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Automation of visual acuity determination when testing colour perception in cartographic design

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The article describes the structure of the eye and the mechanism of image formation. It also discusses visual disorders (short-sightedness and farsightedness) that may influence the perception of colours. The methodology of the determination of visual acuity, as well as the principle of functioning and the purpose of "Visus" software developed on the basis of this methodology are described. The results of colour perception tests will be evaluated more objectively, using this software.

Key words: short-sightedness, farsightedness, visual acuity, colour perception, cartography

INTRODUCTION

Even 80% of all information about the environment is received by a human through vision. It can be stated with confidence that the eyes give a human being the biggest opportunity to learn about the outer world. The greater part of all information received through vision is perception of colours (Bautrėnas, 2002, 2004), therefore, in thematic cartography the problem of colour perception has always been and will always be very relevant. When conducting research on colour perception, it is important to understand not only the very mechanism of vision, but also to know how to evaluate it.

As recent research showed, one of the most common vision disorders is short-sightedness (myopia), and the majority of short-sighted people live in economically well developed countries, especially young people with university education. Among Japanese, the short-sighted constitute 38%, and among students they reach 68%. In Lithuania, over the past 20 years the percentage of short-sighted among children rose from 13.5 to 26.7% (http://www.sveikas.lt/).

Such deviations from normal vision can have a direct influence on colour perception (Bautrėnas, 2005), which is important not only when using cartographical information, but also when developing new thematic maps.

IMAGE FORMATION IN THE EYE

The eye is an optical system that can be compared to a camera. A lens, together with an anterior chamber (Fig. 1) and a vitreous humour of an eye play the role of a "camera lens". This optical system makes the rays of light coming from an observed object to cross each other in the retina, the light-sensitive part of the eye. In such a way, thanks to the process of accommodation, sharp yet reduced and upside-down image of the object is formed in the retina (Fig. 1).

The retina contains photoreceptors (light-sensitive cells) which, depending on their form, are separated into cons and rods (Bautrėnas, 2002; http://akis.lass.lt/schema/dalis12.htm). Depending on the energy of light absorbed (intensity), photochemical reactions take place in cons and rods, i. e. biological (electrical) currents are formed, which trigger nerve impulses. Theses impulses are sent to the vision centres of the cortex via nerve fibres and are transduced into the sense of vision or light.

The cons are situated in the central part of the retina and form the so called *macula.* In a healthy eye, the image of the observed object is formed (is focused) in this very place, and it is the sharpest here. Unfortunately, not everybody has healthy eyes. It is a common phenomenon when the rays coming from the observed object are focused not in the central part of the

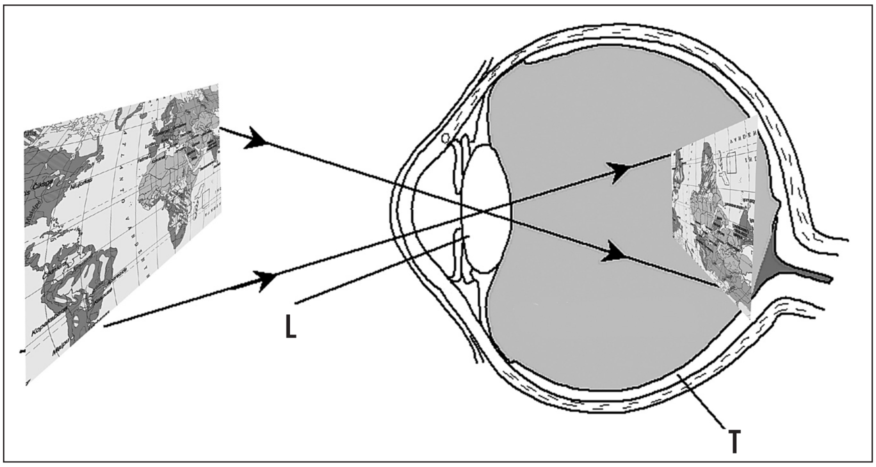


Fig. 1. Image formation in the eye. L – lens, T – retina
1 pav. Atvaizdo formavimasis akyje. L – lęšiukas. T – tinklainė

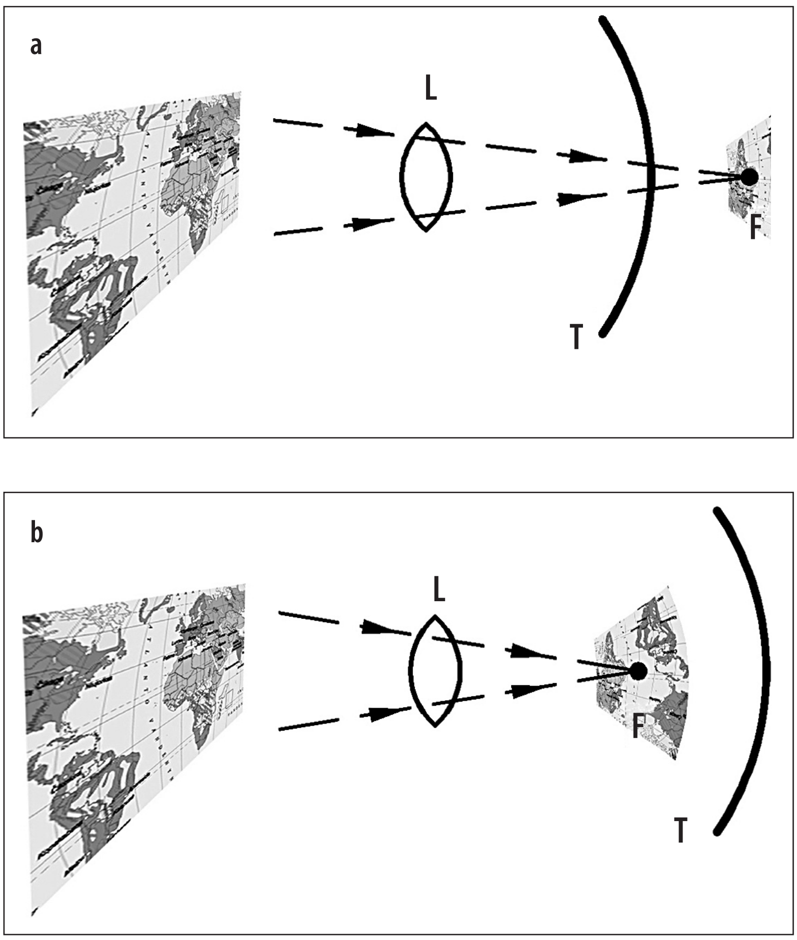


Fig. 2. The focusing of image in the eye: *a* – behind the retina (farsightedness), *b* – before the retina (short-sightedness), L – lens, T – retina, F – the image focusing point
2 pav. Vaizdo fokusavimas akyje: *a* – už tinklainės (toliaregystė), *b* – prieš tinklainę (trumparegystė), L – lęšiukas, T – tinklainė, F – vaizdo fokusavimo taškas

eye (Fig. 2), but before the retina (short-sightedness) or behind it (farsightedness) (http://www.sveikas.lt/).

The further from the centre the image of the observed object is formed, the more indistinct (blurred) it is and the worse is the colour perception (Fig. 3). It is possible that the colours seen are totally different, because several neighbouring colours blend (Bautrėnas, 2006).

In most cases, short-sightedness or farsightedness is easily corrected with respective light dispersing or concentrating optical lenses, i. e. with glasses. Whether the colour perception improves after such correction of image focussing is not clear. Supposedly, the colour perception remains the same, and only the resolution of the eye improves, however, additional research should be done to prove it.

When conducting various colour perception tests (Bautrėnas, 2004; 2005; 2006), one should evaluate the following possible deviations of image focussing. One of the simplest methods is to determine the *visual acuity*.

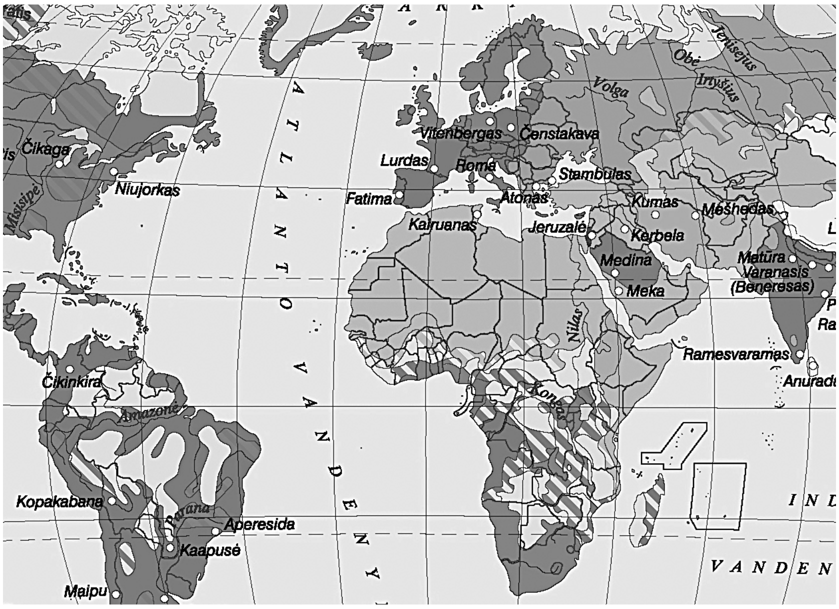


Fig. 3. The image as it is seen: *a* – by a normal eye, *b* – by a short-sighted or a farsighted eye
3 pav. Matomas vaizdas: *a* – normalia akimi, *b* – trumparegio arba toliaregio

METHODOLOGY OF DETERMINING VISUAL ACUITY

Vision acuity (lat. *visus*) is the capability of the eye to distinguish two dots that are approx. one angular minute away from each other. This angle (distance) can be explained by the anatomical structure of the eye. It is known that the diameter of cons in the central part of the retina is 2–4 μm, and a one minute angle (1') is equal to a 4–5 μm image on the retina (Bagdonas ir kt., 2006), therefore, the eye distinguishes between two dots only if their image falls on two separate cons that have at least one not stimulated con between them. If the image of every observed dot would be projected onto the cons next to each other, these images would blend and only one dot would be seen.

In 1862, a famous ophthalmologist of that time Herman Snellen (1834–1908) suggested to use optotypes (Watt, 2008), i. e. tables of Landolt rings, letters or symbols, to test visual acuity (Fig. 4).

For example, the table of Landolt optotypes contains 7 rows of rings seen at a five-minute (5') angle from a distance L of 60, 36, 24, 18, 12, 8 and 6 meters (Fig. 5).

Visual acuity is calculated using the formula (Transtronics, 2007)

$$V = L / S, \qquad (1)$$

where V is visual acuity, L is the distance from which an optotype is recognized, S is the distance, from which a healthy eye should be able to see the optotypes in that row.

For example, if a tested person is able to see a row of optotypes from a distance of 6 meters when a person with normal

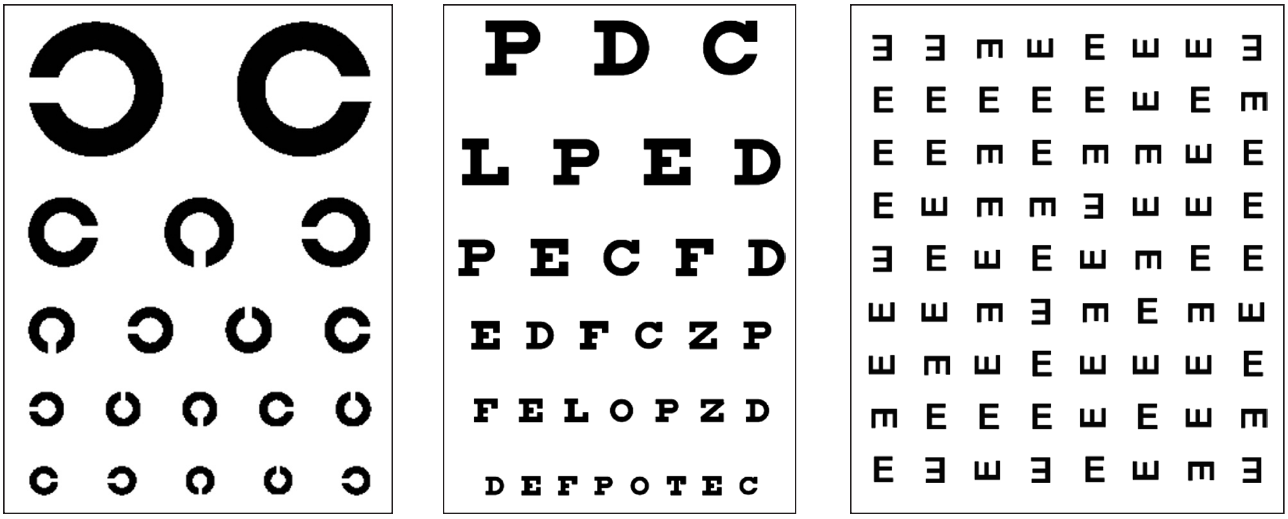


Fig. 4. Fragments of optotype tables
4 pav. Optotipų lentelių fragmentai

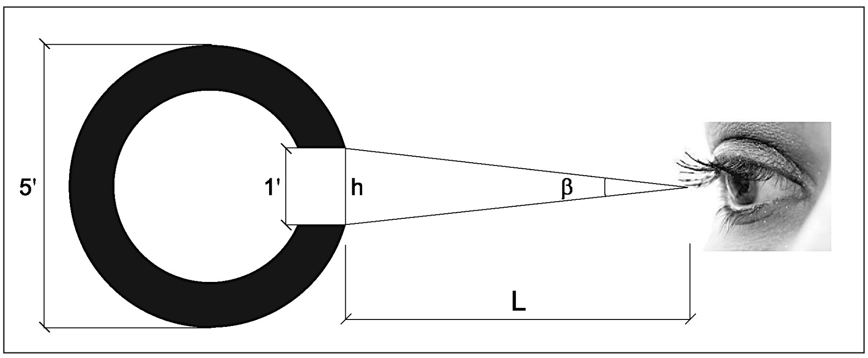


Fig. 5. Determination of visual acuity
5 pav. Regėjimo aštrumo nustatymas

vision would see this row from a distance of 12 meters, it means that the visual acuity of the former is two times weaker ($V = 0.5 = 6/12$). Visual acuity is measured in dioptres (D). One dioptre is a breaking power of any optical system (of an eye), which has a focal length of 1 m (Transtronics, 2007).

Modern standard tables consist of 12 rows of optotypes and are adapted to measure visual acuity from a distance of 5 meters. If from such a distance and with sufficient lighting an eye is able to see well the tenth row from above, it means its visual acuity is equal to 1.0 ($V = 1.0$).

As you can see, the methodology of determination of visual acuity is simple and sufficiently accurate; therefore, before doing any research on colour perception, one should evaluate the visual acuity of each examined person. This would allow evaluating more objectively the results of the research. The problem is that many of the persons visit their ophthalmologist rarely and do not know what their visual acuity is. In order to determine the visual acuity of a person quickly and with a sufficient accuracy, the author suggests automating this check-up.

AUTOMATION OF VISUAL ACUITY DETERMINATION

Since the research on colour perception is carried out using TC software created by the author (Bautrėnas, 2005, 2005), the automation of the determination of visual acuity also requires a PC.

Using the methodology described above, it is easy to imitate a table of optotypes required for the research on the PC screen, however, one needs to consider that the PC screen is viewed from a much closer distance than 5 meters.

From the given chart (Fig. 5) one can see that, knowing the exact distance to the observed optotype and the value of the angle of vision, one can easily calculate the minimum distance that an eye is able to distinguish, by using the formula

$$h = L \operatorname{tg} \beta, \qquad (2)$$

where h is the smallest distance between two dots distinguishable by the eye, L is a distance from the eye to the observed optotype, β is the an angle of vision ($\beta = 1'$).

The whole size of the optotype will be 5 times bigger than the calculated smallest distance *h,* because the angle needed for its observation must be equal to 5'. Attention should be paid to the fact that the size of the symbol (optotype) seen on the screen is different from the calculated size of the same symbol. It is so because the size of the symbol seen on the screen is directly related to the size of the monitor (diagonal) and the resolution of its dots. Therefore, the true size of the optotypes used *H* must be calculated using the formulae

$$H = 5hP, \tag{3}$$

$$P = R/F, \tag{4}$$

where *H* is the true size of the optotype on the screen, *P* is correction due to the technical parameters of the monitor, *R* is resolution of the dots of the monitor, *F* is the size of the diagonal of the monitor.

Following the methodology of determination of visual acuity and the formulae (3, 4) proposed for calculating of the size of the optotypes, the author developed software with a conditional name "Visus" (Figs. 6, 7) for the determination of visual acuity.

RESULTS

When working with "Visus" software it is critical to enter both accurate technical parameters of the PC used and the distance between the test person and the monitor. The reliability of the results depends on these data. The technical parameters of the PC are entered in the beginning of the test and hardly ever change; nevertheless, the distance between the test person and the monitor is a non-constant value. It depends on the comfortable position of the person relative to the monitor. Research has shown that this distance may vary (on average) from 60 to 100 cm. Therefore, this distance has to be measured and

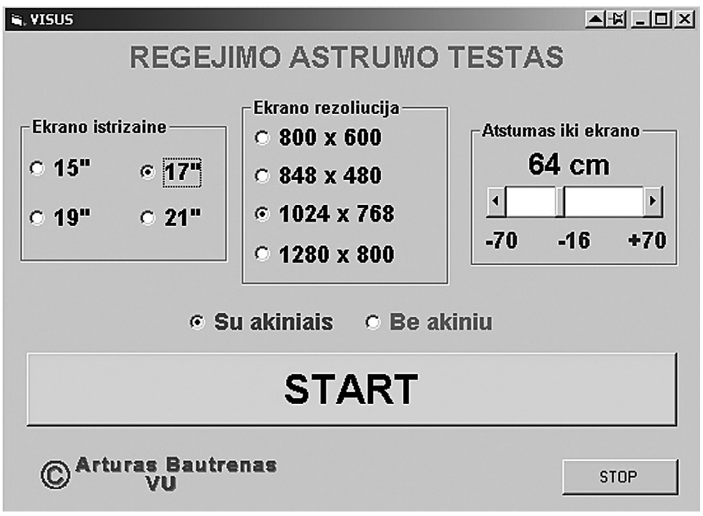


Fig. 6. "Visus" software. Entering the initial parameters of the test
6 pav. „Visus" kompiuterinė programa. Testo pradinių parametrų įvedimas

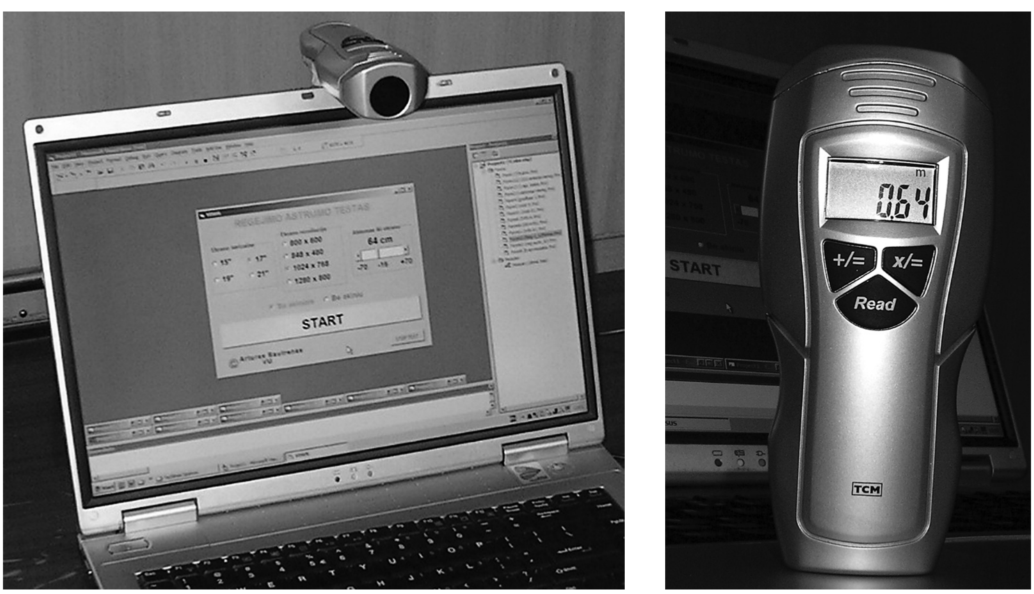
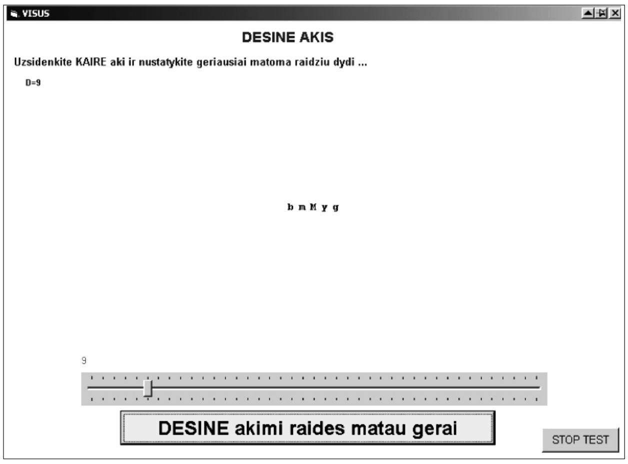


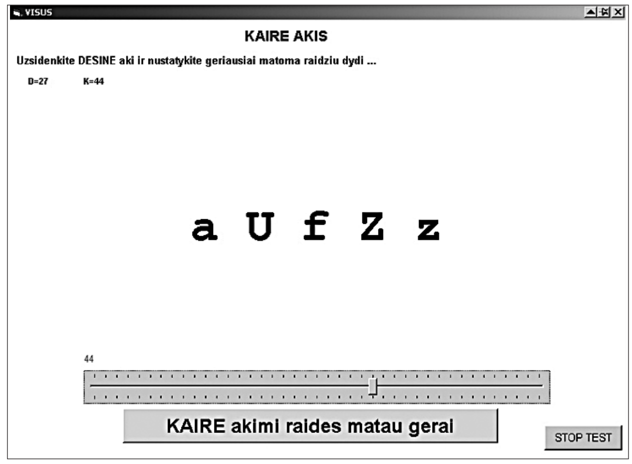
Fig. 7. The TCM ultrasound distance meter
7 pav. Ultragarsis atstumų matuoklis TCM

entered not only in the beginning of the test (6 pav.), but it may be necessary to correct it in the course of the test.

The distance to the test person has been measured using a TCM ultrasound distance meter, attached to the monitor (Fig. 7). Measurements were made every 10 seconds with a tolerance of 1 cm, and the result of this measurement was sent to the "Visus" software which automatically calculated (Siler, 1998) and adjusted the true size of the optotypes *H* (3rd formula).

The visual acuity is evaluated according to the smallest size of the optotypes shown to the test person that he or she is able to see on the screen. The smallest visible size of the optotypes is determined by the test person (or the operator) by moving the slide bar at the bottom of the software window (Fig. 8).





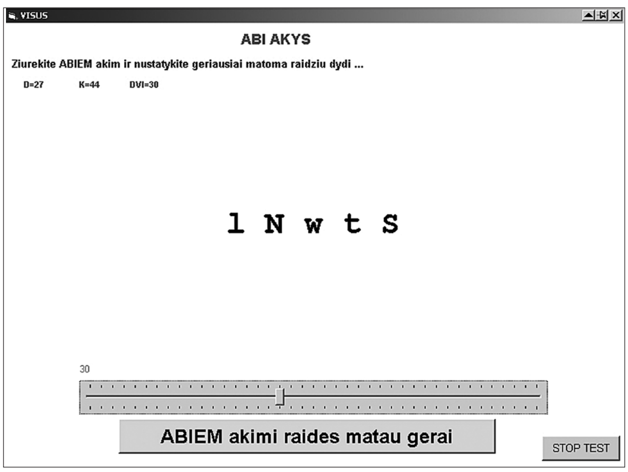


Fig. 8. Determination of the visible size of the optotypes
8 pav. Optotipų matomo dydžio reguliavimas

Lentelė. **Regėjimo aštrumo matavimo rezultatai**
Table. **Results of visual acuity measurement**

Number of persons / Testuojamųjų skaičius	Measurements of mean visual acuity (D) / Išmatuotas vidutinis regėjimo aštrumas (D)			Noted visual acuity (D) / Žinomas regėjimo aštrumas (D)			Mean error (%) / Vidutinė paklaida (%)		
	Akis / Eye			Akis / Eye			Akis / Eye		
	Left / Kairė	Right / Dešinė	Both / Abi	Left / Kairė	Right / Dešinė	Both / Abi	Left / Kairė	Right / Dešinė	Both / Abi
5	–1.56	–1.37	–1.45	–1.5	–1.5	–1.5	4.0	8.7	3.3
3	–1.69	–1.72	–1.77	–1.75	–1.75	–1.75	3.4	1.7	1.1
2	–2.25	–1.90	–2.10	–2.0	–2.0	–2.0	12.5	5.0	5.0
2	–2.36	–2.74	–2.39	–2.5	–2.5	–2.5	5.6	9.6	4.4
1	–1.59	–2.16	–2.12	–1.5	–2.5	–2.0	6.0	13.6	6.0
1	–3.74	–1.59	–2.50	–3.5	–1.7	–2.6	6.9	6.5	3.8
3	–3.36	–3.68	–3.52	–3.5	–3.5	–3.5	4.0	5.1	0.6
1	–3.91	–4.12	–4.21	–4.0	–4.0	–4.0	2.3	3.0	5.3
						Average (%) / Vidurkis (%)	**5.6**	**6.6**	**3.7**

Measurements of visual acuity of each eye separately and of the total visual acuity (of both eyes) were carried out on eighteen persons (all short-sighted). The results were compared against the data submitted by the test persons themselves regarding their vision. The results of the tests are given in Table.

CONCLUSIONS

1. The test of the "Visus" software on the persons who were aware of their true visual acuity showed that visual acuity is determined rather accurately; i. e. the tolerance did not exceed 7%.

2. Since the determination of visual acuity using "Visus" software is handy, fast and sufficiently accurate, it would be feasible to integrate it as a separate add-on into the TC [4] software designed to test the colour perception, and to repeat the tests carried out before. This would allow evaluating more objectively the results of colour perception tests.

3. The principle of the functioning of the software is based on the honesty of the test person (the test person is the one to determine the smallest visible size of the optotype); therefore, the results are rather subjective.

4. It should be noted that visual acuity determined using this software is not an exhaustive medical examination. The results do not reveal the true state of the eye, but only give grounds for a more objective evaluation of colour perception.

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REGĖJIMO AŠTRUMO NUSTATYMO AUTOMATIZAVIMAS TIRIANT KARTOGRAFINIO DIZAINO SPALVŲ SUVOKIMĄ

S a n t r a u k a

Didžioji dalis visos regėjimu gaunamos informacijos yra spalvų suvokimas, todėl spalvų suvokimo problema visada buvo ir liks itin aktuali teminei kartografijai. Vėliausieji tyrimai rodo, kad vienas iš dažniausiai pasitaikančių regėjimo sutrikimų yra trumparegystė. Trumparegių sparčiai daugėja gerai ekonomiškai išsivysčiusiose šalyse ir ypač tarp jaunų, aukštąjį išsilavinimą turinčių asmenų. Sutrikęs regėjimas gali tiesiogiai paveikti spalvų suvokimą, o tai svarbu ne tik naudojantis kartografine informacija, bet ir kuriant naujus teminius žemėlapius. Tiriant spalvų suvokimą, reikia greitai ir tiksliai įvertinti pasitaikančius regos sutrikimus.

Straipsnyje pateikiamas akies sandaros bei vaizdo susiformavimo mechanizmas, nagrinėjamos regėjimo problemos (trumparegystė, toliaregystė), galinčios turėti įtakos spalvų suvokimui. Aprašoma praktikoje dažniausiai naudojama regėjimo aštrumo nustatymo metodika ir šios metodikos pagrindu straipsnio autoriaus sukurtos kompiuterinės programos „Visus“ veikimo principas bei paskirtis.

Sukurtos kompiuterinės programos tyrimo rezultatai leidžia teigti, kad ši kompiuterinė programa greitai ir gana tiksliai nustato regėjimo aštrumą. Tikslinga „Visus“ kompiuterinę programą naudoti visuose spalvų suvokimo tyrimuose, tuomet atliktų tyrimų rezultatai bus įvertinti objektyviau.