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ORIGINAL ARTICLE

# A Modified ETDRS Visual Acuity Chart for European-Wide Use

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**ABSTRACT**

***Purpose.*** The log MAR visual acuity (VA) chart developed for use in the Early Treatment Diabetic Retinopathy Study (ETDRS) is composed of 10 Sloan letters, which are not used in the Greek, Cyrillic, and Central European alphabets. In this study we evaluate a modified ETDRS chart, the University of Crete (UoC) chart, which contains a set of letters readable by all European citizens.

***Methods.*** In the UoC charts, the letters C, D, R, N, V, S, and Z were substituted with E, P, B, X, Y, A, and T, respectively. The similarity between the modified and the standard acuity charts was evaluated using two procedures. First, VA of 227 secondary school children (454 eyes) was evaluated using both sets of charts. Second, the relative difficulty for the identification of individual Sloan letters used in both charts, as well as letter M, was assessed from psychometric functions for five subjects.

***Results.*** Bland–Altman plots revealed no statistical significant differences in the value of VA between the standard and the UoC set of charts. Although, estimates of identification log MAR threshold showed relatively significant interletter variability, in total, the new set of Sloan letters was equally identifiable with the original set.

***Conclusions.*** The overall pattern of results suggests that the modified log MAR UoC charts forms a valid alternative to the ETDRS for assessing VA in multinational clinical trials, offering the advantage of containing letters recognizable by a wider population basis, such as European citizens, as well as subjects from countries using the Cyrillic alphabet.
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Key Words: visual acuity charts, letter identification, Sloan letters, psychometric function

The measurement of visual acuity (VA) is the most widely used test for assessing the integrity of the visual function. It forms an essential part of the routine ophthalmological examination and is used in the basic set of exams for the evaluation of ocular pathologic conditions (e.g., diagnosis and/or progress of ophthalmic diseases, monitoring of therapeutic interventions). It also comprises one of the main criteria that define, internationally, visual "fitness" for driving a vehicle,[1] and visual "readiness" for many occupations, such as for aircraft pilots.[2]

The development of the VA charts for the Early Treatment Diabetic Retinopathy Study (ETDRS),[3] offered to the ophthalmologic/optometric community a rigorous test design, which has been widely adopted in basic and clinical vision research[4] in preference to the traditional Snellen chart, which has recognized drawbacks.[5–7] The ETDRS chart consists of a set of 10 letters[8] from the Roman alphabet, is based on the design principles proposed by Bailey and Lovie,[9] and it incorporates the recommendations of the Committee on Vision of the American Academy of Sciences—National Research Council.[10] Although, the letters in these charts were purposely chosen to be equally legible,[3,8] a revised ETDRS chart was later proposed,[11] in order to minimize the differences in relative difficulty between lines on the charts.

Since the characterization of the ETDRS as the gold standard for measuring VA, a number of alternative designs[12–17] and procedures[18–20] have been developed. These modified ETDRS charts might offer reduced test duration,[16,19] decreased test–retest variability,[20,21] and improved data collection in population[13] and pediatric[15,22] studies.

A notable drawback of the ETDRS charts is that they do not offer universal implementation, because they contain Roman characters, which are not readable worldwide. As a result, language-customized charts have been designed in order to record VA among the Arab[23,24] and Thai[25] populations. Moreover, VA charts that contain other symbols, such as the "Landolt ring" or the "illiterate-E"[26] displayed at different (usually four) orientations, have been adopted for use in non-Latin speaking countries. Although "Landolt C" optotype would offer real universal implementation, they have not been adopted by Sloan,[8] the American Medical Association (see Sloan[27]) and the American Academy of Sciences—National Research Council,[10] because "it is cumbersome to use." Moreover, "detecting a gap in a Landolt-C" introduces a different task of visual function, i.e., resolution acuity, that does not implement the compensatory cognitive processes involved in recognition acuity (i.e., identification of a letter), resulting in noncomparable VA scores.[28–31]

The aim of this study is to evaluate a modified log MAR/ETDRS chart which utilizes a new set of letters readable by all European citizens and used in almost all European alphabets (European Committee for Standardization, 1997[32]), with the exception of the Armenian and the Georgian alphabets.

## PATIENTS AND METHODS

The University of Crete (UoC) chart, is a modified log MAR/ETDRS chart that uses a new set of letters. More specifically, the Sloan letters C, D, N, R, S, V, and Z in the revised ETDRS charts (chart 1 and chart 2) were substituted with E, P, X, B, T, Y, and A, respectively (Fig. 1). The new letters were constructed to the specifications of Sloan letters.[8] The similarity between the modified and the standard charts was evaluated using two experimental procedures. First, VA of secondary school children was evaluated using both sets of charts. Second, the relative difficulty in identifying individual Sloan letters was assessed from psychometric functions.

## Experiment 1

*Participants.* The study was conducted in two secondary schools in Heraklion, Crete, Greece between April and May 2006. Two hundred twenty-seven Greek secondary school children, (109 boys and 118 girls) with a mean age of 14.1 years (age range: 13 to 16) participated in the study. All children were English-speaking, and had been practicing the English language for more than 4 years.

Written informed consent was obtained from the parents and the regional department of secondary education. The research conformed to the tenets of the Declaration of Helsinki and followed a protocol approved by the Institutional Research Board.

*Experimental Procedure.* VA was assessed, by a single examiner, using the two standard log MAR ETDRS charts and the two UoC log MAR ETDRS charts with the modified set of letters (chart 1 for right eyes (RE) and chart 2 for left eyes (LE); Fig. 1). A back-illuminated slim stand (Cat No. 392, Sussex Vision Ltd., UK), at 4 m distance, held the acuity charts. The luminance at the center and the four corners of the chart ranged from 168 to 176 cd/m$^2$ for the standard charts and 164 to 167 cd/m$^2$ for the UoC charts. This was in compliance with the recommendations for standardizing the measurement of VA (approximately 160 cd/m$^2$).[4]

Subjects were tested with their own (if any) habitual spectacle correction. Each subject underwent four acuity measurements (two for each eye). The four charts were viewed in random order to limit any learning effects. All subjects were asked to identify each letter (equivalent to 0.02 log MAR) one by one in each line starting from the upper left-hand letter, and to proceed by row until they could no longer name correctly all the letters in a line. They were instructed to read slowly and guess the letters when they were unsure. Letter by letter scoring was applied. The termination rule for stopping was four or five (all letters) mistakes on a line.[21] The experimenter scored correct responses on specially designed data

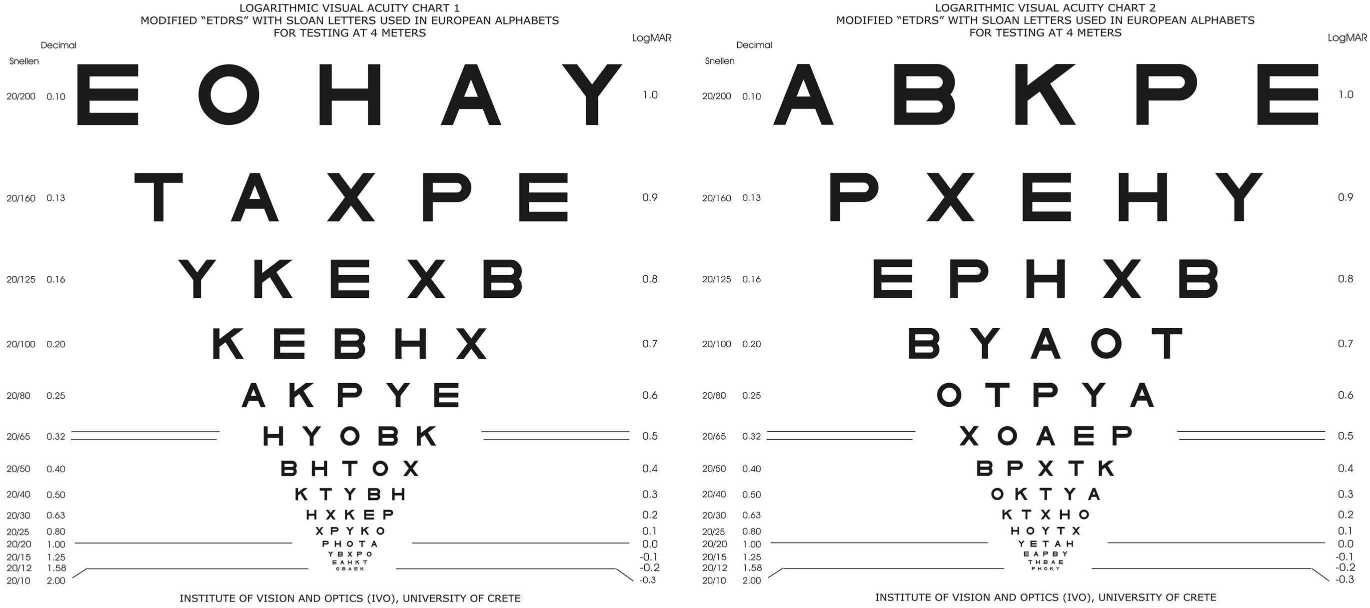


**FIGURE 1.**
The UoC ETDRS acuity charts with the modified set of letters. Chart 1 (left) used for right eyes and chart 2 (right) used for left eyes.

forms. A VA score was derived from the calculation of missed letters up to the last readable line. The same procedure was repeated for all the acuity charts.

*Data Analysis.* For statistical analysis, acuities were expressed in log MAR (logarithm of the minimum angle of resolution) units. For each subject, the difference in the two acuity measurements (the results from each eye were analyzed separately) between the two charts was calculated. The standard deviation (SD) of these differences across all 227 subjects was calculated. The agreement between the two sets of charts was evaluated by Bland and Altman analysis[33] (95% range, ±1.96 SD), making the assumption that the differences are normally distributed. The assumption of normality itself was evaluated by inspection of quantile-quantile normal plots.

## Experiment 2

*Participants.* Data were obtained from the dominant eye of five participants (age range: 26 to 36, three males/two females) with normal vision. All the subjects had considerable experience in psychophysical experiments and were informed about the set of letters used. Two of them were myopes (<2.0 D), best-corrected with spectacles. The best-corrected VA in log MAR ranged between −0.16 and −0.24 (mean: −0.20 ± 0.03). Informed consent was obtained from all participants after they received a verbal explanation of the nature of the study.

*Procedure.* Test stimuli consisted of any of the 18 Sloan letters (10 of the standard ETDRS charts, 7 of the modified UoC chart and the letter M, which is the only supplemental letter used in the alphabets). At 4 m distance, the smallest letters tested (−0.35 in log MAR) were constructed from a 10 × 10 pixel array. The letters were projected on a Sony GDM F-520 CRT monitor (CRS, UK) (background luminance of 100 cd/m$^2$, frame rate of 120 Hz) by means of a VSG2/5 stimulus generator card (CRS, UK) and purpose-written software. The display monitor was the only source of illumination in the test area.

Subjects were instructed to identify verbally which letter had been presented, and to guess if they were uncertain. They were also informed that all letters would be presented equally often at a variety of sizes. Their visual acuities served as a reference for choosing seven letter sizes with a progression of 0.05 log units. Each letter was presented 20 times at the seven predetermined log MAR sizes in random order, resulting to a total of 3380 presentations. The interstimulus interval was set to 4 s. The experiments were conducted at two sessions of duration 90 min each.

*Data Analysis.* Threshold estimates for each letter were obtained from psychometric functions, which usually resemble a sigmoid function with the percentage of correct responses displayed on the y axis and the physical parameter (i.e., log MAR size) on the x axis. In the current study, log MAR thresholds were calculated by least-squares best fits of a Weibull[34] function, as was firstly described by Pelli et al.[35]

$$P = 1 - (1 - g)\exp[-10^{b(x-t)}]$$

where P is the ratio of correct responses at a given log MAR size (x), g is the probability of correct response at zero threshold, equal to 1/N (where N is the number of letters used, i.e., 18), and t and b are the parameters that define the threshold (in log MAR) and the slope of the Weibull function, respectively.

To exclude any intersubject differences due to their different visual acuities, threshold data were normalized for each subject by subtracting the mean letter threshold from the threshold of each letter. The difference in identification across the letters was performed using a one-factor (letters) analysis of variance on the normalized threshold scores.

## RESULTS

### VA Measures

The VA of the school children, as measured with the standard ETDRS charts (chart 1 and chart 2), ranged between −0.26 and 0.90 (mean: 0.03 ± 0.18, median: −0.04) for the RE and between −0.26 and 0.94 (mean: 0.03 ± 0.17, median: 0.00) for the LE. Correspondingly, VA, as measured with the UoC charts, ranged between −0.22 and 0.86 for the RE (mean: 0.01 ± 0.18, median: −0.06) and between −0.26 and 0.84 for the LE (mean: 0.00 ± 0.17, median: −0.04).

Correlation between the standard and the UoC charts was good in both the RE (r = 0.97) and LE (r = 0.96) charts. The mean difference in log MAR between the two sets of charts was −0.02 (SD: 0.05) for the RE and −0.03 (SD: 0.05) for the LE, indicating that the UoC charts were on average less difficult. When the difference is expressed in "missed letters," then this corresponds to about 1.0 (SD: 2.3) and 1.5 (SD: 2.5) letters for the RE (chart 1) and LE (chart 2), respectively. Fig. 2 plots the differences in VA (in log MAR) between the standard and the UoC charts. The normal distribution of the data was confirmed using quantile-quantile normal plots.

To farther illustrate the differences across the two sets of charts, Bland–Altman analysis[33] is shown in Fig. 3. The upper and lower limits of agreement (mean differences ±1.96 SD) are 0.08 and −0.12 for the RE and 0.07 and −0.13 for the LE, respectively. This indicates that the 96.5% of the values for the RE and 95.2% for the LE lie between the limits of agreement.

### Letter Identification

Psychometric functions for the identification of each of the 18 letters, for one subject (GS), are depicted in Fig. 4. From the best fits of Weibull functions the thresholds in log MAR was calculated. Letter identification thresholds (in log MAR), for all the participants tested, are given in Table 1. As might be expected there are quantitative differences between subjects' letter thresholds, but the overall pattern (e.g., A and P being the easiest letters, B and S the most difficult) is repeated for all subjects. For this reason, scores of normalized identification threshold, i.e., the difference between letter threshold and the mean threshold for all letters, were calculated for each subject. This resulted to a mean normalized threshold for each subject equal to zero.

The mean normalized thresholds of the five participants, in log MAR units, ranged between −0.108 and 0.123. This difference corresponds to about 11.5 letters in log MAR chart. Fig. 5 illustrates mean normalized thresholds for all letters. Letters O, D, M, and H are equally identifiable, with their thresholds being very close to the mean normalized threshold for all letters. Letter B was

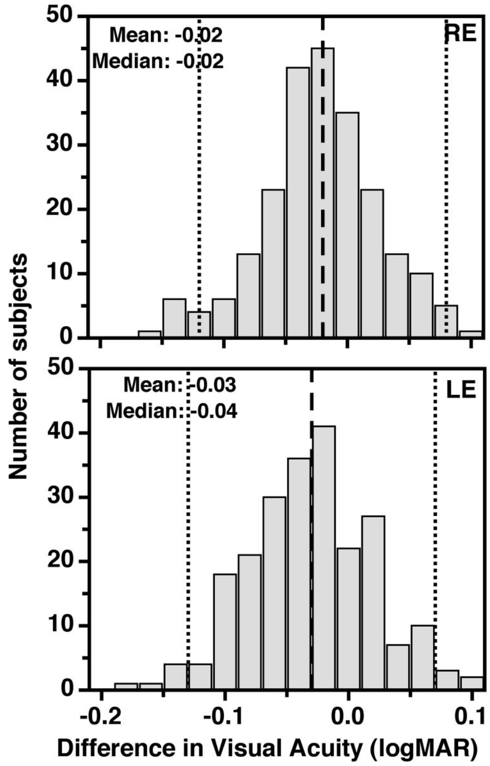


**FIGURE 2.**

Frequency histograms of the differences in visual acuity measurements between the standard and the UoC charts for the right (upper graph) and left (lower graph) eyes of the population tested. Note that each bar corresponds to one letter (0.02 log MAR). The dashed line represents the mean difference, whereas the dotted lines the mean ±1.96 SD.

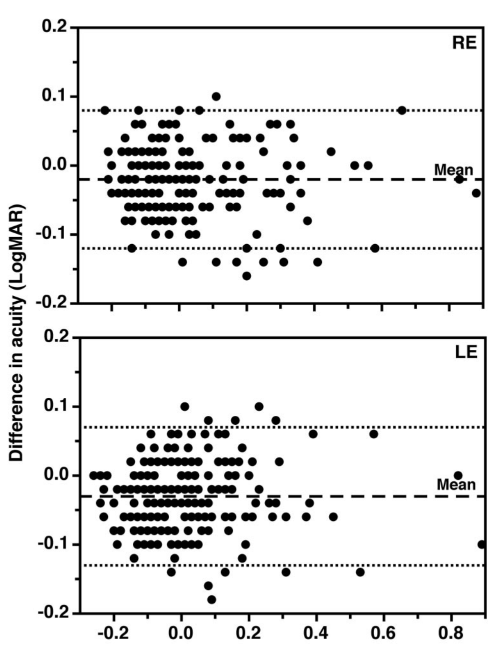


**FIGURE 3.**

Plot of the difference in log MAR VA score between the standard ETDRS and the UoC charts (standard ETDRS minus UoC) against their average (Bland–Altman analysis) for the right (upper graph) and left (lower graph) eyes. The dashed line represents the mean difference, whereas the dotted lines the mean ±1.96 SD.

the most difficult letter (followed by letters S and K), whereas letter A was the easiest letter (followed by letters P and V). Moreover, letter Y showed the highest SD, followed by letters B and O. A one-factor analysis of variance revealed a statistically significant difference in normalized threshold scores between letters ($F_{1,17} = 9.96$, $p < 0.001$). Post hoc testing (Fisher's protected LSD) revealed that normalized threshold of letters V, Z, N, T, C, O, D, M, H, E, X are not significantly different from one another and from the mean normalized threshold for all letters. On the other hand, normalized thresholds of letters R, S, Y, K, B, A, and P showed significant differences (p value $<0.05$) from the mean normalized threshold for all letters.

## DISCUSSION

The proposed log MAR UoC charts (modified versions of the ETDRS chart) with a different set of letters, produced VA scores comparable with the standard procedure. The small improvement in VA scores (0.022 for RE and 0.031 for LE chart, in log MAR) did not reach statistical significance. The Bland–Altman[33] scatter plots demonstrated that for both RE and LE charts, the agreement between the standard and the UoC charts were consistent across the range of acuities (95% confidence limit for agreement, ±0.10 for both charts). The limits of agreement between the two sets of charts are very close to the published estimates of test–retest variability (TRV) for the standard ETDRS charts,[18,20,36–39] which ranges between ±0.07 and ±0.11 log MAR for normal population. Higher TRV values (±0.16[40]; ±0.18 to ±0.24[38]) have been found with small amounts of defocus.

It is recognized that a limitation of the present study is that very low visual acuities were not examined, as only 8% of the eyes tested had VA lower than 0.30 log MAR. It is conceivable that the differences between the two charts are mostly attributed to the letters contained in lines close to zero. However, the population tested (secondary school children with their habitual correction), is selected from a community setting, forming a population-based survey.

The results on letter identification thresholds are in close agreement with previous studies.[8,31,41,42] Mean identification threshold (in normalized log MAR units) ranges from −0.11 for letter A to 0.12 for letter B. The letters C, O, and D (having curved features) and M, H, and E (having angular features), were found to be almost equally identifiable. The correlation of the spatial content and other features of letters with their identification thresholds forms a part of a separate study. There is an option to substitute letter B (being the most difficult letter) with letter M, which forms an ideal letter of medium difficulty.

The total normalized identification threshold of the letters contained in the standard ETDRS and the UoC charts was found to be 0.008 (SD: 0.045) and 0.037 (SD: 0.070), correspondingly. The results indicate, that although there are significant differences in "difficulty" between letters, the mean difficulty for the two acuity charts is approximately similar (0.03 log MAR difference—corresponding to 1.5 letter). It is also evident that the within-chart SD in letter difficulty is higher for the UoC chart. There is a possibility that this might lead to increased test–retest variability of the chart: this issue is being addressed in a separate study. It should be noted that, though, the use of individual letter thresholds cannot accurately predict the difficulty of the letters contained in

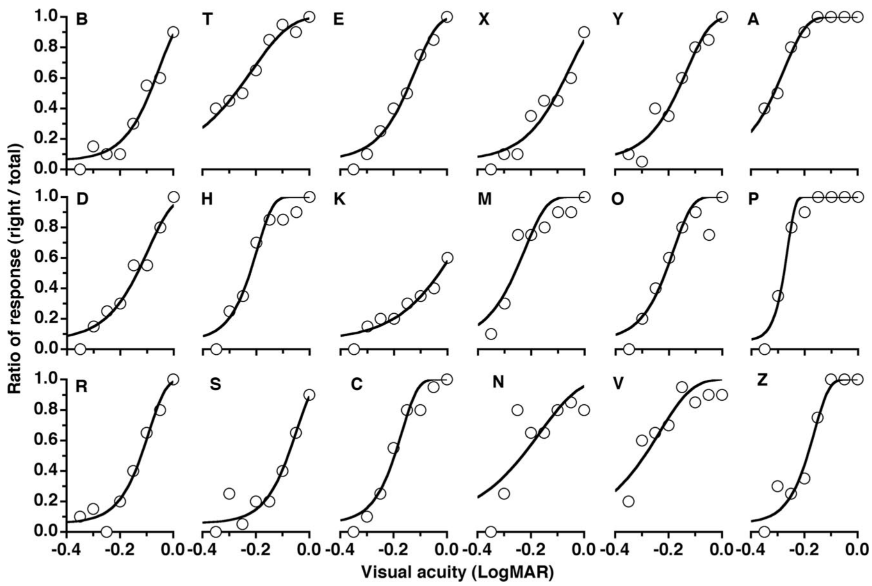


**FIGURE 4.**

Psychometric functions for identification of each of the 18 letters used, for subject GS. Solid curves represent least-squares best fits of Weibull functions.

**TABLE 1.**

Identification letter thresholds (in log MAR) for the five participants tested

| | Threshold (in log MAR) | | | | | |
|---|---|---|---|---|---|---|
| Letters | SP | TG | GS | TP | VT | Mean |
| A | −0.35 | −0.33 | −0.28 | −0.32 | −0.26 | −0.31 |
| B | −0.13 | 0.01 | −0.06 | −0.12 | −0.08 | −0.08 |
| C | −0.24 | −0.23 | −0.17 | −0.26 | −0.18 | −0.22 |
| D | −0.27 | −0.28 | −0.10 | −0.25 | −0.12 | −0.20 |
| E | −0.27 | −0.23 | −0.12 | −0.19 | −0.15 | −0.19 |
| H | −0.24 | −0.21 | −0.20 | −0.18 | −0.17 | −0.20 |
| K | −0.23 | −0.15 | −0.03 | −0.12 | −0.13 | −0.13 |
| M | −0.29 | −0.19 | −0.22 | −0.21 | −0.10 | −0.20 |
| N | −0.30 | −0.27 | −0.16 | −0.27 | −0.18 | −0.24 |
| O | −0.24 | −0.32 | −0.18 | −0.19 | −0.10 | −0.21 |
| P | −0.35 | −0.33 | −0.27 | −0.27 | −0.22 | −0.29 |
| R | −0.25 | −0.19 | −0.09 | −0.21 | −0.11 | −0.17 |
| S | −0.17 | −0.18 | −0.05 | −0.10 | −0.10 | −0.12 |
| T | −0.26 | −0.32 | −0.21 | −0.27 | −0.12 | −0.24 |
| V | −0.29 | −0.32 | −0.23 | −0.23 | −0.21 | −0.26 |
| X | −0.26 | −0.22 | −0.06 | −0.18 | −0.15 | −0.17 |
| Y | −0.25 | −0.03 | −0.13 | −0.19 | −0.13 | −0.15 |
| Z | −0.31 | −0.29 | −0.16 | −0.25 | −0.18 | −0.24 |
| Mean | −0.25 | −0.23 | −0.15 | −0.21 | −0.15 | −0.20 |
| SD | 0.05 | 0.10 | 0.05 | 0.06 | 0.05 | 0.06 |

charts as it is well-established that letter legibility reduces in the presence of other letters,[43–46] a phenomenon referred to as "crowding" or "contour interaction" in visual literature. Furthermore, recent evidence[47] demonstrates that, under conditions of contour interaction (e.g., the presence of nearby letters), the spatial content of letters and therefore their legibility might be differentially affected. This may result in a lower variability in difficulty between letters contained in an acuity chart.

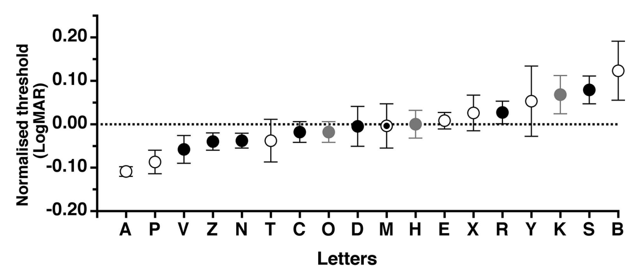


**FIGURE 5.**

Plot of the average normalized threshold (log MAR) of five subjects for each of the 18 letters used. Zero indicates the average threshold of all letters. Error bars represent ±1 SD. Note, that 0.02 log MAR corresponds to one letter. Full circles indicate the letters of the standard ETDRS charts, open circles the letters of the UoC charts, and gray circles the common letters.

The overall pattern of results suggests that the UoC chart forms a valid alternative to the standard method for assessing VA, offering the advantage of containing letters recognizable by a wider population basis, such as European citizens, as well as subjects from countries using the Cyrillic alphabet. Because the new chart secures validity of VA screening among population using Latin, Greek, and Cyrillic alphabets it may represent an ideal alternative to the ETDRS chart for multinational clinical trials.

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