1024). Using the given monitor size and resolution, VA from 0.02 up to 3.2 can be tested at a distance of 4 m. At 1 m, the possible VA range is from 0.005 to 0.8. When used at 0.5 m, the range is from 0.0025 to 0.4. The testing distance can be set to any value.

FrACT always tests at the currently most probable VA threshold on the basis of all previous answers after the best PEST algorithm (best parameter estimation by sequential testing).[12,13] The algorithm operates on a log(VA) scale; thus, the step sizes automatically take the logarithmic progression of VA into account. The steps are calculated by an adaptive-staircase procedure,[12,13] consequently, step sizes are initially quite large (equivalent to approximately 3 lines), but become smaller than 1 line when the algorithm homes in on the VA threshold. This method results in a higher number of optotype presentations near the patient's VA threshold. It also means that the size of the Landolt C typically changes with every trial, as does its orientation, which is fully randomized. With computer monitors, pixel-discreteness artifacts limit the presentation of very small stimuli. By using anti-aliasing[14] (smoothing of contours by multiple gray levels), spatial resolution was improved by a factor of four over the pixel size.

**Snellen Eye Chart.** The standard clinical VA was determined using a standard clinical Snellen eye chart according to the conventional testing protocol described in the next section.

## Procedure

All VA measurements were performed by a single examiner. While one eye was tested, the other was occluded. All subjects wore correction for the testing distance. The correction was based on the results of automatic refractometry, followed by cross cylinder optimization.

Before the main testing procedure, the standard clinical VA was determined for each subject. The patients started to read each row from the top of the Snellen eye chart and proceeded toward the bottom. This was terminated when the hit rate was less than five of eight (an approximation to 56.25%, the steepest point of the psychometric acuity function). The observation distance was 5 m if the participant could identify the largest letters on the chart at that distance. Otherwise, it was reduced to 1 m. If this was not successful (when the largest optotype could not be recognized correctly), VA was classified using the semiquantitative ordinal scale CF, HM, and LP at a distance of 30 cm.

Each patient was trained extensively with the ETDRS "R" chart and the FrACT. Two ETDRS and two FrACT measurements were then obtained in a block design, alternating in successive patients (ABBA/BAAB), where "A" stands for ETDRS and "B" for FrACT. ETDRS chart 1

**TABLE 2.** Quantitative Data for HM and CF

| Decimal Acuity | Log(VA) | LogMAR | Snellen Ratio | Low-Vision Category Range | Low-Vision Category Mean (decimal) |
|---|---|---|---|---|---|
| 0.0033 | −2.48 | 2.48 | 20/6060 | HM | HM: 0.0052 (FrACT) (range: 0.0033–0.0090) |
| 0.0040 | −2.40 | 2.40 | 20/5020 | | |
| 0.0050 | −2.30 | 2.30 | 20/4000 | | |
| 0.0063 | −2.20 | 2.20 | 20/3170 | | |
| 0.0080 | −2.10 | 2.10 | 20/2500 | | |
| 0.010 | −2.00 | 2.00 | 20/2000 | CF | CF: 0.014 (EDTRS + FrACT) (range: 0.01–0.02) |
| 0.013 | −1.90 | 1.90 | 20/1600 | | |
| 0.014 | −1.85 | 1.85 | 20/1400 | | |
| 0.020 | −1.70 | 1.70 | 20/1000 | | |
| — | — | — | — | | |
| 0.1 | −1.00 | 1.00 | 20/200 | — | |
| — | — | — | — | | |
| 1.0 | 0.00 | 0.00 | 20/20 | — | |

For intuitive display, these low visual acuity ranges are converted into different notations.

and ETDRS chart 2 were alternated. All VA tests were performed in a dimly lit room. Illumination measured at the subject's eye was 50 lux. The FrACT optotypes were presented on the monitor at a distance of 50 cm. Landolt C optotypes were displayed in one of four orientations and at high contrast. Although the FrACT can optionally display Landolt rings in eight different gap positions, we chose four positions in this study, because in a pilot study this had proven to be less confusing for elderly patients and those with low vision. During the training phase, the examiner subjectively evaluated the patient's behavior. When right–left confounds were observed, the patient was instructed to point to the perceived direction. Only one Landolt ring was displayed at a time, and the subjects' verbal response was entered into the computer by the examiner. Then, the next optotype was presented. When the optotypes became so small that they were in the threshold region of the psychometric acuity function, patients typically reported "I'm not sure" or "I can't see anything." However, to avoid bias by the subjects' "criterion" (as the signal detection theorists call it), we used the forced-choice procedure. Thus, the patients always had to report a direction, even if based on "best guess." This required gentle coaxing in the training phase. Forced choice was used in every one of the 3 tests compared herein. FrACT measurement terminated after a fixed number (30) trials[7] (the presentation of one optotype counts as one trial). Finally, the result was calculated and presented on the screen, optionally in Snellen format or in decimal notation. A FrACT examination was deemed unsuccessful when acuity was so low that the hit rate for the largest optotype was below 62.5%.

The ETDRS charts were presented at a distance of 50 cm for visual acuities up to decimal 0.2. For VAs higher than 0.2 and up to 0.32, the charts were presented at a distance of 100 cm. The standard procedure for VA determination using ETDRS charts has been described in detail.[1,15] It was required that the subject read down the chart letter by letter and row by row, beginning with the first letter on the top row. When the subject had difficulties reading a letter, he or she was encouraged to make a best guess. The test was stopped only when the hit rate was at chance level, despite having urged the subject to read or guess. A logMAR score was specified based on the number of letters read correctly and according to the test distance. An ETDRS examination was recorded as unsuccessful when acuity was so low that less than three of five letters in the largest line could be recognized.

### Statistical Analysis

All statistical evaluations were performed on the approximately normally distributed log(VA) = −logMAR scale. The mean (with SD) of the coefficients of variation (CVs) was used for assessing the agreement between ETDRS and FrACT and the reproducibility of each method between the first and the second measurement. The CVs and the SDs were also used for assessing the reproducibility of the quantified VA measurements for CF and HM. For intuitive display, all results were transformed to the decimal VA scale: decimal VA = $10^{\log(VA)}$.

## Results

The mean age of the subjects was 68 years (range, 20–92 years). From the 100 patients, 80 eyes were examined successfully with a standard clinical eye chart, 84 with ETDRS charts, and 98 with the FrACT. Eighty patients had a VA ≥ 0.02, 6 had CF, and 12 HM.

### Standard Clinical Eye Chart

Successful measurements were obtained down to a VA of 0.02 in all eyes ($n$ = 80). It was not possible to obtain numbers for CF, HM, and LP.

### ETDRS Charts

ETDRS charts provided successful measurements down to CF (Fig. 1A). For VA ≥ 0.02 ($n$ = 80), ETDRS results were obtainable in all subjects. Successful ETDRS measurements were possible in four of six patients regarding CF (two subjects could not correctly recognize any letter on the ETDRS chart). ETDRS measurements for CF resulted in a mean VA of 0.0134 ± 0.0022 (range, 0.0115–0.0174; $n$ = 4). The mean test–retest CV for CF was 9% ± 9%. No successful measurements could be performed with ETDRS charts for HM and LP.

### Freiburg Visual Acuity Test

The FrACT provided reproducible measurements down to HM (Fig. 1B). FrACT measurements for CF resulted in a mean

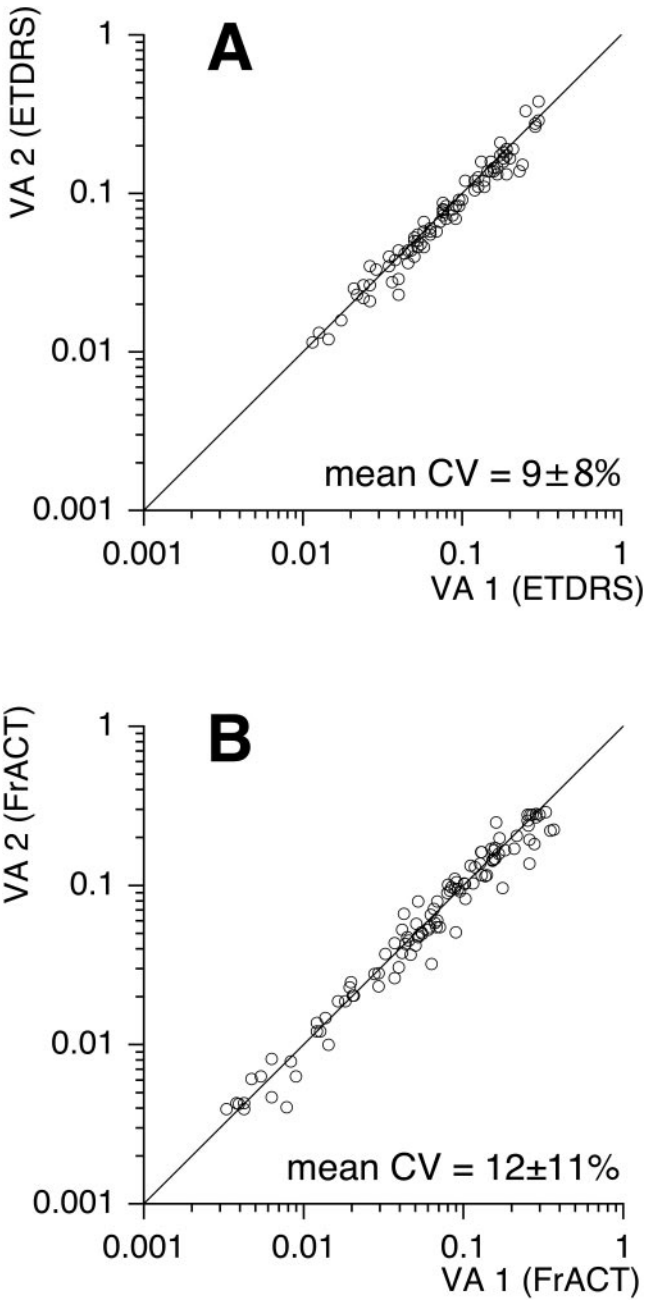
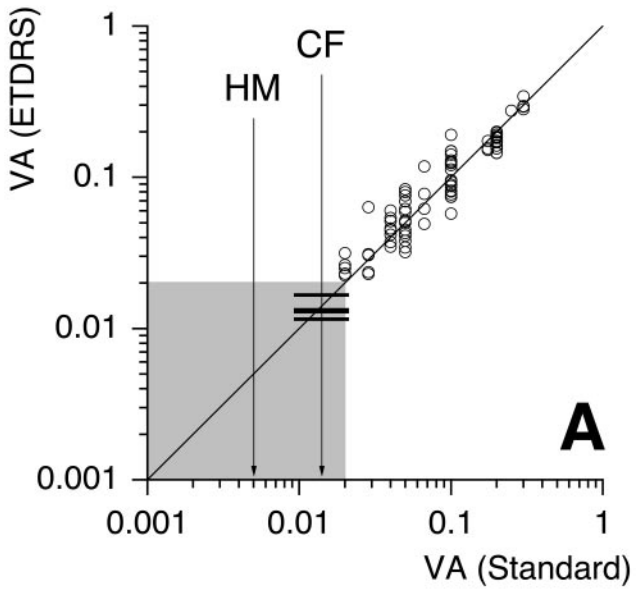



**Figure 1.** Reproducibility of ETDRS and FrACT. VAs (decimal notation) of the first measurement versus those of the second measurement for ETDRS (**A**) and FrACT (**B**). The reproducibility was quantified by the mean of the CVs ± SD, averaged over all patients. Test–retest reliability was high for both procedures; both tests had a mean CV of ~10%.

decimal VA of 0.0137 ± 0.0032 (range, 0.0100–0.0206; $n$ = 6). The mean test–retest CV for CF was 10% ± 11%. The FrACT's VA results for HM were 0.0052 ± 0.0015 (range, 0.0033–0.0090; $n$ = 12), and individual values were highly reproducible (mean test–retest CV for HM = 14% ± 13%). No successful measurement could be performed with the FrACT for LP ($n$ = 2).

The reproducibilities of ETDRS and FrACT are reported in Figure 1. VAs of the first measurement for both methods are plotted against those of the second measurement. The mean of the CVs with SD between the first and the second measurement, averaged over all patients, was used to assess the reproducibility of each method: mean $CV_{ETDRS}$ = 9% ± 8%, mean $CV_{FrACT}$ = 12% ± 11%.

The agreement between ETDRS (or FrACT) and the standard clinical eye chart is depicted in Figure 2. ETDRS and FrACT correspond well with the standard clinical eye chart results for VA ≥ 0.02. The agreement between ETDRS and FrACT is depicted in Figure 3, which shows a scatterplot of VAs measured with ETDRS against those measured with the FrACT. ETDRS and FrACT coincided closely without systematic bias and with a mean CV of 15% ± 11%.



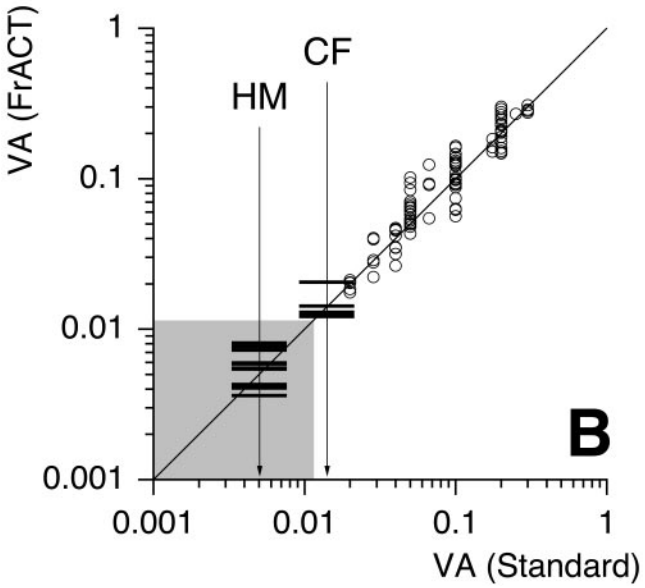




**FIGURE 2.** Agreement between ETDRS (**A**) and FrACT (**B**) and a standard clinical eye chart. The data for CF and HM are represented as *horizontal lines*, because no measurements were obtained by standard eye chart testing in these cases. CF and HM are centered on their means as obtained by ETDRS and/or FrACT. *Shading*: range that cannot be accessed with standard eye charts (**A**) or ETDRS (**B**).

## DISCUSSION

The results of the FrACT and the ETDRS charts were highly reproducible, even in patients with low vision. It was possible to expand the VA measurement down to the HM range and to replace the estimated values for CF (FrACT and ETDRS) and HM (FrACT) by quantitative measurements. The VA category CF can now be replaced by 0.014 with ETDRS or FrACT, with the latter technique also reproducibly quantifying VA in the HM range, down to a VA of 0.005.

Reproducibility was high for ETDRS and FrACT (Fig. 1). This results concurs with those of Arditi and Cagenello,[16] who tested the reproducibility of ETDRS charts, and those of Loumann Knudsen,[8] who tested the reproducibility of FrACT.

The comparisons across tests showed that ETDRS and FrACT coincided closely with the standard clinical eye chart results (Fig. 2). The VAs were comparable. ETDRS and FrACT both have relatively fine grading scales, but standard clinical eye chart's grading scales are coarser. As reported by Bailey et al.,[17] finer grading scales improve the ability of VA tests to detect clinical change.

As shown in Figure 3, the agreement between ETDRS and FrACT was high. Both tests coincided closely and without systematic bias.

Only one testing distance was necessary for the FrACT in this study, because of FrACT's wide testing range of from 0.0025 to 0.4 at a distance of 50 cm. For the ETDRS charts, two different distances (50 and 100 cm) were necessary because only a limited number of optotypes can fit on a chart. In contrast, FrACT presents one optotype at a time. Further, because FrACT chooses optotype orientation randomly, there is no danger that the patient memorizes the sequence on repeat testing.

This study included 80 patients with VA ≥ 0.02, but only 20 patients with the VA categories CF ($n$ = 6), HM ($n$ = 12), and LP ($n$ = 2). This somewhat limits our current conclusion, and we plan further studies focusing on CF and HM.

Below HM, the categories LP with projection, LP without projection, and no light perception are used. Because these are detection, rather than discrimination tasks, they do not assess vision on a comparable scale.

The present results show more than 4 'lines' difference between CF and HM: 0.014/0.005 = 2.8; log(2.8) = 0.45, corresponding to 4.5 lines. This supports the clinical experience that this difference is noticeable for patients. In low-vision clinics it is possible to enable patients to read words or letters if they can count fingers, but next to impossible if the patient's VA is only HM. Therefore the difference between CF and HM is quite relevant for the patient and for the ophthalmologist. We expect that studies in patients with low vision (e.g., macular degeneration with the new medical and surgical treatments, or retinitis pigmentosa with retina implants) will markedly profit from an ability to estimate VA quantitatively

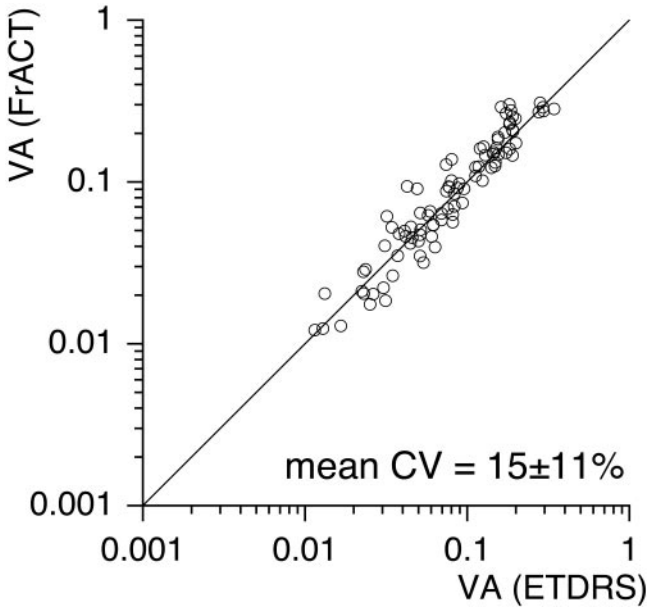



**FIGURE 3.** Agreement between ETDRS and FrACT. VAs measured with FrACT are plotted against those obtained with ETDRS. The two measurements coincided without systematic bias and with a mean CV between the two measurements of 15% ± 11%.

and reliably in the very low VA range—for example, by using the FrACT.

In summary, the high agreement of the three acuity procedures above VA = 0.02 cross-validates all three of them—in particular, the less widely used FrACT. Furthermore, the FrACT makes reproducible and quantitative VA estimates possible down to the HM range. Based on the present results, CF can be replaced by a decimal acuity of 0.014 (≃20/1500), and HM would correspond to 0.005 (≙20/4000). Thus 4 lines (in 0.1-log-unit steps) separate HM and CF, which corroborates the clinical impression that the change in VA from HM to CF is relevant. The FrACT appeared to be a valid instrument with a wide testing range that can be used for clinical studies, even in patients with low vision.

## *References*

1. Ferris FL, Kassoff A, Bresnick GH, Bailey I. New visual acuity charts for clinical research. *Am J Ophthalmol*. 1982;94:91–96.
2. Grover S, Fishman GA, Anderson RJ, et al. Visual acuity impairment in patients with retinitis pigmentosa at age 45 years or older. *Ophthalmology*. 1999;106:1780–1785.
3. Holladay JT. Proper method for calculating average visual acuity. *J Refract Surg*. 1997;13:388–391.
4. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. *Am J Optom Physiol Opt*. 1976;53:740–745.
5. Committee on Vision. Recommended standard procedures for the clinical measurement and specification of visual acuity. *Adv Ophthalmol*. 1980;41:103–148.
6. Ferris FL 3rd, Sperduto RD. Standardized illumination for visual acuity testing in clinical research. *Am J Ophthalmol*. 1982;94:97–98.
7. Bach M. The Freiburg Visual Acuity Test: automatic measurement of visual acuity. *Optometry Vision Sci*. 1996;73:49–53.
8. Loumann Knudsen L. Visual acuity testing in diabetic subjects: the decimal progression chart versus the Freiburg visual acuity test. *Graefes Arch Clin Exp Ophthalmol*. 2003;241:615–618.
9. Wesemann W. Visual acuity measured via the Freiburg visual acuity test (FVT), Bailey Lovie chart and Landolt Ring chart [in German]. *Klin Monatsbl Augenheilkd*. 2002;219:660–667.
10. Dennis RJ, Beer JM, Baldwin JB, Ivan DJ, Lorusso FJ, Thompson WT. Using the Freiburg Acuity and Contrast Test to measure visual performance in USAF personnel after PRK. *Optom Vis Sci*. 2004; 81:516–524.
11. Bach M. *Freiburg Visual Acuity & Contrast Test* (FrACT); 2002. http://www.michaelbach.de/fract.html.
12. Lieberman HR, Pentland AP. Microcomputer-based estimation of psychophysical thresholds: The best PEST. *Behav Res Methods Instrument*. 1982;14:21–25.
13. Treutwein B. Adaptive psychophysical procedures. *Vision Res*. 1995;35:2503–2522.
14. Bach M. Anti-aliasing and dithering in the Freiburg Visual Acuity Test. *Spat Vision*. 1997;11:85–89.
15. Early Treatment Diabetic Retinopathy Study Research Group: Early Treatment Diabetic Retinopathy Study: Manual of Operations. Bethesda, MD: Public Health Service; 1980:1–15.
16. Arditi A, Cagenello R. On the statistical reliability of letter-chart visual acuity measurements. *Invest Ophthalmol Vis Sci*. 1993;34: 120–129.
17. Bailey IL, Bullimore MA, Raasch TW, Taylor HR. Clinical grading and the effects of scaling. *Invest Ophthalmol Vis Sci*. 1991;32: 422–432.