1040-5488/13/9002-0174/0 VOL. 90, NO. 2, PP. 174–178
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Comparison of Visual Acuity Charts in Young Adults and Patients with Diabetic Retinopathy

Sotiris Plainis*, George Kontadakis†, Eftychia Feloni‡, Trisevgeni Giannakopoulou‡, Miltiadis K. Tsilimbaris§, Ioannis G. Pallikaris§, and Joanna Moschandreas||

ABSTRACT

Purpose. To compare visual acuity (VA) assessed in healthy eyes and eyes with diabetic retinopathy (DR) using three different logMAR charts: the Sloan letter European-wide chart, the tumbling E chart, and the Landolt C chart.

Methods. Measurements on one eye of 40 volunteers (aged 29 ± 4 years) without visual impairment and 31 DR patients (aged 70 ± 9 years) with mild/moderate visual impairment were included. Visual acuity was assessed, with habitual refractive correction, using each of the three charts. Bland-Altman charts were constructed, and 95% limits of agreement were calculated to measure agreement.

Results. Mean VA in the group of young adults was −0.05 ± 0.10 (Sloan letter), −0.02 ± 0.13 (tumbling E), and 0.00 ± 0.12 (Landolt C) logMAR. Average VA estimates differed to a statistically significant extent between all charts. Mean VA in the DR group was 0.46 ± 0.25 (Sloan letter), 0.48 ± 0.26 (tumbling E), and 0.59 ± 0.28 (Landolt C). A statistically significant difference was observed for average Sloan letter versus Landolt C ($p < 0.001$) and tumbling E versus Landolt C ($p < 0.001$) acuities. Moreover, in healthy eyes, a moderate correlation ($r = -0.38$, $p = 0.015$) was found between the discrepancy in Sloan letter and Landolt C acuity and the mean VA estimate. The 95% limits of agreement were wide (more than approximately 0.2 logMAR for each comparison) and wider in the DR group chart comparisons than in healthy eyes.

Conclusions. Landolt C charts resulted in worse VA estimates compared with letter and tumbling E charts in both young adults and visually impaired subjects with DR. These differences seem more pronounced in DR patients who exhibit worse VAs. The specific study population must be considered in comparing outcomes from different clinical practices.
(Optom Vis Sci 2013;90:174–178)

Key Words: visual acuity, diabetic retinopathy, Landolt C, tumbling E, visual acuity charts

Visual acuity (VA) typically represents the finest spatial detail that the visual system can resolve, describing its "sharpness." Assessment of VA forms the standard procedure in quantifying the severity of most ocular disorders, the efficacy of therapeutic interventions, and the impairment of central visual function. Thus, both in clinical practice and research, VA assessment should be performed with methods that are as accurate as possible.

During the past decades, there have been several modifications and significant progress in the methods and the procedures used for the evaluation of VA. The most widely adopted tool worldwide is the Snellen VA chart, which was introduced in 1862.[1] In 1976, Bailey and Lovie[2] developed a rigorous chart design and test protocol based on the logarithmic progression of letter sizes, which was later used for the Early Treatment of Diabetic Retinopathy Study (ETDRS).[2,3] Currently, the ETDRS acuity offers the gold standard and has been widely adopted in basic and clinical vision research.[4,5]

The conventional optotypes used in VA charts are letters. To facilitate reliable VA screening for clinical trials and exchange of patient data between clinics and researchers throughout Europe, a modified ETDRS chart with selected (Sloan font) letters has been developed as a common tool for countries using the Latin, Greek, and Cyrillic alphabets.[6] In situations where the use of alphabet-based optotypes is not possible, such as when subjects are illiterate or cannot read Latin characters, the Landolt C and the tumbling E optotypes are commonly used. Testing VA with such charts introduces a different task because it requires detection of the

*MSc, PhD
†MSc, MD
‡MSc
§MD, PhD
||PhD
Institute of Vision and Optics, University of Crete, Greece (SP, GK, TG, MKT, IGP); Faculty of Life Sciences, University of Manchester, Manchester, United Kingdom (SP); and Department of Social Medicine, University of Crete, Greece (JM).

orientation of the symbol (or gap in Landolt C) rather than letter recognition or discrimination, which implements different visual processes.[7] The purpose of the current study is to compare the results of VA measurements in young adults without visual impairment and a DR population using logMAR charts with three different optotypes: the Sloan letter chart, the Landolt C chart, and the tumbling E chart.

METHODS

Participants

Two groups of subjects participated in the study: young adults without visual impairment and subjects with DR. Subjects with high sphero-cylindrical error (>4.00 diopters [D]) and astigmatism (>2.00 D) were excluded from the study. Forty apparently healthy volunteers, either students or employees of the University of Crete, comprised the group of subjects without visual impairment (spherical equivalent, +1.00 to −3.87 D). Their mean age was 29 (SD 4) years, and 16 (40%) were male. These subjects underwent complete ophthalmic examination to rule out any ocular disease. Thirty-one subjects with DR agreed to participate in the study (mean age ± SD, 70 ± 9 years) (spherical equivalent, +2.25 to −3.50 D). All DR subjects had insulin-dependent diabetes mellitus but no history of systemic or eye disease other than the DR. Twelve subjects (39%) were male. The DR subjects were regular outpatients at the ophthalmology clinic of the University Hospital of Crete. Fourteen patients had signs of diabetic maculopathy. The VA in the DR patients ranged from 0.10 to 0.90 logMAR. All subjects were naive regarding VA measurements apart from their possible participation in regular ophthalmologic examinations. One eye of each subject was randomly selected for inclusion.[8] The study conformed to the tenets of the Declaration of Helsinki and followed a research protocol approved by the institutional review board of the University of Crete. All participants were informed verbally about the nature of the study and provided written informed consent.

VA Measurements

Visual acuity was assessed with habitual refractive correction (if any, contact lenses were not allowed) using three logMAR charts: the chart composed of Sloan letters developed for European-wide use, the Landolt C chart, and the tumbling E chart (Precision Vision, La Salle, Ill). The letter chart was a modified ETDRS chart, which follows the logMAR progression and line spacing design elements.[6] A back-illuminated slim stand (catalog no. 392; Sussex Vision Ltd., Rustington, West Sussex, UK), at 4 m distance, held the acuity charts. Luminance values were within the recommendations for standardizing the measurement of VA (160 cd m^{-2}). The three charts were presented in random order. All subjects were asked to identify each letter in turn in each row starting from the letter in the top left corner and proceeding row by row until they could no longer name at least one letter in a row correctly. They were instructed to read slowly and guess the letters when they were unsure. The termination rule for stopping was making four mistakes on a line. The experimenter scored correct letters on custom-designed data forms. Visual acuity was derived from the calculation of missed letters up to the last readable line.

Statistical Analysis

The Bland-Altman method was used to assess agreement between the charts (Bland and Altman 1986).[9] Paired-sample *t* tests were also

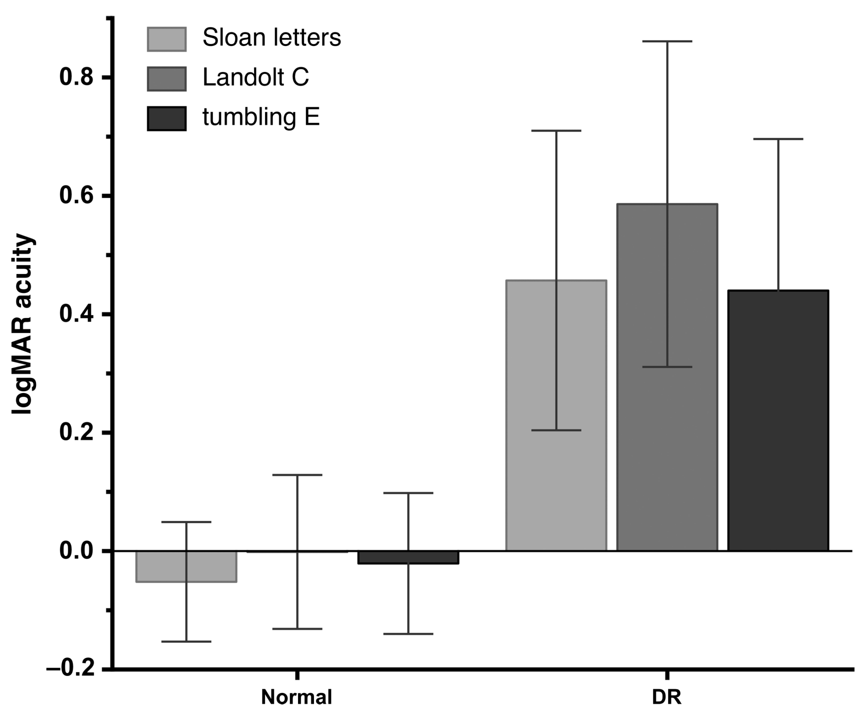

FIGURE 1.
Plot of the average logMAR acuity with the three logMAR charts used for the young adults with non–impaired vision and the DR group. Error bars represent ±1.96 SD.

applied to assess average agreement (bias). Where the differences between measurements had a symmetric distribution and the level of discrepancy did not seem to depend on the magnitude of the measurements, 95% limits of agreement (LoA) were calculated as the mean difference ±1.96 SD. Where the Bland-Altman scatterplot indicated a linear trend between difference and average, regression-based LoA were calculated.[10] Pearson correlation coefficients were calculated to assess the direction and magnitude of the linear correlation between difference and average.[11] The significance level was set to 5%. The statistical package SPSS 19.0 (SPSS Inc., Chicago, Ill) was used throughout.

RESULTS

Fig. 1 presents mean VA for the two groups tested using the three logMAR charts. Mean VA in the group of young adults with non-impaired vision was −0.05 (SD, 0.10) logMAR using the Sloan letter chart, −0.02 (SD, 0.13) logMAR using the tumbling E chart, and 0.00 (SD, 0.12) logMAR using the Landolt C chart. A mean difference of 0.05 logMAR (2.5 optotypes) was found between the Landolt C and the letter VA charts ($p < 0.001$; 95% CI, 0.02 to 0.08) and a mean difference of 0.02 logMAR (1 optotype) between the Landolt C and tumbling E VA charts ($p = 0.034$; 95% CI, 0.00 to 0.04). The mean difference in VA (0.04 logMAR) between the Sloan and the tumbling E charts was also significantly different from zero ($p = 0.015$; 95% CI, 0.01 to 0.06).

Mean (SD) VA in the DR group was 0.46 (0.25) logMAR with the Sloan letter chart, 0.48 (0.28) logMAR using the tumbling E chart, and 0.59 (0.26) logMAR using the Landolt C chart. The mean difference in VA between the Landolt C and the letter chart was statistically significant (0.13 logMAR; $p < 0.001$; 95% CI, 0.09 to 0.17) as was the mean difference between the Landolt C and the tumbling-E chart (0.11 logMAR; $p < 0.001$; 95% CI, 0.08 to 0.15). On the other hand, VA was not found to differ substantially between the Sloan letter and the tumbling E charts (0.02 logMAR; $p = 0.341$; 95% CI, −0.02 to 0.06).

The Bland-Altman plot revealed a moderate negative correlation between the discrepancy in estimated VA between Landolt C and Sloan letter charts and average VA estimates in the healthy subject group ($r = -0.38$, $p = 0.015$). The lower the estimated VA (i.e., higher logMAR values), the greater the absolute discrepancy between the charts (Fig. 2). A weak, negative, nonstatistically significant correlation was seen in the DR patient group ($r = -0.23$, $p = 0.219$). In the Sloan letter–tumbling E comparison, a weak, negative, nonstatistically significant correlation was seen in the young-adult group ($r = -0.24$, $p = 0.129$), and there was no evidence of a trend in the DR group ($r = -0.04$, $p = 0.852$). The 95% LoA were −0.18 to 0.12 logMAR in the non–visually impaired group, implying that, for 95% of such subjects, VA measured using the Sloan letter chart would be between 0.18 logMAR better and 0.12 logMAR worse than that measured using the tumbling E chart. The LoA in the DR patient group were wider than in the young-adult group in each of the three comparisons, being from −0.22 to 0.19 in the Sloan letter–tumbling E comparison, from −0.33 to 0.07 in the Sloan letter–Landolt C comparison, and from −0.08 to 0.30 in the Landolt C–tumbling E comparison. In the Landolt C–tumbling E chart comparison, a weak, positive, nonstatistically significant correlation was seen in both groups ($r = 0.22$, $p = 0.164$ in young adults and $r = 0.197$, $p = 0.288$ in DR patients).

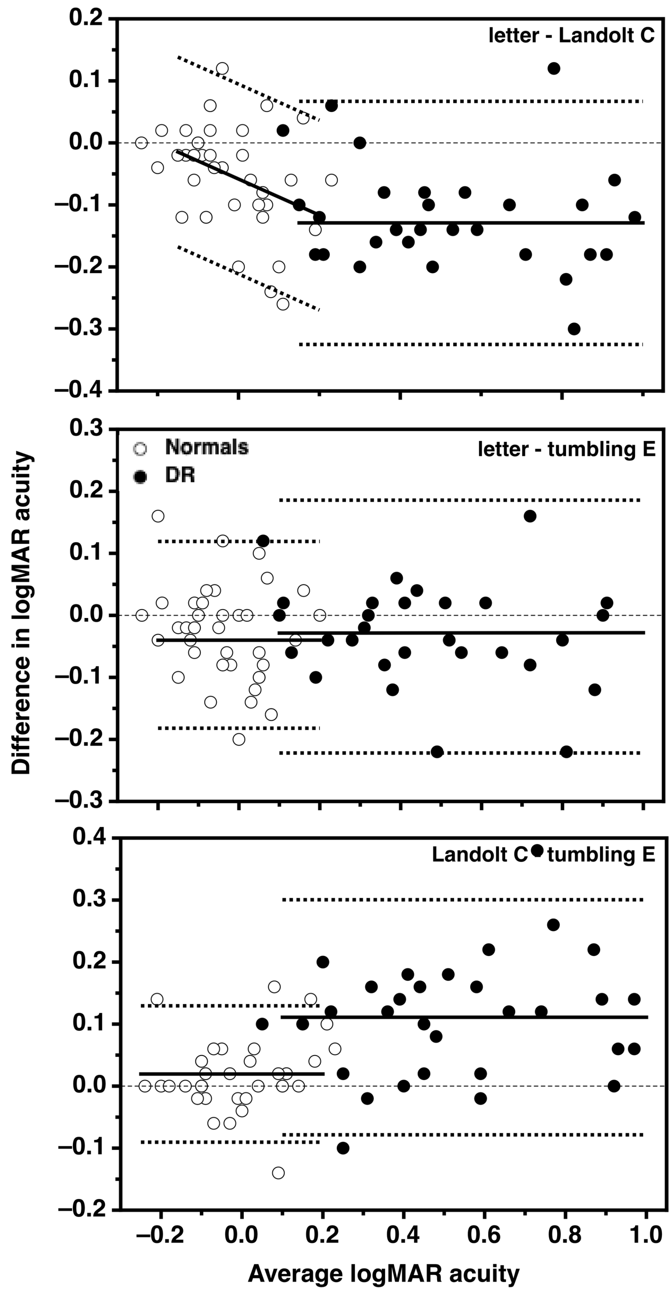

FIGURE 2.
Bland-Altman plots of the difference in logMAR acuity for the three charts used as a function of the average logMAR acuity. Empty and filled circles represent data from the young adults and DR patients, respectively. The solid lines are average differences and the dotted lines are the 95% limits of agreement (LoA). Note that, in the upper graph, the lines for the young-adult group correspond to linear regression fit and regression-based 95% LoA.

DISCUSSION

Visual acuity assessment is the fundamental tool for the evaluation of the integrity of visual function in the clinical practice and the core part of clinical ophthalmologic examination. Variability between methods used for the measurement of VA forms one of the main drawbacks in clinical practice.[4,5,12] The different optotypes used in various ETDRS-like charts may account for differences in VA results in clinical studies and also in the published literature. In the current study, the main finding is that measurement of VA with the Landolt C chart and the tumbling E chart results in worse VA, on average, compared with that of the Sloan letter chart in both healthy young adults and visually impaired patients. Also, the LoA were found to be wide in all comparisons and wider for the DR groups than for the young adults without visual impairment, indicating that it might not be appropriate to use the different charts interchangeably. In the healthy adult group, the magnitude of the discrepancy was found to be related to VA in the Sloan letter–Landolt C comparison. Published estimates of ETDRS test-retest variability range from ±0.07 to ±0.11 logMAR. The LoA for the Sloan letter–Landolt C chart comparisons fall outside this range for both groups.

When measuring VA with Landolt C and tumbling E optotypes, the task accomplished is to identify a single feature such as the orientation of the letter E or the detection of the gap in Landolt C rather than to discriminate or recognize a letter from a set of letters (recognition/discrimination acuity).[7] Despite the complexity of the task in recognition acuity, most of the studies conclude that interpretation of letter optotypes involves compensatory cognitive mechanisms resulting in higher VA compared with Landolt C and tumbling E. Wittich et al.[7] tested patients with macular hole with Landolt C and letter optotypes and found significant differences. According to the authors, complex letter shapes facilitate the recognition task through a cortical cognitive process rather than obstruct it.[7]

It seems that when visual impairment is caused by retinal disease—as in our study—and in cases that impairment is in cortical level—as in amblyopia—the difference between recognition and resolution acuity is significant. van den Brom et al.[13] postulated that patients with moderate cataract recognize fewer Landolt C optotypes compared with Sloan letters, with the difference being irrespective of VA. Rassow and Wang[14] presented a difference between ETDRS and Landolt C acuity of approximately three lines in patients with strabismus-amblyopia or deprivation-amblyopia. Similarly, Kuo et al.[15] found significant differences between the Landolt C and ETDRS charts in patients with maculopathy and vision worse than 20/200, and Becker et al.[16] found the same in patients with amblyopia. Both of these studies[15,16] also compared the Landolt C and ETDRS charts in normal subjects but did not find any differences. In contrast, Grimm et al.[14] found that letters should be 5% smaller than Landolt C to have the same legibility. The current study is the first to show a difference between Sloan letter and Landolt C logMAR charts in normally sighted subjects. It has to be acknowledged, though, that normal subjects were tested with their habitual refraction, and any uncorrected refractive error, such as uncorrected astigmatism, may affect the VA measure in one test more than the other.

In most of the studies comparing ETDRS and Landolt C acuity, the difference in VA between the charts correlates with the VA of subjects.[7] The findings of the present study (using the modified ETDRS chart with Sloan letter optotypes) are in agreement with this, particularly for the healthy adult group. No such correlation was seen between the tumbling E and Sloan charts. Consequently, the possibility of overestimation of VA by letter charts in comparison with symbol charts should be taken into consideration when patients with low VA are concerned.

Measuring VA with tumbling E charts has not been cited in the literature as extensively as Landolt C, but results of most studies agree that the former yields better VA threshold results than Landolt C. According to Grimm et al.,[17] the tumbling E should be approximately 15% smaller than Landolt C to obtain comparable VA scores. Becker and Gräf[18] reported a slight overestimation of VA by the tumbling E compared with the Landolt C, even in strabismus amblyopia. Reich and Ekabutr[19] found that acuities measured with induced blur are better with tumbling E than those with Landolt C but found no difference in viewing without blur. In agreement with previous studies, VA as measured with the tumbling E chart was higher than as measured with the Landolt C chart in the visually impaired group and also (but to a smaller extent) in the group of patients with normal vision. In addition, the tumbling E chart was found to yield worse average VA estimates compared with that using Sloan letters in patients with normal vision, thus supporting the statement that the task of identifying orientation is more difficult than letter discrimination in normal vision.

Interestingly, the latter finding was not confirmed in visually impaired patients, where tumbling E yielded similar results with Sloan letters, although a difference between Sloan and Landolt C was found in this group. It seems that despite the similar nature of the two tests (tumbling E and Landolt C), subjects' responses differed compared with that when using the Sloan chart. Bondarko and Danilova[20] proposed that tumbling E offers a better estimation of the highest spatial frequency that the visual system can resolve and may be less susceptible to training effects and adaptation processes than are measurements with Landolt C. Their assumption that Landolt C would yield a better threshold is not supported by the literature. A possible explanation for the better acuity observed with tumbling E compared with that observed with Landolt C symbols may stem from the differences in their spatial characteristics, that is, letter E offers the advantage of two "gaps" to be detected. For patients with large central or paracentral scotomas, the gap in a very large Landolt C might fall outside the field of view or preferred retinal locus, whereas tumbling E has two gaps between its three limbs, simulating a grating. It has been found that VA measured with gratings is less affected by optical defocus, which might also be found in patients with various ocular diseases.[21–23]

In conclusion, notable differences in VA measurements were found between the three commonly used charts in both nonvisually impaired young adults and visually impaired patients with DR. Landolt C yields worse VA estimates than tumbling E and Sloan letter charts, whereas tumbling E yields worse VA than Sloan letters in normal subjects. Differences between Landolt C and the other two optotypes are more pronounced with poorer VA, and this should be taken into consideration in clinical practice and research.

ACKNOWLEDGMENTS

Received August 14, 2012; accepted October 7, 2012.

REFERENCES

1. Snellen H. Optotypi ad visum determinandum. Utrecht, Netherlands: PW van de Weijer; 1862.
2. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. Am J Optom Physiol Opt 1976;53:740–5.

3. Ferris FL, 3rd, Kassoff A, Bresnick GH, Bailey I. New visual acuity charts for clinical research. Am J Ophthalmol 1982;94:91–6.
4. Falkenstein IA, Cochran DE, Azen SP, Dustin L, Tammewar AM, Kozak I, Freeman WR. Comparison of visual acuity in macular degeneration patients measured with snellen and early treatment diabetic retinopathy study charts. Ophthalmology 2008;115:319–23.
5. Hussain B, Saleh GM, Sivaprasad S, Hammond CJ. Changing from Snellen to LogMAR: debate or delay? Clin Exp Ophthalmol 2006;34: 6–8.
6. Plainis S, Tzatzala P, Orphanos Y, Tsilimbaris MK. A modified ETDRS visual acuity chart for European-wide use. Optom Vis Sci 2007;84:647–53.
7. Wittich W, Overbury O, Kapusta MA, Watanabe DH. Differences between recognition and resolution acuity in patients undergoing macular hole surgery. Invest Ophthalmol Vis Sci 2006;47:3690–4.
8. Karakosta A, Vassilaki M, Plainis S, Elfadl NH, Tsilimbaris M, Moschandreas J. Choice of analytic approach for eye-specific outcomes: one eye or two? Am J Ophthalmol 2012;153:571–9.
9. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307–10.
10. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res 1999;8:135–60.
11. Bland JM, Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. Lancet 1995;346:1085–7.
12. Raasch TW, Bailey IL, Bullimore MA. Repeatability of visual acuity measurement. Optom Vis Sci 1998;75:342–8.
13. van den Brom HJ, Kooijman AC, Blanksma LJ, van Rij G. Measurement of visual acuity with two different charts; a comparison of results and repeatability in patients with cataract. Doc Ophthalmol 1995;90:61–6.
14. Rassow B, Wang Y. [Correlation of letter optotypes with Landholt ring for different degrees of visual acuity]. Klin Monbl Augenheilkd 1999;215:119–26.
15. Kuo HK, Kuo MT, Tiong IS, Wu PC, Chen YJ, Chen CH. Visual acuity as measured with Landolt C chart and Early Treatment of Diabetic Retinopathy Study (ETDRS) chart. Graefes Arch Clin Exp Ophthalmol 2010;249:601–5.
16. Becker R, Teichler G, Graf M. [Comparison of visual acuity measured using Landolt-C and ETDRS charts in healthy subjects and patients with various eye diseases]. Klin Monbl Augenheilkd 2011;228:864–7.
17. Grimm W, Rassow B, Wesemann W, Saur K, Hilz R. Correlation of optotypes with the Landolt ring—a fresh look at the comparability of optotypes. Optom Vis Sci 1994;71:6–13.
18. Becker R, Gräf M. [Landolt C and Snellen E acuity: differences in strabismus amblyopia?]. Klin Monbl Augenheilkd 2006;223:24–8.
19. Reich LN, Ekabutr M. The effects of optical defocus on the legibility of the Tumbling-E and Landolt-C. Optom Vis Sci 2002;79:389–93.
20. Bondarko VM, Danilova MV. What spatial frequency do we use to detect the orientation of a Landolt C? Vision Res 1997;37:2153–6.
21. Thorn F, Schwartz F. Effects of dioptric blur on Snellen and grating acuity. Optom Vis Sci 1990;67:3–7.
22. Herse PR, Bedell HE. Contrast sensitivity for letter and grating targets under various stimulus conditions. Optom Vis Sci 1989;66:774–81.
23. Bittner AK, Jeter P, Dagnelie G. Grating acuity and contrast tests for clinical trials of severe vision loss. Optom Vis Sci 2011;88:1153–63.

Sotiris Plainis
Institute of Vision and Optics
School of Health Sciences
University of Crete
71003 Heraklion Crete
Greece
e-mail: plainis@med.uoc.gr