DOI 10.1007/s10527-020-09988-0
Biomedical Engineering, Vol. 54, No. 2, July, 2020, pp. 125-129. Translated from Meditsinskaya Tekhnika, Vol. 54, No. 2, Mar.-Apr., 2020, pp. 34-37.
Original article submitted November 26, 2019.

A Comparative Analysis of the Reproducibility of the Results of Visual Acuity Assessment Using Optotype Charts

I. B. Medvedev[1], M. A. Gracheva[2]*, D. F. Pokrovskiy[1], and A. A. Kazakova[1,2]

Visual acuity charts were compared in terms of differences between the test and retest results. Four charts were compared: ETDRS chart, Lea screener, Sivtsev chart, and a chart developed at the Institute for Information Transmission Problems (Kharkevich Institute; IITP), Russian Academy of Sciences, and based on modified 3-bar optotypes. According to the results obtained in 33 subjects, the IITP chart provided the best repeatability of measurements.

Introduction

Visual acuity characterizes the ability to see small objects and to distinguish small details [1-3]. Measurement of visual acuity is one of the mandatory procedures for eyesight monitoring. Its results serve as a starting point for assessing pathology.

Visual acuity is usually assessed using special charts containing a set of characters – optotypes – of different sizes. In Russia, Sivtsev–Golovin charts (first published in 1923 [4]) are usually used. Eye doctors in other countries use Snellen, ETDRS, Lea, and other charts differing in the type and spatial arrangement (design) of optotypes. Optotypes can be subdivided into letters, numbers, pictures, and special characters (Landolt rings, 3-bar optotypes, tumbling Es, etc.). The main requirement for optotypes is equal legibility, i.e. the similarity of their blurred shapes at the threshold of visual discrimination [5-8]. Letter optotypes are often criticized as not meeting this requirement [9]. Chart designs vary according to the distribution of characters over the chart, the number of characters in a row, and the distances between characters and between rows. In charts with a wide-spaced design, the distances between characters and between rows do not depend on the character size, while in charts with a proportional design, the distances change in proportion to the character size. In addition, different charts use different optotype size increments between adjacent rows. Development and testing of new charts and optotypes continues both in Russia [3, 6, 13] and in other countries [10-12].

Comparative analysis of some optotype charts has been carried out in several recent studies [14-16]. Most often, the charts have been compared in terms of the repeatability of the results, using the test—retest approach to measure the difference in the obtained values [17-20]. Ideally, the test and retest measurements should yield exactly the same results. Thus, the smaller the difference between the test and retest results, the better the chart. Based on the results of 24 recent comparative studies, we have compiled a histogram showing the frequency with which different charts are mentioned in these works. The ETDRS (15 of 24 papers) and Lea (12 papers) charts were found to be most frequently compared to each other and other charts (Fig. 1).

Many authors consider the Lea chart [21] to be the most convenient for vision assessment in children [16, 22-24]. However, according to some researchers, the Lea chart, as compared to other charts, tends to overestimation [15, 16, 22, 25].

The ETDRS charts are considered by some sources as the "gold standard" for measuring visual acuity [20]. However, some authors criticize the letter optotypes used in them [26, 27] and the charts themselves [28, 29]. In addition, letter optotypes are difficult to use for testing younger children [14, 23].

[1] Pirogov Russian National Research Medical University, Ministry of Health of the Russian Federation, Moscow, Russia.
[2] Institute for Information Transmission Problems (Kharkevich Institute), Russian Academy of Sciences, Moscow, Russia; E-mail: mg.iitp@gmail.com
* To whom correspondence should be addressed.

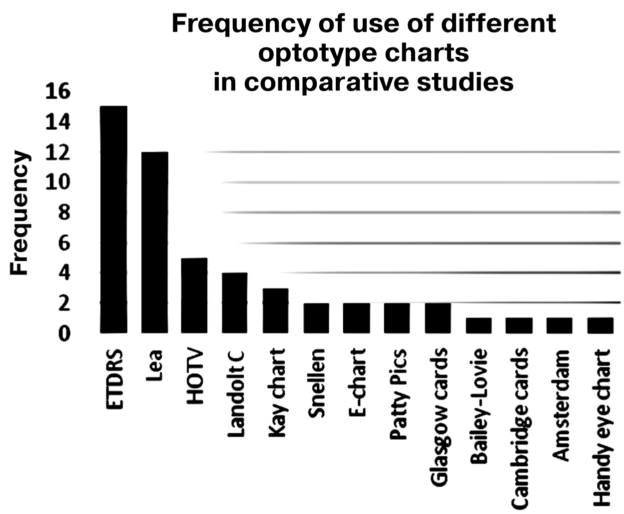

Fig. 1. Frequency of use of different optotype charts in recent comparative studies.

The available comparative studies do not consider the Sivtsev–Golovin chart used for many years in ophthalmic practice. In our opinion, it was important to conduct such a comparative study, as well as to compare the widely used ETDRS, Lea, and Sivtsev–Golovin charts with the charts based on new optotypes developed recently at the Institute for Information Transmission Problems (IITP), Russian Academy of Sciences.

The goal of this work was to compare four types of charts for assessing visual acuity (ETDRS, Lea screener, Sivtsev–Golovin chart, and IITP circular chart) in terms of the reproducibility of the results and the ease of use.

Materials and Methods

The following four charts were used: an ETDRS chart from Good-Lite (USA) containing 10 Sloan letter optotypes (Fig. 2a), a Lea screener (Precision Vision, USA) containing four picture optotypes (Fig. 2b), a standard Sivtsev chart with seven letter optotypes (Fig. 2c), and a chart with modified 3-bar optotypes developed at the IITP (Russia) [7, 13] (Fig. 2d).

The optotypes in the IITP charts are accompanied by accommodation stimuli: larger lines with no threshold size stimulating the adjustment of the accommodation system. In the circular charts used in this study, these lines were circular.

Test subjects. A total of 33 subjects 17-33 years old were examined (average age, 25.4; median age, 26.0; standard deviation, 3.9). The group included 15 subjects with emmetropia; 11, with mild myopia; 5, with moderate myopia; 1, with severe myopia; 1, with mild hyperopia.

Procedure. The charts were presented in a random order from a distance of 4 m. Visual acuity (first monocular for each eye in a random order, then binocular) was evaluated using each chart. After a break (at least 1 day), retest examination using the same charts was carried out by the same researcher. A chin rest was used to ensure the invariance of the distance to the chart. The brightness of the charts was ~160 cd/m^2. Standard illumination conditions (250 lux) for visual acuity assessment were maintained. Refraction was evaluated using a Huvits MRK-3100P autorefractor (Korea). If necessary, optical correction was performed. Following the prescription of the ETDRS manual, the subject had to make less than two errors per row. The complete test algorithm involves nam-

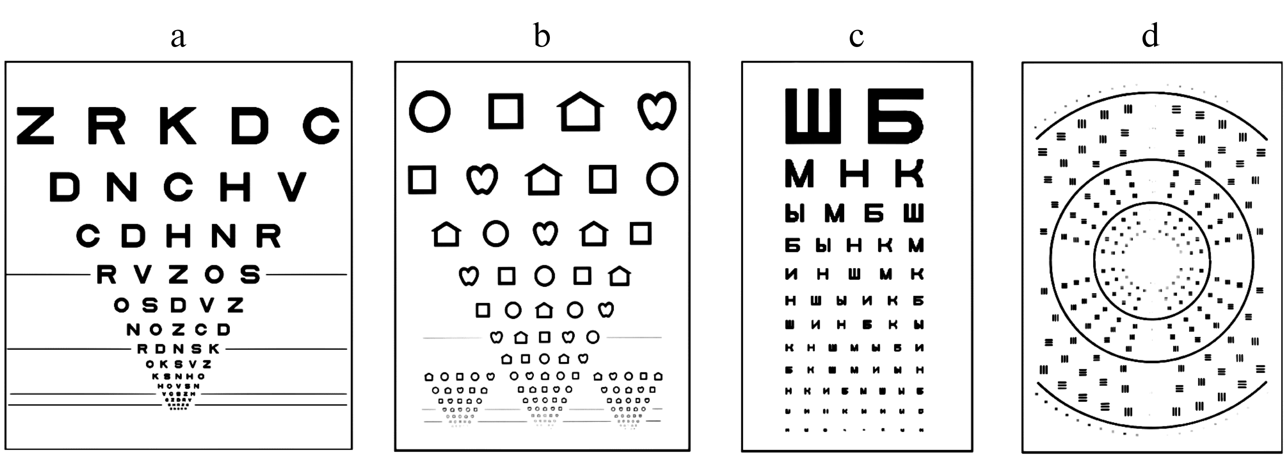

Fig. 2. Test charts used in the study: a) ETDRS chart; b) Lea chart; c) Sivtsev chart; d) IITP chart.

TABLE 1. Mean Indices of Visual Acuity and Test–Retest Difference (decimal units)

Chart	Mean visual acuity ± SE, test	Mean visual acuity ± SE, retest	Mean difference ± SE	Significance
Sivtsev	1.12 ± 0.026	1.18 ± 0.026	0.06 ± 0.019	$p < 0.05$
Lea	1.37 ± 0.032	1.43 ± 0.032	0.06 ± 0.019	$p < 0.05$
ETDRS	1.27 ± 0.027	1.33 ± 0.027	0.07 ± 0.014	$p < 0.05$
IITP	1.34 ± 0.023	1.37 ± 0.024	0.02 ± 0.013	$p > 0.05$

ing all letters in a row, starting with the largest characters. However, as the test group consisted of healthy young adults without serious visual impairment, we used an abridged version of the procedure to avoid excessive fatigue of the subjects: each subject started three rows before the row that he/she could hardly distinguish.

Results

The repeatability was assessed by analyzing the difference between the test and retest results, i.e., evaluating the stability of the data obtained using each chart. Monocular and binocular data were analyzed together, so that for each chart 99 pairs of indices were processed (3 measurements for 33 subjects). A difference equal or close to zero corresponded to the best repeatability: it showed that the test and retest results were exactly or almost the same. The difference was found to be smallest for the IITP charts (Table 1).

Test and retest data distributions were also compared to evaluate the repeatability. The Shapiro–Wilk and Kolmogorov–Smirnov tests showed that the data was not distributed normally ($p < 0.05$ for both tests for all 4 charts, separately for the test and retest). In view of this, the non-parametric test was used. The Wilcoxon T test showed that the test and retest data were statistically indistinguishable ($p > 0.05$) only for the IITP chart. Thus, among the four charts under study, the IITP chart provided the best repeatability of the test results. Statistical analysis of the obtained data was performed using the IBM SPSS Statistics v. 25 software.

Individual test and retest data are shown in Fig. 3. The abscissa is the measurement number (1 to 99); the

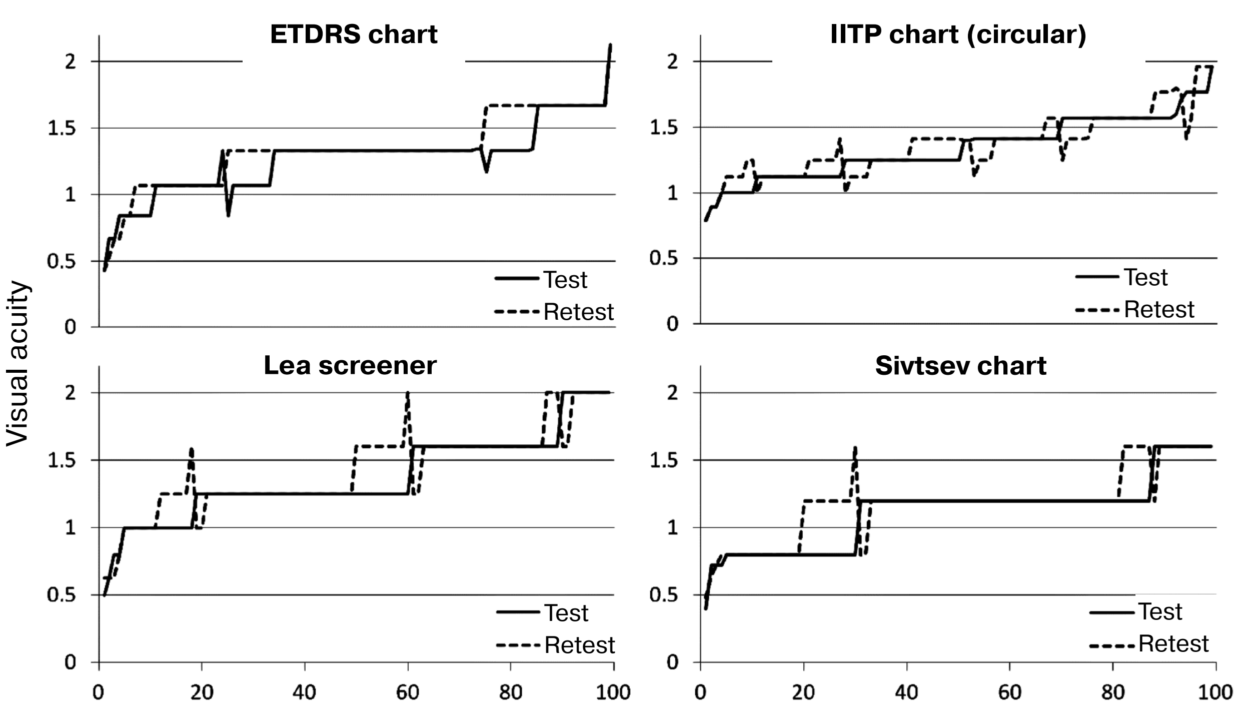

Fig. 3. Individual test (solid line) and retest (dashed line) data. The graphs combine results of monocular and binocular measurements. The abscissa is the individual measurement number. For clarity, the indices are sorted by their values during the first (test) measurement.

ordinate is the test (solid line) and retest (dashed line) index. The coincidence of the solid and dashed lines means that the test and retest results coincide completely; if the retest result exceeds that obtained during the first measurement, the dashed line lies above the solid line. Figure 3 shows that the difference amplitude was largest for the Sivtsev and Lea charts: it reached 0.5 decimal units or more. The test–retest difference was found to be smallest for the IITP charts.

In addition to quantitative assessment of the repeatability, we also systematized the subjective impressions of the researcher and the test subjects regarding the convenience of working with the charts. The unequal recognizability of characters should be mentioned as a disadvantage of the ETDRS chart. This disadvantage is typical of letter-based charts: test subjects often mistake O for Q; G for C; V is confused with Y; S, with B or G. Some subjects made several such mistakes in one row, while recognizing the smaller letters in the next row without any error. Similar results are described in [26, 27]. When the Sivtsev chart was used, many subjects memorized the sequence of letters, which made retesting difficult. This problem was less frequent when using the ETDRS chart, probably because all test subjects had Russian as their native language and were, therefore, accustomed to the Cyrillic script, while the ETDRS charts use Latin letters as optotypes. When using Lea charts, the subjects confidently discriminated between distinguishable and indistinguishable optotypes, saying beforehand that they no longer recognized the characters in the next row and saw all optotypes in it as "circles". This made the Lea charts convenient and sped up examination. However, the individual test–retest differences were high for the Lea chart, probably due to the size increment between the rows. When using the IITP charts with 3-bar optotypes, some subjects, on the contrary, said that they no longer saw any differences between characters in a row, but still could correctly guess them. We also attribute this to the size increment used in these charts, which is smaller than those used in the Lea and ETDRS charts.

The circular design of the IITP charts is inconvenient and, apparently, needs to be improved: the circular arrangement of characters confused both the subjects and the researcher, often making the use of a pointer necessary.

Conclusions

A considerable amount of research in the field of optometry has been devoted to the assessment and comparison of existing methods for measuring visual acuity. The goal of this work was to compare several such methods in terms of both the reproducibility of the results and the ease of use by doctors and patients. For the first time, a new chart with 3-bar optotypes and a design comfortable for the accommodation system was assessed. A detailed comparison of the Sivtsev chart with foreign analogues was also carried out for the first time.

The repeatability of the results is a very important criterion in assessing the results of treatment and age-related dynamics of visual functions, in occupational health examinations, etc. In the comparative study of charts for assessing visual acuity presented in this work, the best repeatability of the results was achieved using the chart with modified 3-bar optotypes developed at the Institute for Information Transmission Problems (Kharkevich Institute), Russian Academy of Sciences. However, both the design and the increment used in this chart were found to be suboptimal for the purposes of this study. It will be of interest to assess, in a future study, the repeatability of results obtained using 3-bar optotype charts with a greater increment and a less complicated arrangement of characters.

It can be concluded both from the literature data and the results obtained in this work that most letter optotypes are unsuitable for accurate assessment of visual acuity. It is necessary to develop charts with more elaborate optotypes, more similar to each other in their general shape, i.e. with equal legibility.

Preliminary results obtained in the course of this study were presented at the International Symposium on Visual Physiology, Environment, and Perception [30].

The authors would like to thank professor Galina I. Rozhkova for the test charts and discussion.

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