Standardized ETDRS charts for mobile devices

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Abstract—Charts displayed on mobile devices were verified in comparison to standardized ETDRS charts. Such a method of visual acuity assessment is characterized by stabile brightness and contrast. Moreover the ability to dynamically display random optotypes eliminates the problem of memorizing the contents of charts, making measurements more reliable. Our tests showed that the VA measured with a mobile device and the VA tested using standardized printed charts are not significantly different.

Nowadays, mobile devices are commonly used in technologically advanced societies. Such tools improve the quality of life and can be used in diagnostic applications – for example: cardiovascular monitors, hearing screening, pain management, glucometers, IQ tests and others [1-2]. Smartphones, tablets and laptops successfully became used even by people with vision impairment [3-4]. Moreover, new technologies open new areas of optometric diagnosis with ultra-high resolution and good contrast of displayed images [5]. Mobile displays offer higher resolutions than those available in the majority of printing techniques. High resolutions are crucial for proper examining of near vision. In spite of this, popular visual acuity testing applications like Eye Handbook, iSight test or SightBook are not standardized and have poor scientific validation, especially in near vision testing. Although there are some papers comparing Snellen or Tumbling E tests for printed and smartphone-displayed charts [6-7], they do not analyze the correctness of displayed charts. This work investigates technical limitations of mobile devices used in visual acuity testing, under the assumption that displayed charts meet the requirements of the Early Treatment Diabetic Retinopathy Study (ETDRS) protocol [8].

According to the ETDRS protocol, the smallest optotype corresponds to -0.3 logMAR, [9] i.e. it has an angular size of 2.5 arcmin. At near vision testing distance (333mm), it requires a linear dimension of 0.24mm with details of about 48μm. On the other hand the five largest optotypes should be displayed in one line, separated by a distance equal to their widths (i.e. minimal chart width including margin cannot be less than eleven optotypes of size 50 arcmin). Minimal angular height of the screen required to display the whole chart is defined by the number and size of consecutive lines, and equal to 7.78degrees [10]. These limitations are important because of small mobile device screen dimensions. For example, testing visual acuity at a distance of 500mm requires a screen with a width at least equal to 80.7mm while the height cannot be less than 68.3mm. The minimal parameters of mobile device screens required at different test distances are presented in Table 1.

Table 1. Required screen properties for different test distances (margins of the size of largest optotype were assumed)

Test distance [mm]	Minimum screen size (diagonal) [in]		Minimum pixel density [ppi]
	Ratio 4:3	Ratio 16:9	
5000	49.4	60.4	35
2000	19.8	24.2	88
1000	9.9	12.1	175
667	6.6	8.1	262
500	5.0	6.1	349
400	4.0	4.9	436
333	3.3	4.1	524
280	2.8	3.4	623
250	2.5	3.1	698

We created an application displaying ETDRS charts of random optotypes, scaled for a given distance. The application displays the whole chart, a single line or one optotype and is dedicated for the Android (Google Inc., Mountain View, USA) and Windows (Microsoft, Redmond, Washington, USA) environment. The LG G3 smartphone (LG Corporation, Seoul, Korea) was used for the distance range from 333 to 500mm. It is equipped with a 5.5" 1440×2560 pixel IPS LCD display with 538 ppi resolution (pixel size 47.2μm).

We displayed ETDRS charts on the smartphone and created their printed versions with a 2400 dpi nominal resolution on transparent film with white pieces of paper. The printed charts were illuminated at level 200cd/m^2 from the bottom to avoid shadows. The brightness of mobile screens was also set to its maximal value equal to 200cd/m^2 also. We focused on the optotypes associated with the best visual acuity because their correct display is the most difficult. Thus, monocular acuity tests for eyes of 70 patients were performed to evaluate dynamically displayed charts on mobile devices in comparison to

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classical printed ETDRS charts. The average age of examined people was 32 years (the oldest and youngest persons were 70 and 19 years old respectively). The study was conducted to assess whether any significant differences between the two above methods occur. The line-by-line method was used, i.e. visual acuity (VA) score was determined by the last line with at least half of optotypes recognized correctly. We performed an in-group experiment where all participants were tested using both chart presenting methods in random order. The illumination conditions of the test room were homogeneous at a value of 250±50 lx [11]. Any reflections were minimized.

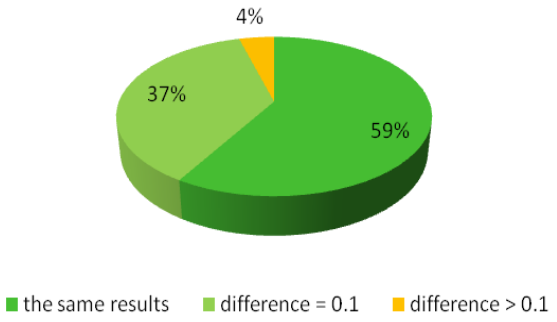

Fig. 1. Pie chart presented the results of comparing two methods. 59% of people perform both VA tests alike, 37% of them indicate one line differences, 4% of tests show larger divergences.

The simple comparison of the results is presented at a pie chart (Fig. 1). We could see that over 59% examined persons have the same results and 37% have similar results on mobile and printed charts.

For more reliable assessment of differences we performed the Wilcoxon Signed Ranks Test on collected data [12]. This nonparametric test was chosen because of non-Gaussian distribution of data. The established null hypothesis stated that the results obtained from both methods in fact were taken in the same experimental conditions. According to the results, with a probability of $p = 0.247$ we can conclude that any differences in visual acuity measured by printed charts (VA_p) and mobile ones (VA_m) arise from a sampling error and therefore they are not significant ($p > \alpha = 0.05$).

The Bland and Altman plot (Fig 2.) is another [13] commonly used possibility for comparing the two methods of measurement. At the OX axis we plotted the mean of the values provided by the compared methods while the OY axis relates to the difference between them. We marked the number of overlapping results by the proportional size of the points.

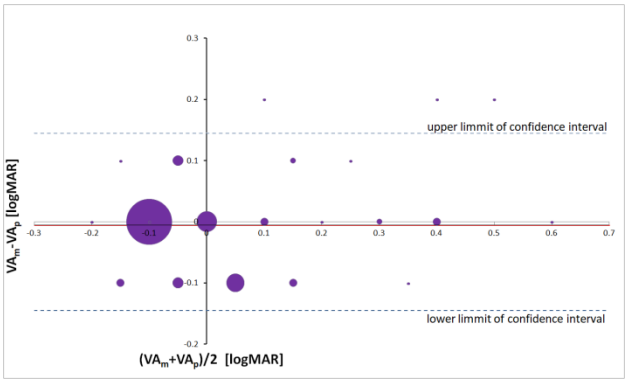

Fig. 2. Bland and Altman plot for visual acuity tests at a distance of 333 mm. The size of points is proportional to the number of results related to the same coordinates. The scale is quantized with value 0.1

The differences in the results obtained by both methods should be small enough to cause no issues with clinical interpretation. As shown in Fig. 2, only 3 results are off the limits of a confidence level of 0.95 standard deviation (± 0.15 logMAR), concluding that the results obtained using mobile charts are in a good agreement with paper charts. The points are distributed evenly above and below the zero horizontal line, so no predominance of any of them can be stated. Considering that norms and standards are based on printed charts [14-15], our results confirm the usability of the charts displayed on mobile devices. Another advantage of this chart displaying method, such as dynamic optotype creation was then prevailing.

Near vision tests are especially important in changes of effectiveness of ocular accommodation abilities associated with presbyopia [16]. We have demonstrated the possibility of using proper ETDRS charts displayed on common mobile devices. The resolution of images depends on the hardware that is used and can be sufficient for standardized testing of visual acuity up to -0.3 logMAR. Such dynamic charts can be implemented in ophthalmological practice as well as in vision self-testing mobile applications.

Mobile devices exhibit the capability of displaying a standardized ETDRS chart with a sufficient quality. Optotypes can be randomized to avoid the memorizing effect during examination of both eyes or testing at different distances. Mobile devices can also be used to display other optotypes like Snellen letters, e.g. tumbling E, Landolt C or Lea optotypes [17-18]. The testing process can be easily automated with the use of a microphone and speech recognition as well as camera and distance control algorithms [19-20].

Charts displayed by mobile devices offer substantial flexibility. They can be generated in different sizes, forms and geometries, being useful not only to control vision

acuity but also to investigate contrast sensitivity and color vision.

In contrast to other solutions available on the market based commonly on single optotypes and having test distances limited to intermediate and distance vision, new method enables possibility of full ETDRS-standardized visual acuity testing at any distance including near vision assessment. Besides the well-known advantages of this standard such as reliability and comparability of results, dynamic charts are characterized by constant brightness and contrast, whereas random optotypes eliminate the problem of memorizing the contents of charts during the measurements.

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