ETDRS-Fast: Implementing Psychophysical Adaptive Methods to Standardized Visual Acuity Measurement with ETDRS Charts

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PURPOSE. To measure visual acuity (VA) on Early Treatment Diabetic Retinopathy Study (ETDRS) charts with a modified faster procedure (ETDRS-Fast), based on adaptive psychophysical methods and to assess the method’s validity and reproducibility.

METHODS. Whereas the standard method for measuring VA with the ETDRS charts requires that the subject read all the letters beginning with the top row, in the ETDRS-Fast procedure, the subject is asked to read only one letter per row until a mistake is made. Then, following simple rules, the examiner finds a row from which the subject can begin reading all the letters downward, thus making the method identical with the standard method near threshold. VA determination was performed twice with both methods in 57 subjects in two separate sessions to assess validity and reproducibility.

RESULTS. In both sessions the correlation between the two procedures was high (intraclass correlation coefficient 0.95), confirming the validity of the ETDRS-Fast procedure. Reproducibility was good for both procedures, with intraclass correlation coefficients of 0.94 for the standard and 0.96 for the ETDRS-Fast method. The ETDRS-Fast procedure allowed a significantly shorter test duration (~30%; P < 0.0001).

CONCLUSIONS. Adaptive procedures allow accurate and fast determination of psychophysical thresholds by reducing the number of stimulus presentations when the subject is far from threshold. In the ETDRS-Fast method a few simple rules applied to optotype chart reading allow adaptation to each patient’s level of VA. The ETDRS-Fast procedure significantly reduces test time and still yields results that are as accurate as those obtained with the standard method. (Invest Ophthalmol Vis Sci. 2001;42:1226–1231)

Measurement of best corrected visual acuity (VA) is probably the most important and definitely the most widely used test of visual function. Unfortunately, VA testing is far from being a standardized procedure in most clinical settings, making comparison of data often difficult. Physical differences between charts and different reading procedures contribute to VA testing variability. The development by Ferris et al. of VA charts for the Early Treatment Diabetic Retinopathy Study (ETDRS), based on a chart designed by Bailey and Lovie, probably represents the most important contribution to the standardization of VA measurement, and they are now widely adopted in basic and clinical vision research. The use of ETDRS charts implies adherence to a standardized testing procedure (here referred to as the standard method), basically requiring the subject to read all letters beginning from the top row, with the examiner scoring VA letter by letter rather than line by line, resulting in improved measurement accuracy. It is common experience that the standard procedure is time-consuming and not always well accepted by patients. This is probably one of the main reasons limiting the widespread acceptance of standardized VA measurement with ETDRS charts in everyday practice.

Improvement in both efficiency and accuracy of psychophysical threshold determination has been obtained with adaptive procedures (see Treutwein for review). Whereas in classic psychophysical procedures the stimulus values that are presented to the subject are completely fixed before the experiment, in the adaptive methods they depend critically on the responses of the subject. This results in a marked reduction of the number of stimulus presentations when the patient’s VA is well above threshold, and thereby more time and patient attention are dedicated to the threshold region. Implementation of adaptive procedures in everyday clinical use is fundamentally limited to the measurement of differential light sensitivity threshold with static computerized perimetry, but has been extensively used for contrast sensitivity and also for VA tests, although several factors including complexity of the computer equipment, cost, and lack of standardization have prevented their diffusion.

Although full implementation of adaptive psychophysical procedures usually requires computer-driven stimulus presentation, the basic ideas of such procedures can be applied to VA determination with standard ETDRS charts by adopting a few simple rules.

In the present report we propose a method (ETDRS-Fast) of standardized VA determination with ETDRS charts that allows reduction of the number of letter presentations when the subject is far from threshold and retains the same letter-by-letter accuracy of the standard method near threshold level, therefore “adapting” to each patient’s level of VA.

MATERIALS AND METHODS

Patients

From December 1999 through May 2000 we examined 57 subjects (age range, 21–85 years; mean age, 49.1) who agreed to participate in the study, among 71 patients referred to one of us (PC) for different ophthalmologic problems: refractive errors (n = 35), cataract (n = 6), age-related macular degeneration (n = 8), trauma (n = 3) glaucoma (n = 2), diabetic retinopathy (n = 2), and thyroid associated ophthalmopathy (n = 1). Visual acuities ranged from 20/100 to 20/10. Only the right eye of each patient was tested. The tenets of the Declaration of Helsinki were followed, and informed consent was obtained.
Study Design

For each subject, a single examiner performed VA determination with both the standard and ETDRS-Fast methods in two separate sessions, to assess the validity of the fast method compared with the standard one and the reproducibility of both procedures. The method to be used first was randomly assigned, and the order was reversed between the first and second sessions, to avoid having any learning effect act preferentially on one procedure. The first and second sessions were at least 1 hour, but not more than 24 hours, apart. Within each session, VA assessment with one method was performed approximately 10 minutes after VA assessment with the other method, with the subject exiting the examination room between assessments. To minimize a possible intrasession learning effect, the VA determination on the study eye (right, with ETDRS chart 1) was followed by determination of VA on the fellow eye with chart 2. To further reduce a possible bias toward achieving agreement between the ETDRS-Fast and standard measurements, the score sheet from a previous test of a given patient was never available to the examiner performing a new VA measurement. Test duration was recorded to verify whether there was a significant difference between standard and ETDRS-Fast procedures.

Procedure

Best corrected VA was determined with ETDRS charts (Lighthouse Low Vision Products, New York, NY) viewed at a 4-m distance in standard illumination condition. The standard procedure for VA determination using ETDRS charts has been described in detail. It requires that the subject read down first and the second sessions, to avoid having any learning effect act preferentially on one procedure. The first and second sessions were at least 1 hour, but not more than 24 hours, apart. Within each session, VA assessment with one method was performed approximately 10 minutes after VA assessment with the other method, with the subject exiting the examination room between assessments. To minimize a possible intrasession learning effect, the VA determination on the study eye (right, with ETDRS chart 1) was followed by determination of VA on the fellow eye with chart 2. To further reduce a possible bias toward achieving agreement between the ETDRS-Fast and standard measurements, the score sheet from a previous test of a given patient was never available to the examiner performing a new VA measurement. Test duration was recorded to verify whether there was a significant difference between standard and ETDRS-Fast procedures.
the chart slowly, letter by letter and row by row, beginning with the first letter on the top row. When the subject has difficulty reading a letter, he or she is encouraged to guess, according to detailed “stopping rules” as described in the ETDRS Manual of Operations. The examiner stops the test only when it becomes evident that no further meaningful readings can be made, despite urging the subject to read or guess. The examiner circles the letters read correctly on a score sheet with a layout identical with that of the chart. VA score can be specified with the number of letters read correctly (a log minimum angle of resolution [MAR] score can also be calculated by assigning 0.02 logMAR units for each letter). In the ETDRS-Fast procedure, beginning with the top row, the examiner invites the subject to identify only one letter per line, by briefly pointing to the letter. To guarantee the same degree of difficulty for each row, only Sloan letters of intermediate difficulty coefficient are chosen (D, K, V, R, H), to avoid presenting letters in the same position from one row to the next. Although this could result in several different sequences of letters, for practical reasons, a fixed sequence was chosen for each chart and was preliminarily marked on the score sheet to facilitate the examiner. At the first letter that is not read correctly, the subject is required to read the whole preceding row. This step has to be repeated upward every time the subject makes two or more errors. When a row is read correctly with not more than one error, the fast procedure becomes identical with the standard, in making the subject read all the rows downward, letter by letter, according to the same stopping rules.

In a procedure different from the standard method, the examiner begins circling the correctly identified letters on the score sheet only when the subject begins the downward letter-by-letter reading—that is, at the first complete line read with one or no mistakes. All the chart lines above are considered to have been read correctly even if their letters have not been circled on the score sheet. In the situation in which the subject reads all the letters correctly down to the bottom, the bottom row must be read completely. The test ends if four or all five letters of the bottom row are read correctly (and are circled on the score sheet), whereas if two or more mistakes are made, reading upward is necessary, according to the general rules described earlier.

### Statistical Analysis

The intraclass correlation coefficient was used for assessing the agreement between the two procedures and the repeatability of each procedure between sessions. Agreement between methods was additionally evaluated by the analysis method of Bland and Altman. Student’s $t$-test was used to assess differences between procedures and between sessions. The SDs of the intertest differences for the two procedures

![Plot of the difference in VA score between the standard and the ETDRS-Fast method (standard minus ETDRS-Fast) against their mean (Bland–Altman analysis) for the first (A) and the second sessions (B).](image-url)
were compared by a test designed to compare correlated variances in paired samples. Pearson's coefficient ($r$) was calculated to assess correlation.

**RESULTS**

The agreement between the two methods is reported in Figure 1, which shows scatterplots of acuity scores measured with the ETDRS-Fast method against those measured with the standard method in both sessions. Correlation between the ETDRS-Fast and the standard procedures was good in both the first and second sessions (intraclass correlation coefficient = 0.95). Differences in VA measurements between procedures (ETDRS-Fast subtracted from standard) are given in Table 1. To further evaluate the agreement between methods, Bland–Altman analysis13 is shown in Figure 2 for both sessions. The mean differences of $-0.86$ letters (first session) and $-0.70$ letters (second session) indicate a tendency for the ETDRS-Fast procedure to produce a slightly higher VA score, although this difference does not quite reach statistical significance ($P = 0.058$ and $P = 0.119$ for the first and second sessions, respectively).

Figure 3 shows scatterplots of acuity scores measured in the second session against those measured in the first session for each procedure. Differences in VA measurements between sessions with the standard and the ETDRS-Fast procedures are given in Table 2. Test-retest reliability, as measured with the
The intraclass correlation coefficient, was good for both procedures (0.94 and 0.96 for the standard and ETDRS-Fast methods, respectively). To further illustrate the repeatability across sessions, Bland–Altman analysis is shown in Figure 4 for both sessions. The SD of test–retest differences obtained with the ETDRS-Fast procedure was significantly smaller (3.02 versus 3.98 letters) compared with that obtained with the standard procedure ($P = 0.037$).

The assumption that in the ETDRS-Fast procedure all letters in the lines above threshold are read correctly could explain both the slightly better mean score and the reduced variability obtained with this procedure. To test this hypothesis, the VA scores obtained with the standard procedure have been corrected by adding the letters that were missed above the threshold region—that is, where in the ETDRS-Fast assessment the subject begins downward letter-by-letter reading. The analysis of the corrected standard VA scores resulted in smaller VA mean differences between standard and ETDRS-Fast methods (−0.26 and −0.11 letters for the first and second sessions, respectively). Similarly, for the standard procedure, reduced test–retest variability was found (SD = 3.66 letters) that was no longer significantly different from the test–retest variability of the ETDRS-Fast method (SD = 3.02 letters).

To assess whether a significant intrasession learning effect was induced by the reuse of the same chart, we compared the VA scores obtained with the test performed first in the session with those obtained with the test performed second in the same session. The absence of a systematic difference between the two measurements indicates that a significant learning effect is unlikely.

Test duration was 99.1 ± 28.8 seconds (mean ± SD) with the standard method, whereas it was 69.4 ± 17.5 seconds with the ETDRS-Fast procedure. The difference was statistically significant ($P < 0.0001$), with the ETDRS-Fast method allowing the examiner (and the patient) to save up to 67% testing time (average 30% reduction).

No significant correlation was found between test duration and VA score for both the standard and the ETDRS-Fast methods ($r = 0.02$ and $r = 0.077$, respectively). Moreover, the correlation between time saved and standard VA score was not significant ($r = -0.055$).

**DISCUSSION**

The proposed ETDRS-Fast procedure for standardized VA determination with ETDRS charts had reproducible results, was
efficient, and produced VA scores comparable with those of the standard procedure.

The reduction in testing time obtained with the ETDRS-Fast method was significant and very well accepted by patients, who can save time and effort when the measurement procedure is still far from their threshold level.

The data presented in Table 1 and Figures 1 and 2 provide evidence that the ETDRS-Fast procedure is a valid alternative to the standard method. The small improvement in VA (less than one letter), although it did not reach statistical significance, might be explained by the fact that the ETDRS-Fast procedure allows the patient to retain more concentration near threshold and possibly to end up with slightly higher scores.

Similarly, that the ETDRS-Fast procedure was even more reproducible than the standard (smaller variability of test–retest differences) could be interpreted as a consequence of its ability to make more efficient use of the patient’s time and attention. On the other hand, the results obtained from the analysis of the corrected standard VA scores indicate that the significantly better mean score and the reduced variability obtained with the ETDRS-Fast procedure can be at least in part explained by the assumption that with this method, all letters in the lines above threshold are read correctly, whereas with the standard procedure there is a small but non-zero chance that some of those letters will be missed and the final VA score affected. Similar effects on VA score and test–retest variability of different scoring methods have been already described by Raasch et al.15

The ETDRS-Fast method, using only responses in the threshold region to calculate VA score, was less influenced by errors that are not threshold related and in the end had lower test–retest variability and slightly better VA scores. In other words, because determining the threshold is the goal of VA measurement, letters that are not read correctly above the threshold region could be considered as errors that might be regarded as false-negative responses. Similar to computerized visual field perimetry, a stimulus that lies above the threshold region (as demonstrated by other responses of the subject) is considered to be a stimulus that the subject should have recognized—that is, a false-negative response. Such responses, although their count could be of interest (i.e., they may be more frequent in specific diseases), should not affect threshold determination. The smaller test–retest variability of the ETDRS-Fast method compared with the standard tends to support this view.

It is interesting that no correlation was found between time saved and VA level, indicating that the ETDRS-Fast method allowed a reduction in testing time in the tested range of VA. This may be explained by the observation that testing time did not correlate with VA with either procedure, probably implying that subjects with lower visual acuities read more slowly, because they were closer to their threshold. On the other hand, a limitation of the present study is that very low visual acuities (worse than 20/100) were not examined, and it is conceivable that less or no reduction in testing time might be obtained using the ETDRS-Fast method in particular patient groups, such as patients with macular degeneration and central scotomas.

Conversely, there are patient groups in which using the ETDRS-Fast procedure might be particularly useful. As pointed out by Blackhurst and Maguire,16 older persons may tire more easily. A method that allows rapid determination of the threshold may be even more efficient in this subgroup. Similarly, preschool children tire easily when from reading a VA chart (e.g., a logarithmic Landolt-C ETDRS-style chart) with the standard procedure and may benefit from using the ETDRS-Fast method. This hypothesis is currently under evaluation.

The efficiency in determining VA observed with the ETDRS-Fast procedure can be regarded as an instance of the advantages that adaptive psychophysical procedures6 have over classical ones. In fact, the latter techniques generally have the problem that little information is gained with many of the measurements, so the procedures can be inefficient. Conversely, adaptive procedures manipulate the physical variable to determine the value that yields threshold responses with the fewest number of measurements, thereby minimizing the amount of effort required.

Even if the ETDRS-Fast method is a rather rough implementation of the basic concepts of adaptive procedures (whose full implementation would require application of sophisticated algorithms to compute the level of the next presentation, as well as a computerized system to produce such a presentation), nevertheless, it was successful in adapting to each patient’s level of VA.

In conclusion, the ETDRS-Fast method is a simple standardized procedure for VA assessment with ETDRS charts that allows reduction of testing time and effort, while retaining the same accuracy of the standard method. Thus, ETDRS-Fast can be considered an alternative procedure for the standardized measurement of VA in clinical research. Moreover, the higher efficiency of the ETDRS-Fast method could extend the use of standardized VA determination with ETDRS charts to the clinical setting.

References