A Quantitative Investigation on the Effect of Edge Enhancement for Improving Visual Acuity at Different Levels of Contrast

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ABSTRACT

Background: The major limitation in human vision is refractive error. Auxiliary equipment and methods for these people are not always available. In addition, limited range of accommodation in adult people when switching from a far point to a near point is not simply possible. In this paper, we are looking for solutions to use the facilities of digital image processing and displaying to improve visual acuity when using digital display devices. We quantitatively investigate the effect of edge enhancement on improving the visual acuity at different levels of contrast. We can improve visual acuity for people such as emmetropia, myopia and hyperopia when they utilize display devices.

Materials and Methods: According to the objective of this research, 24 visual acuity optical charts were designed using MATLAB software, based on logMAR standard. The charts have different levels of contrast with enhanced edges of optotypes at two brightness levels: 0 and 255. The proposed patterns were tested on 20 human subjects. The obtained results for each chart were analyzed in SPSS software.

Results: The results show that at all contrast levels, edge enhancement improves visual acuity. The degree of improvement where the edges have brightness level of 0 is higher than where the edges have brightness level of 255.

Conclusion: Based on the results, enhancing the edges of optotypes in the background image improves visual acuity by about 16.1% on logMAR scale.

Keywords

Optical Aberrations, Pre-compensation, Visual Acuity, Contrast Sensitivity, Edge Enhancement

Introduction

Human eye, like any other optical system, suffers from a number of specific optical aberrations [1]. Any deviation in the path of light rays from the ideal state in an optical system is called an aberration. Optical aberrations are the main causes of degradation of image quality in the eye and are divided into two categories: low-order optical aberrations and high-order optical aberrations. Low order aberrations such as regular astigmatism, myopia and hyperopia account for approximately 90% of overall optical aberrations in the eye [2]. Nowadays, studies are conducted in the field of developing techniques to improve the quality of images to help the people with visual impairments.

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For example, in 2006, efforts were made to enhance the image quality by adjusting the light direction and increasing the local contrast using shading exaggeration method but did not make significant difference in visual acuity [3] or in [4, 5] reference in 2009 amplifying the high-frequencies of images was proposed to improve the quality of images, but due to the limitation in frequency range of the human eye and the dynamic range of digital displays, practically, this method could enhance only the limited frequency bands of an image. In 2011, image resolution enhancement techniques were presented in movies and animations, in which by increasing the local resolution, they solved the problem of time fluctuations and improved image quality [6, 7]. In 2012, the multi-layer displays were proposed in order to improve the static optical aberrations such as astigmatism and defocus [8]. In that year, a display technique was presented which could dynamically adapt the optical content of the image proportional to the subject's specific conditions [8]. But this method is only able to show a very small area of one's field of view. After that, a proprietary multi-layer display was introduced based on deconvolution. Although, the subject can see images more clearly and edges more sharply [9], in this method, the image contrast is very low and it cannot be used for color images due to the presence of different wavelengths. Also, the subject is not in a fixed position relative to the display, and so, these methods are not practically efficient in increasing visual acuity. Later, three-dimensional display technologies were introduced in 2013. In this method of displaying, angular resolution is one of the limiting factors which causes only a limited depth of the field of view to be displayed. These constraints blur images outside this range and make it unclear for vision [10]. Another method was presented to correct optical aberration based on the pre-compensation of images. In this method, to implement pre-compensation, the PSF (Point Spread Function) of the subject's eye is required. PSF describes the image of the system from a point light source. In this method, the image changes based on the PSF measured from the patient, in that, the patient perceives the pre-compensated image clearly and without any aberration [11, 12].

In this field, several articles were presented, but in 2015, a reverse filter was designed based on the deconvolution of the total variation. In this method, the amount of ringing artifacts decreases. Moreover, the pre-compensated image has a higher contrast than those in previous methods, and the edges of the image has been preserved relatively better [13]. An error which can be seen in all these researches is lack of correct normalization of PSF. Also the PSF is under the influence of pupil size, which has not been regarded in these studies.

Optical flaws and refractive errors of the eye in addition to reducing visual acuity affect contrast sensitivity. Having a high contrast sensitivity and accurate diagnosis, directly depends on how to focus the image on the retina. Thus, the scattering and diffraction cause a lack of precise focus of the image especially its edges on the retina. In addition, the contrast decreases between the desired objects and background, and consequently the edges of the objects will be lost. In this study, we deal with investigating the effect of enhancing the edge of an object on improving visual acuity at different levels of contrast between the object and the background in an image. Then, we quantitatively consider how much edge enhancement can be useful to improve visual acuity. For this purpose, standard optical charts were designed and presented to a group of 20 human subjects. The test results were recorded based on different sizes of the signs and were analyzed using SPSS software.

Material and Methods

To conduct this study, 24 dynamic charts for visual acuity were designed using MATLAB software. The standard of logMAR chart and E optotype has been used in this design. The direction of optotypes can randomly change each time during the test. Thus, the error rate is reduced due to memorizing the direction of optotypes and deceiving operator (Figure 1). To avoid the crowding effect, each optotype has distance from the adjacent optotype at least as much as its size. This spacing is applied from the highest to the lowest row in the chart.

The logMAR chart has been designed to achieve a more accurate estimate of visual acuity compared with other tests such as Snellen chart [14]. Nowadays, the logMAR chart is used for optical studies. The results are expressed in the form of logarithm of the minimum angle of resolution (MAR). In the logMAR chart, each optotype has a score value of 0.02 log unit, and the total score for a line represents a change of 0.1 log unit. According to this, an increase of 0.1 log unit represents the loss of one line on the visual acuity chart. The formula used in calculating the score in the LogMAR method is as follows [15]:

$$\text{MAR} = \frac{1}{Visual\ Acuity} \quad (1)$$

log MAR = 0.1 + log MAR value of the best line read - (0.02 × (number of letters read))

In the logMAR presentation, the results vary between the two numbers -0.3 and 1, in which the number -0.3 is for 20/10 and the number 1 for 20/200 on the Snellen chart.

$$\text{LogMAR}\frac{20}{10} = 0.1 + \text{Log}\frac{10}{20} - (0.02 \times 5) = -0.3$$

$$\text{LogMAR}\frac{20}{200} = 0.1 + \text{Log}\frac{200}{20} - (0.02 \times 5) = 1$$

A smaller number in the logMAR presentation shows a better visual acuity. Where, zero represents the normal acuity and smaller-than-zero numbers show better acuity. According to the definition of World Health Organization a number equal to 1.3 in the logMAR scale, is considered Blind [16].

The size of each optotype is calculated based on the following formula:

Y: min X: meter R: distance (2)

$$Y = X \times \left(\frac{360}{2\pi}\right) \times \left(\frac{1}{R}\right) \times 60$$

Table 1 shows the size of optotypes at each row in millimeter unit for 6-meter distance from designed charts.

Charts 1 to 12 are designed at different contrast levels. The contrast levels of optotypes and the background vary from 0 to 255 (Table 2). In this research, Weber's formula is used to express the contrast (Equation 3).

$$\text{Weber contrast} = \frac{L_{max} - L_{min}}{L_{max}} \quad (3)$$

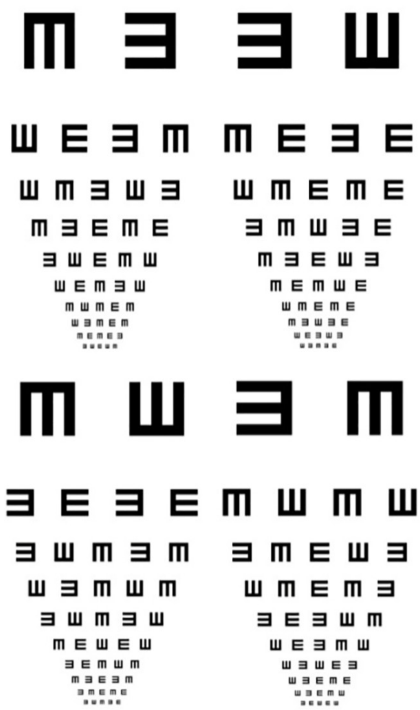

Figure 1: View of a chart designed with different directions of optotypes

Table 1: Size of the optotypes in each row of the visual acuity charts, for a distance of six meters.

Visual Acuity	Optotypes Size (mm)
20/15	6.541
20/20	8.722
20/25	10.927
20/30	13.083
20/40	17.444
20/50	21.805
20/60	26.166
20/70	30.527
20/100	43.611
20/200	87.222

Where, L_{max} and L_{min} respectively show the maximum and minimum brightness of the image [17].

Figure 2 shows an optotype from each of 12 charts at different levels of Weber contrast.

In terms of contrast, charts 13 to 18 are similar to charts 1 to 6 peer to peer. However, brightness level of 2 pixel from the edge of each optotype has become 0. Also, charts 19 to 24 are analogous to charts 7 to 12 one to one, but 2 pixel from the edge of each optotype has become 255 (Figure 3).

The charts were shown to the human subjects on a 27-inch display screen, which has a resolution of 2560 × 1440 pixels and a minimum quantization error of 0.233 millimeter. Moreover, each case study was in six meters distance form display. Due to use of a digital display, the background of the optotypes has uniform brightness without any color change. In addition, the brightness level of the laboratory was set to be equal to 500 lux, and there was not any direct or indirect dazzling light source in the field of view [18].

In this research, 20 human subjects were tested in the range of age from 20 to 35 years with a mean age of 29.4. In this study, we consider the cases without any systemic ocular and neurological diseases. All cases had the optical aberration myopia. The required information has been obtained through the examination of the subjects.

Table 2: Specifications of contrast levels of charts 1 to 12.

Chart No.	Optotypes Contrast	Background Contrast	Weber Contrast
Ch-1	0	255	1
Ch-2	25	230	0.89
Ch-3	50	205	0.75
Ch-4	75	180	0.58
Ch-5	100	155	0.35
Ch-6	125	130	0.03
Ch-7	130	125	0.03
Ch-8	155	100	0.35
Ch-9	180	75	0.58
Ch-10	205	50	0.75
Ch-11	230	25	0.89
Ch-12	255	0	1

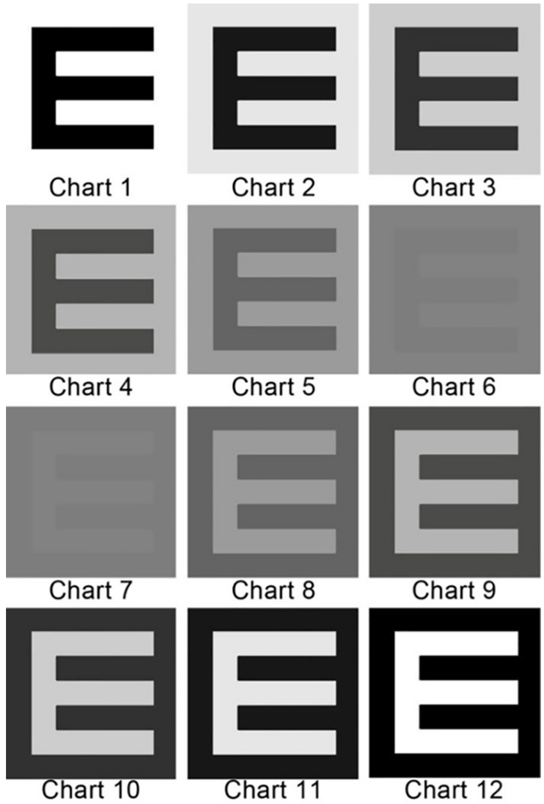

Figure 2: Differences in the level of contrast between the background and optotypes on the charts

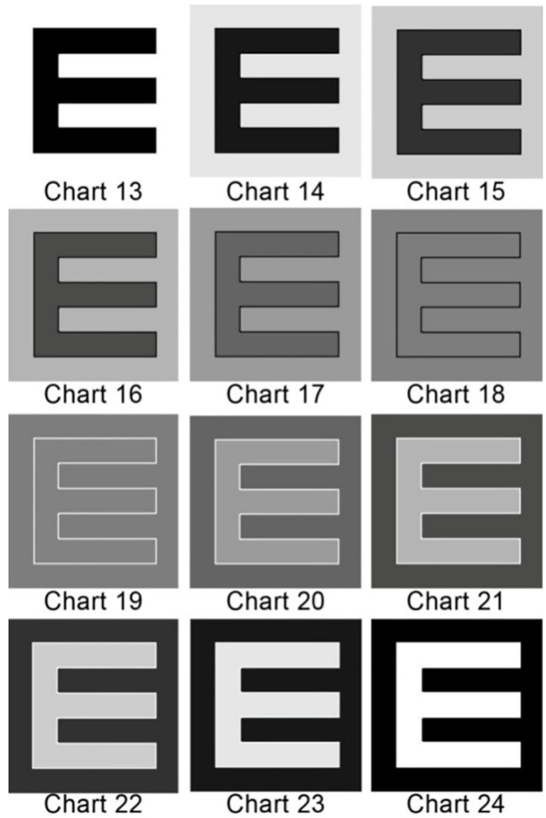

Figure 3: Enhance the edge of the optotypes on the charts

Results

To serve the final purpose, all obtained information was analyzed using paired T-test in SPSS statistical software.

In order to apply paired T-test, the normality of data distribution was investigated through Kolmogorov-Smirnov test. The data had a normal distribution based on P-value, $P > 0.05$, (Table 3).

The paired T-test was applied to two sets of charts (1 to 6 and 13 to 18) and (7 to 12 and 19 to 24) peer to peer for considering the presence of a significant difference between the data of two charts. In order to find potential significant differences, the P-value must be less than 0.05. Tables 4 and 5 show the obtained results from the paired T-test.

The results from the first set indicate that the mean values of each chart form 1 to 6 are greater than corresponding charts 13 to 18 (Figure 4). These results illustrate that blackening 2 pixels from the edges of the optotypes improves visual acuity. This improvement is maximized when the Weber contrast is equal to 3 percent. Also, visual acuity increases by 16.1 percent on the LogMAR scale. For the Pair No.1 in Table 4, the percentage of Weber contrast is equal to 100 percent and the brightness level of the optotypes is 0. Thus, blackening 2 pixels from the edges makes minor difference by about 0.3 percent that is considered an error.

According to table 4, low P-value (less than 0.05) in the comparison from pair No. 2 onwards shows that there was a significant dif-

Table 3: Mean, standard deviation and the results of the K-S test for 40 data

Chart No.	Mean	Std. Deviation	Kolmogorov-Smirnov Z	Asymp. Sig.(2tailed)
Ch-1	0.245	0.173	1.122	0.161
Ch-2	0.249	0.169	0.938	0.342
Ch-3	0.265	0.164	0.814	0.522
Ch-4	0.297	0.160	0.942	0.337
Ch-5	0.347	0.178	0.882	0.418
Ch-6	0.668	0.405	0.654	0.786
Ch-7	0.656	0.317	0.922	0.363
Ch-8	0.306	0.168	0.701	0.709
Ch-9	0.252	0.161	0.749	0.629
Ch-10	0.211	0.158	0.807	0.532
Ch-11	0.175	0.154	0.760	0.610
Ch-12	0.139	0.151	0.631	0.821
Ch-13	0.242	0.170	1.015	0.255
Ch-14	0.230	0.166	0.737	0.649
Ch-15	0.222	0.178	1.015	0.255
Ch-16	0.241	0.176	1.044	0.226
Ch-17	0.257	0.179	0.748	0.630
Ch-18	0.507	0.212	0.916	0.371
Ch-19	0.521	0.217	0.908	0.381
Ch-20	0.279	0.151	0.870	0.436
Ch-21	0.233	0.151	0.557	0.916
Ch-22	0.194	0.130	0.913	0.376
Ch-23	0.161	0.148	0.674	0.754
Ch-24	0.141	0.149	0.661	0.775

Table 4: Investigating the significance of the difference between data in the paired comparison between charts 1 to 6 and 13 to 18

Pair No.	Pair Chart	T	Sig.(2-tailed)
1	Ch-1&Ch-13	0.798	0.430
2	Ch-2&Ch-14	3.733	0.001
3	Ch-3&Ch15	8.205	0.000
4	Ch-4&Ch-16	8.688	0.000
5	Ch-5&Ch-17	12.337	0.000
6	Ch-6&Ch-18	5.407	0.000

Table 5: Investigating the significance of the difference between the data in the paired comparison between charts 7 to 12 and 19 to 24

Pair No.	Pair Chart	T	Sig.(2-tailed)
1	Ch-12&Ch-24	-0.438	0.664
2	Ch-11&Ch-23	2.573	0.014
3	Ch-10&Ch-22	2.190	0.035
4	Ch-9&Ch-21	2.042	0.048
5	Ch-8&Ch-20	3.166	0.003
6	Ch-7&Ch-19	4.775	0.000

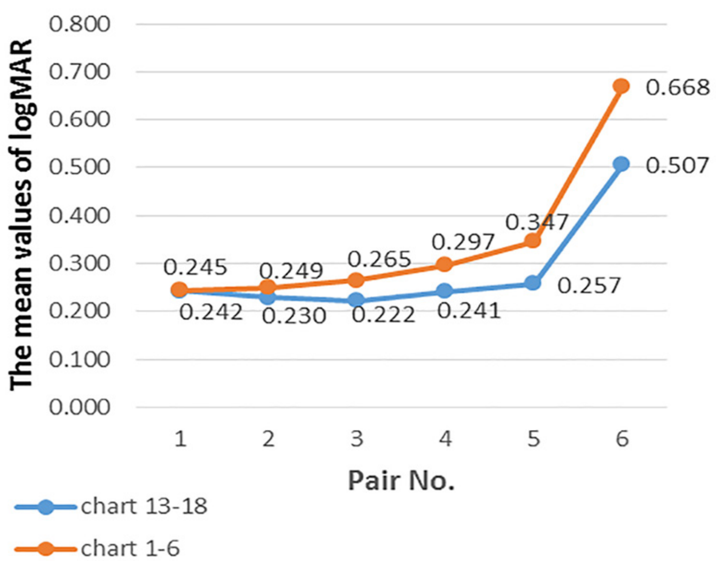

Figure 4: The graph of the paired comparison between charts 1 to 6 and 13 to 18

ference between the data of these pairs. As expected, this difference is not significant in the analysis of pair No.1.

The results from the second set were the same (Figure 5). This means that whitening 2 pixels from the edges of the optotypes improves visual acuity. The maximum effect is equal to 13.5 percent for the pair No.6 in Table 5. In this case, 0.2 percent improvement was considered an error.

Table 5 shows P-value in comparison with other pairs. There was a significant difference between the pairs from pair No.2 onwards.

Discussion

The most significant feature of this study in comparison with previous studies is the quantitative presentation of the results based on the obtained information from human subjects. In addition, the optical patterns utilized in this re-

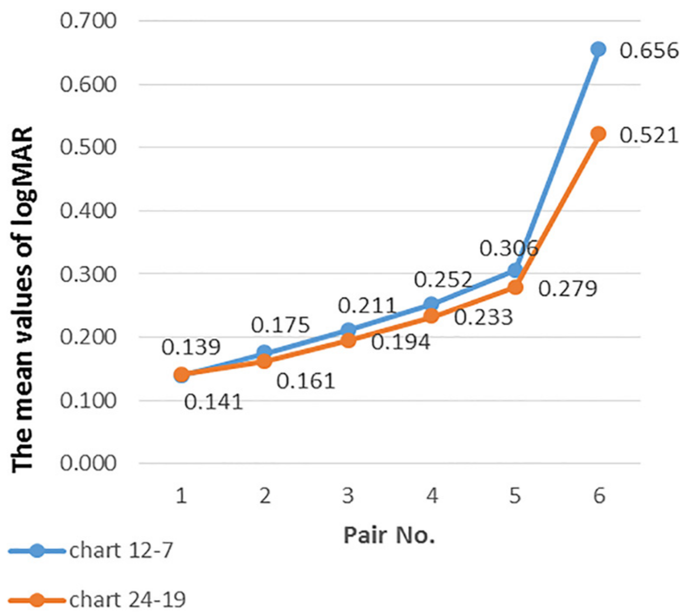

Figure 5: Graph of the paired comparison between charts 12 to 7 and 24 to 19

search, have been designed based on the standard of visual acuity charts. For each level of contrast, a separate chart has been designed. All experiment settings have been done based on the standards provided in Iranian National Standards Organization (INSO 16285, 2013) .The result has been expressed exactly based on the number of optotypes recognized by the subject. In this study, it was determined that by reducing the contrast, visual acuity decreases against the mean value of logMAR numbers and the slope of the graph increases. The results show that blackening the edges of the optotypes further improves visual acuity as compared with whitening them (Table 6).

Table 6: Percent of improvement in visual acuity on LogMAR scale, for different states of edge enhancement

Pair No.	1	2	3	4	5	6
Weber Contrast percent	100	89	75	58	35	3
Visual Acuity	0.245	0.249	0.265	0.297	0.347	0.668
Visual Acuity with black edge	0.242	0.230	0.222	0.241	0.257	0.507
Percent of improvement in visual acuity	0.3	1.9	4.3	5.6	9	16.1

Pair No.	1	2	3	4	5	6
Weber Contrast percent	100	89	75	58	35	3
Visual Acuity	0.139	0.175	0.211	0.252	0.306	0.656
Visual Acuity with black edge	0.141	0.161	0.194	0.233	0.279	0.521
Percent of improvement in visual acuity	0.2	1.4	1.7	1.9	2.7	13.5

Conclusion

In this research, we came to know that edge enhancement improves visual acuity by about 14.8 percent on average for 3 percent Weber contrast. The aforementioned method enhances visual acuity, but it is not complete for the full compensation of low-order optical aberrations. For future research, we suggest a combination of this method and the reverse filter technique to be used to assess more improvement in human vision.

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Conflict of Interest

None

References

1. Cervino A, Hosking SL, Montes-Mico R, Bates K. Clinical ocular wavefront analyzers. *J Refract Surg*. 2007;**23**:603-16. PubMed PMID: 17598581.
2. Lombardo M, Lombardo G. Wave aberration of human eyes and new descriptors of image optical quality and visual performance. *J Cataract Refract Surg*. 2010;**36**:313-31. doi.org/10.1016/j.jcrs.2009.09.026. PubMed PMID: 20152616.
3. Golovinskiy A, Matusik W, Pfister H, Rusinkiewicz S, Funkhouser T. A statistical model for synthesis of detailed facial geometry. ACM Transactions on Graphics (TOG) 2006;25:1025–34.
4. Peli E, Woods RL. Image enhancement for impaired vision: the challenge of evaluation. *Int J Artif Intell Tools*. 2009;**18**:415-38. doi.org/10.1142/S0218213009000214. PubMed PMID: 20161188. PubMed PMCID: 2727758.
5. Peli E. Limitations of image enhancement for the visually impaired. *Optom Vis Sci*. 1992;**69**:15-24. doi.org/10.1097/00006324-199201000-00003. PubMed PMID: 1371332.
6. Templin K, Didyk P, Ritschel T, Eisemann E, Myszkowski K, Seidel H-P, editors. Apparent resolution enhancement for animations. April 28 - 30, 2011. New York: Proceedings of the 27th Spring Conference on Computer Graphics; 2011.
7. Stengel M, Eisemann M, Wenger S, Hell B, Magnor M. Optimizing apparent display resolution enhancement for arbitrary videos. *IEEE Trans Image Process*. 2013;**22**:3604-13. doi.org/10.1109/TIP.2013.2265885. PubMed PMID: 23744682.
8. Pamplona VF, Oliveira MM, Aliaga DG, Raskar R. Tailored displays to compensate for visual aberrations. ACM Transactions on Graphics. 2012;31:1–12.
9. Huang F-C, Lanman D, Barsky BA, Raskar R. Correcting for optical aberrations using multilayer displays. *ACM Transactions on Graphics* (TOG). 2012;**31**:185. doi.org/10.1145/2366145.2366204.
10. Masia B, Wetzstein G, Aliaga C, Raskar R, Gutierrez D. Display adaptive 3D content remapping. *Computers & Graphics*. 2013;**37**:983-96. doi.org/10.1016/j.cag.2013.06.004.
11. Alonso Jr M, Barreto A, Cremades JG. Image pre-compensation to facilitate computer access for users with refractive errors. ACM SIGACCESS Accessibility and Computing; 2004: ACM. ACM SIGACCESS Accessibility and Computing. 2004;77-78:126–32.
12. Alonso J, Barreto A, Cremades JG, Jacko JA, Adjouadi M. Image pre-compensation to facilitate computer access for users with refractive errors. *Behaviour & Information Technology*. 2005;**24**:161-73. doi.org/10.1080/01449290412331327456.
13. Montalto C, Garcia-Dorado I, Aliaga D, Oliveira MM, Meng F. A total variation approach for customizing imagery to improve visual acuity. ACM *Transactions on Graphics* (TOG). 2015;**34**:28. doi.org/10.1145/2717307.
14. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. *Am J Optom Physiol Opt*. 1976;**53**:740-5. doi.

org/10.1097/00006324-197611000-00006. PubMed PMID: 998716.

15. Carlson NB, Kurtz D, Hines C. Clinical procedures for ocular examination. New York: McGraw-Hill; 2004.

16. Virgili G, Acosta R. Reading aids for adults with low vision. *Cochrane Database Syst Rev*. 2006;(4):CD003303. doi.org/10.1002/14651858.cd003303.pub2. PubMed PMID: 17054166.

17. Rangayyan RM. Biomedical image analysis. Florida: CRC press; 2004.

18. Staff Z. The lighting handbook. Austria: Zumtobel; 2004.