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A COMPARATIVE COST AND ACCURACY ANALYSIS OF SELECTED COLORBLINDNESS DETECTION METHODS

Commonly, colorblindness detection is associated mainly with such industry fields as logistics or transport. The following paper shows that color vision disorders have strong impact on the life of the person affected, not only on the professional, but also on the everyday level. Moreover, in some cases the undetected colorblindness may endanger health and life of the affected person. The author discusses several different colorblindness detection methods and analyzes their costs and efficiency.

Keywords: *colorblindness, color vision disorders, detection methods, cost and efficiency analysis.*

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ПОРІВНЯЛЬНИЙ АНАЛІЗ ВАРТОСТІ І ТОЧНОСТІ ДЕЯКИХ МЕТОДІВ ДІАГНОСТИКИ ДАЛЬТОНІЗМУ

У статті представлено результати діагностики різних ступенів дальтонізму, що має велике економічне значення, особливо у сфері логістики і транспорту. Показано, що порушення колірного зору має великий вплив на професійні якості і повсякденне життя людини. В деяких випадках невиявлений дальтонізм може поставити під загрозу здоров'я і життя. Проаналізовано різні методи діагностики дальтонізму, їх вартість і відповідні економічні ефекти.

Ключові слова: *дальтонізм, порушення колірного зору, методи діагностики, аналіз вартості і економічних ефектів.*

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ СТОИМОСТИ И ТОЧНОСТИ НЕКОТОРЫХ МЕТОДОВ ДИАГНОСТИКИ ДАЛЬТОНИЗМА

В статье представлены результаты диагностики различных степеней дальтонизма, что имеет большое экономическое значение, особенно в сфере логистики и транспорта. Показано, что нарушение цветового зрения оказывает большое влияние на профессиональные качества и повседневную жизнь человека. В некоторых случаях невыявленный дальтонизм может поставить под угрозу здоровье и жизнь. Проанализированы различные методы диагностики дальтонизма, их стоимость и соответствующие экономические эффекты.

Ключевые слова: *дальтонизм, нарушения цветового зрения, методы диагностики, анализ стоимости и экономических эффектов.*

1. Introduction. Colorblindness is the inability to perceive differences between some colors that other people can distinguish. In most cases it is of genetic nature (but it may also occur because of eye, nerve or brain damage or exposure to certain chemicals), inherited recessively in feedback with the X chromosome - effects more men than women [1].

There are several types of color vision deficiencies, varying from total colorblindness (monochromacy) to an impairment (but not loss) of normal, three-dimensional color vision. They can be divided into 3 main categories:

- monochromacy, which is the inability to distinguish any color (also known as full colorblindness) [1].

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- Dichromacy, which is a color vision disorder occurring when 1 of 3 cone pigments is missing and color vision is reduced to two dimensions [1]. There are 3 types of dichromacy, depending on the missing cone pigment:

- protanopia is the form of red-green colorblindness, caused by the complete absence of red retinal photoreceptors. People with protanopia tend to confuse reds with black or dark gray, while violet, lavender, and purple are indistinguishable from various shades of blue because of dimmed reddish components [2].

- deuteranopia is the form of green-red colorblindness, caused by the complete absence of green retinal photoreceptors. The deuteranope suffers the same hue discrimination problems as the protanope, but without the abnormal dimming [2].

- tritanopia is the form of blue-yellow colorblindness, caused by the complete absence of blue retinal photoreceptors [2].

- anomalous trichromacy is color vision defect, which occurs when 1 of 3 cone pigments is altered in its spectral sensitivity [1].

According to the data published by WHO, currently about 0,7% of the whole human population is blind. Moreover, the number of people affected with various vision disorders is much higher (e.g. about 10% of total human population has some kind of color vision disorder [3]).

2. Colorblindness and its impact on professional life. In common understanding, being colorblind may prevent a person from engaging in certain occupations, especially when color recognition is either important for safety (e.g., driver, pilot) or essential for the work itself (e.g., painter, designer). Some of those limitations are caused by legal regulations [4].

These limitations originate from railroad accident in Lagerlunda, Sweden in 19th century, where investigation showed that the fatal crash was caused by a colorblind engineer [5]. The usual justification for such restrictions is that drivers must be able to recognize color-coded signals, such as traffic lights or warning lights. This results in certain limitations to a colorblind, in some countries person affected by color vision disorders cannot apply for a professional driving licence while in other (e.g., Romania) a colorblind person cannot obtain even the unprofessional driving licence due to rigorist regulations concerning candidates for drivers [6].

Color vision disorders affect a much wider spectrum of professions, cook being one of the most interesting examples. People with colorblindness may be unable to distinguish cooked (or fried) meat from the raw or may have difficulties in determining the ripeness of certain fruits (e.g., bananas) [7].

[8] and [9] show the importance of proper color recognition in medicine, especially in medical diagnostics. Neglecting or wrong interpretation of some symptoms (e.g., blood stains in samples) may result in wrong diagnosis, which may lead to endangerment of patient's health or life. Only in a few countries (Taiwan, India and Japan [10]), the candidates for students are examined for proper color recognition.

Indian technical universities also require their candidates to distinguish the colors correctly, using the ability to properly recognize the cable colors as a justification for this requirement.

Correct color vision is also important in work of firemen. By analysing the hue of both flame and smoke it is possible to determine both the type of fire and its characteristics (e.g., flame temperature, toxicity of smoke) [11].

Although it should be noted that in some cases people with color vision disorders may perform better at certain work than people with normal color vision. For example, research proves that colorblind people may recognize camouflaged objects better on aerial or satellite photos [12].

3. Colorblindness and its impact on everyday life. Human being comes across color-coded signals throughout all life - school being the first example. From picture coloring, through describing the objects to analysing maps and charts - all those activities are based on colors. In some cases even reading from chalkboard may be difficult. Teachers should be aware of students' colorblindness in order to use different color schema during classes or take the students' limitations into account while marking their work in class.

In case of protanopia or strong protanomaly, red traffic lights may be perceived as blacked out (not working). Thus, a protanope not aware of his disorder may be in risk of a traffic accident even despite not having a driving licence.

Taking everyday medicine is one of the most interesting cases of an impact of colorblindness on one's life. [10] records the glucose monitoring test strips used by diabetics as one of the most important examples of color-coding in medicine.

Being aware of color vision disorder is also significant while taking different medicines at the same time, especially if they are to be taken in a stressful situation (e.g., asthma attack).

Some of the aforementioned aspects of colorblindness, like troubles with determining the rawness of the meat or ripeness of the fruit should also apply to the everyday life of the affected person.

4. Colorblindness detection methods - a short overview. Colorblindness detection methods can be divided into 4 main groups (according to: [13], [14], [15]):

- arrangement methods;
- lamp methods;
- spectral methods;
- pseudoisochromatic plates.

All of these methods differ on the equipment needed, accuracy, examination cost and circumstances of use.

4.1. Arrangement methods. Probing with arrangement method can be twofold: either the examinee has to select a number of samples with color matching (or close to) to the one given by the examiner or he has to arrange the samples in a certain order (e.g., from the lightest to the darkest).

One of the precursors of the first type of this colorblindness detection method was Alaric Fithiof Holmgren, a Swedish doctor examining the aforementioned Lagerlunda railway incident. His method required the examinee to match colors from the set of 160 colored wools to the 3 predefined samples [16]. The original method was modified by William Thompson, who limited the set of wools to 40 and numbered them. This resulted in simplification of examination, which now could be conducted even by a person with no medical experience [17]. Doctor was needed only in case of detecting colorblindness to confirm the diagnose.

Method developed by Holgrem and its modifications are characterized with relatively high error rate (mainly due to the external factors, like light or color fading) and being tolerant to cheating (as the order of samples in the set is always the same) [17].

This type of arrangement method can be used only for detecting only protanopia and deuteranopia or cases of strong protanomaly or deteranomaly.

The D-100 and D-15 Farnsworth-Munsell panel are the examples of the second kind of arrangement method. The examinee has to arrange either 85 or 15 pawns in a specified order of hues. The results are placed on the predefined coordinate system by computing the difference between them and the correct set, the examiner is able to detect not only the type of color vision disorder, but also its degree [18]. The diagnoses are characterized by high accuracy, but due to time-consuming result analysis this method cannot be used to screening large groups of patients [19].

4.2. Lamp methods. Lamp methods are used only to demonstrate the examinee's ability to distinguish only certain signal colors (e.g., used in navy or aviation), not to determine the type of potential color vision disorder [15]. Statement of Demonstrated Ability (SODA) may serve as an example. This examination is granted to a person disqualified from obtaining a pilot's medical certification, only if the disqualifying condition is static or non-progressive and the person has been found capable of performing airman duties without endangering public safety [20]. It usually preformed in a practical way (at an airport), when the examinee has to correctly recognize the signals given by control tower. SODA examination can be repeated only once.

4.3. Spectral methods. Spectral methods are based on the fact that e.g. yellow light can be obtained by mixing green and red light in a certain ratio. The so-called anomaloscope is the most accurate tool to check the severity of one's color vision deficiency and its specific subtype. [21]. Due to this fact, this apparatus is used now as a reference tool for testing the exactness of other colorblindness detection methods. Unfortunately, the cost of this equipment is relatively high (prices starting from 8500 USD, see Table 1), so this method is rarely used.

4.4. Pseudoisochromatic plates. Pseudoisochromatic plates usually contain a circle of points appearing randomized in color and size. Within the pattern there are dots forming a number or shape clearly visible to people with normal color vision and invisible or difficult to see to people with color vision disorders [15]. There are various sets of plates, dedicated to different groups of users, with sets developed by Shinobu Ishihara being the most popular.

The pseudoisochromatic plates are nowadays the most commonly used method for detecting colorblindness [14], mainly due to the low cost of the examination - one set of plates costs about 200$ (see Table 1) and can be used for a few years if stored properly (in order to minimize the fading). Although it should be noticed, that they are often criticized, as some of the plates imply two (or sometimes more) correct answers (e.g., reading the numbers of 23 or 73 is acceptable) [22]. Some people may also perceive this test as unintelligible or outdated [23].

5. The accuracy and cost analysis. Table 1 presents the comparative analysis of cost and estimated accuracy of detecting color vision disorders among the 4 types of diagnostic methods presented above. Each method as assigned with its example: arrangement method -

D-100 Farnsworth-Munsell panel, lamp methods — Farnsworth's Lamp (FALANT), pseudoisochromatic plates — Ishihara plates and spectral methods — HMC anomaloscope.

Table 1. **The comparative accuracy and cost analysis of the selected colorblindness detection methods**

type	method name	usable for scree-ning?	usable for professional examination?	ability to distinguish between dichromacy and anomalous trichromacy	ability to distinguish between certain types of color vision disorders		cost (est., USD)	period of top accuracy	accuracy (est.)	limitations
					red - green	yellow - blue				
arrangement	D-100	no	yes	yes	yes	yes	700[1]	up to 2 years	n/a, the second gold standard	1) patients more than 8 years old 2) time-consuming result analysis by experienced personnel 3) difficult for people with limited capabilities
lamp	FALANT	no	yes	no	not app.	not app.	5000[2]	up to 5 years	low, not reco-mmended by American Army	1) used only for professional purposes (patients more than 18 years old)
Pseudoiso chromatic plates	Ishihara	yes	yes	no	yes	no	200[3]	up to 18 months	90-95%	1) patients more than 6 years old, 2) only several plates for people with limited capabilities
spectral	HMC anomalo-scope	no	no	yes	yes	no	8500[4]	unknown	close to 100%, used as 'golden standard'	requires experienced personnel

Source: own work, based on the data from: [13], [15], [19], [21], [22].
Prices: 1) http://www.munsellstore.com/default.aspx?MenuItemID=472,
2) http://colorvisiontesting.com/color7.htm,
3) http://www.sklepdlalekarza.pl/kategoria,optometria,129.html,
4) http://www.richmondproducts.com/shop/index.php?route=product/product&product_id=697.

The following factors were taken into consideration: usefulness for screening, usefulness for professional examination, ability to distinguish between dichromacy and anomalous trichromacy, ability to distinguish certain types of color vision disorders and limitations. As in several cases the cost of a single examination couldn't be estimated, this factor was replaced with the cost of equipment and period in which it can be used with top accuracy.

6. Summary. The results presented in Table 1 clearly show that examiners conducting colorblindness detection tests have to find a compromise between examination cost and diagnosis accuracy. The most reliable methods use the most expensive equipment which often requires properly trained operators. Moreover, due to their complicated technical nature they cannot be used to test certain groups of patients (Limitations section in Table 1).

Less reliable methods are often cheaper in usage, but are characterized with several drawbacks, e.g. high error rate, high tolerance to cheating etc.

The circumstances of examination should also be taken into account while comparing different diagnostic methods. For example in many driving schools, examination is performed on the same day to the whole training group. This may impact or even compromise the diagnosis, as the medical examiner may inadvertently miss or ignore test results. Moreover, this situation prevents several time-consuming methods (e.g., D-100) from being used, as the results should be obtained relatively quickly.

Lowering the error rate is also important, especially in cases where wrong diagnosis may prevent a person from engaging in certain occupations or may result in endangering one's health or even life (this applies mainly to protanopes, who may percept red as dimmed).

All these factors contribute to the fact, that there is a need for a colorblindness detection method, which should have the following characteristics:

- implementation should be relatively low-cost and simple;
- the results should be obtained quickly;
- in order to obtain reliable results, the colorblindness detection should be automated for screening, requiring human examiner only to confirm the detected cases;
- understandable and accessible to the widest possible audience.

A new colorblindness detecting method, which takes all these factors into account, is currently being developed in the Institute of Computer Science of Lublin University of Technology. The test results, published in [24], show that it may be an interesting alternative to the methods currently used, although the implementation costs cannot be estimated at this level of development.

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