SCIENCE

László Sipos[1], Ákos Nyitrai[1], Dániel Szabó[1], Ágnes Urbin[2], Balázs Vince Nagy[2]

Received: June 2020 – Accepted: October 2020

Vision tests of sensory judges - review

Keywords: visual acuity, contrast sensitivity, color vision, color blindness, pseudo-isochromatic color tests, anomaloscope, color discrimination, color identification

1. SUMMARY

In sensory examinations, judges must be in good general health. They should not have any deficiencies that could affect their perception or adversely affect their sensory performance, and thus can affect the reliability of their judgments. The vision of a judge is basically determined by three factors: visual acuity, contrast sensitivity and color vision. In the international practice of sensory analyses, color vision is generally examined. Color blindness is typically tested using the Ishihara pseudo-isochromatic color test, while color discrimination ability is examined using the Farnsworth-Munsell 100 hue test [1]. The most accurate tool to detect color blind people is the anomaloscope. Screening for color blind people is important because they have both poorer color discrimination abilities and poorer color identification abilities. The results of online color vision tests are significantly affected by the display device and its settings (monitor resolution, color-correct calibration), as well as test conditions: test geometry (relative position of the light source, the test book and the eye), photometric and spectral nature of the light source and the monitor, and the adaptation state of the eye. Unfortunately, the specifications for standard sensory tests do not require the visual acuity and contrast sensitivity testing of sensory judges, however, these properties obviously affect visual perception, so testing them is necessary.

2. Visual acuity (visus)

Visual acuity is a quantified expression of vision sharpness. The unit of measurement for visual acuity is the visual angle, which is the angle between the rays coming form the object and passing through the optical center of the eye. The resolution of a healthy eye, i.e., the angle at which the rays from the object fall on two adjacent rods and cones, is normally 1’ (arc minute), but with adequate lighting it can even be 50” (arc seconds). In everyday practice, boards containing so called optotypes, letters, numbers or rings (Landolt rings) of different sizes are used to determine visual acuity: Snellen chart, Csapody chart, Kettessy chart (***Figures 1. and 2.***). During the test, certain signs, letters or numbers have to be read from a board, depending on which visual acuity test is performed.

The size of the signs or numbers on the board always decreases from top to bottom. Each figure is designed so that when viewed from a certain distance, the entire figure is seen at an angle of 5’, its elemental details at an angle of 1’. The person to be tested is placed at the distance specified above from the well-lit wall-mounted board, which will be 5 m in the following example. Letters and other figures are read from top to bottom. To characterize visual acuity, the formula for visus is used: V = d/D, where d is the distance of the patient from the reading board and D is the distance from which the smallest figure still recognizable is seen at an angle of 5’. Thus, the test arrangement is characterized by the value of d, while the value of D can be used to characterize the individual figures. For an individual with normal visual acuity, V = 5/5, i.e., he or she recognizes the figure from 5 meters that can be seen at an angle

[1] Szent István University, Faculty of Food Science, Department of Postharvest Science and Sensory Evaluation
[2] Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Mechatronics, Optics and Mechanical Engineering Informatics

of 5 arc minutes from a distance of 5 meters. If the value of visus is V = 5/10, then the patient was able to recognize the figure from 5 meters, which can be seen at an angle of 5 arc minutes from 10 meters, so this means a better visual acuity than 5/5 **[2]**.

3. Contrast sensitivity

The contrast sensitivity test is a tool for determining whether the visual system is capable of transmitting or filtering spatial and temporal information about the objects seen. It measures the minimum contrast required to detect a visual stimulus **[3]**. Examination of contrast sensitivity with sine or square wave grids can be a useful auxiliary tool in the assessment of vision loss. While in conventional visual acuity tests the shape to be recognized on the figures changes and the contrast is large and unchanged, in the contrast sensitivity test the shape roughly remains the same and the contrast values change. In most tests, letters or figures must be recognized at low contrast values (Sloan test or Pelli-Robson test (***Figure 3***.), and in other tests, the task is for the subject to identify grids or lines drawn with increasingly less contrast, typically the Gábor pattern (***Figure 4.***). It is important to note that the contrast sensitivity test can never replace the visual acuity test, as its role is limited to situations where sharpness is normal or close to normal **[4]**. Damage to the optic nerve and macular degeneration can reduce contrast sensitivity. The low-contrast Sloan letter sharpness test records the minimum size at which individuals can perceive letters with a given contrast level (shades of gray on a white background).

In the Pelli–Robson test, the two eyes are examined separately. The task of the subject is to identify the letters in each row, starting at the top of the chart. The threshold value of contrast sensitivity as a log value is the point at which the subject reaches a group of three letters that he or she can no longer identify. The low-contrast Sloan letter sharpness test follows a similar principle. In clinical studies, subjects are examined at 2.5% and 1.25% contrast values, respectively. The tables can be presented on hand cards or in reflective cabinets ***[4]***.

4. Color vision

The purpose of a color vision test can be to screen a group (a typical example of this are tests design to detect color blindness), but it can also be a form of validation, tailored to the task to be performed, such as testing a particular product group. It is advisable to test the color vision of individuals in several ways, as a single test does not ensure a complete diagnosis. It is often the case that a combination of methods provides an adequate picture. The following standard methods for examining color vision have been used widely in sensory examinations:

- identification of color blindness (pseudo-isochromatic test books) **[6]**,
- determination of the type of color blindness (anomaloscope) **[6]**,
- hue discrimination test (Farnsworth-Munsell 100 hue test, color mixing method) **[1]**,
- grayscale discrimination test (mixing method) **[1]**.

Apparent color-equal (pseudo-isochromatic) image collection test books have generally been used to identify color blindness. The basic principle for their operation is that for the target group to be screened it is impossible, or at least more difficult, to see the differences between color pairs along so-called confusion axes, than it is for people with normal vision **[7]**. The dots in the figures and background of polka dot books composed of colored, round or irregularly shaped dots form pseudo-isochromatic pairs, with the same brightness and color saturation, but with different hues: they are located along one of the above-mentioned confusion axes. A common feature of pseudo-isochromatic tests is that an object is separated from the background points in the figures. Due to the above properties, the difference can only be determined on the basis of hue. Thus, pseudo-isochromatic tests are based on the examination of color discrimination ability. These objects can be numbers, symbols, letters or easily traceable patterns. On each test sheet, the element to be recognized is embedded in randomly placed dots of various sizes. People with normal vision identify letters/numbers/shapes on the test sheets, while color blind people are enable to recognize them **[8]**. For the standard screening of judges participating in sensory examinations, pseudo-isochromatic image collections are recommended: Ishihara- (Japan), Velhagen- (Germany), Rjabkin- (Russia) and Dvorine- (USA) pseudo-isochromatic test books **[6]**.

In both examinations using pseudo-isochromatic test books and those using other methods, test conditions should be designed carefully because changes in the appearance of hues may result in discrepancies in the results. Test conditions include the test geometry (relative position of the light source, the test book and the eye), the photometric and spectral characteristics of the light source and the samples, as well as the adaptation state of the eye. The ideal visual environment is an observation box designed for color comparison. The eye of the person tested must be at a distance from the sample characteristic of the given test, in an arrangement so that the plane of the sample is perpendicular to the line of sight. This 45°/0° geometry ensures that light falls on the sample at an angle of 45° and the sample is viewed by the judge from a perpendicular position. The test distance is determined by the visual angle at which the object to be recognized should be viewed. In all cases, glistening of the samples or dazzling light

SCIENCE

reflected from colored surfaces should be avoided, as these interfere with perception. A moderate and uniform luminance (100 cd/m^2) must be ensured for the test **[6]**.

For the evaluation of the tests to be correct, it is important to take into account the adaptation state of the persons examined, which is primarily determined by the spectral content of the illumination. Chromatic adaptation is the mechanism by which our visual system is constantly adapting to changes in ambient lighting. When developing color vision tests, the use of light sources approaching D65 illumination is assumed, which are diffuse with medium brightness and their color temperature corresponds to average daytime light. If the study conditions differ from these, the person examined should be allowed a minimum of 2 to 3 minutes to adapt before performing the test, and the adaptation state and its effects should be taken into account when evaluating the results. During the test, the test parameters must be kept constant. If necessary, subjects should be warned not to change the test geometry with their movement, because it modifies their perception. When not performing tests, the test books of the pseudo-isochromatic diagrams must be kept closed and protected from all external influences: external light, touches by the testers, mechanical effects (creasing, indentations, stains, etc.). The application of pseudo-isochromatic test books in practice is simple, they are widespread in diagnostics **[9,10]**.

The Ishihara test was developed (1918) by Dr. Ishihara Shinobu (1879-1963), a Japanese physician, who was a surgeon and then an ophthalmologist in the Japanese Imperial Army. Later, during his work in military medicine, he was asked to develop a color vision test to screen soldiers. The first Ishihara plates were painted by hand in watercolor, using the symbols of Japanese phonetic syllable writing (hiragana). In its present form, the Ishihara test book consists of 38 pages. On the first page, there is a control sheet that can be identified by all subjects, regardless of that person's dischromatography. Each black sheet of paper in the book (14.5 cm x 19 cm) has a white paper square (12.2 cm x 12.2 cm) in its center, in the middle of which there is a „polka dot" round plate (Ø=9 cm). Each plate consists of pseudo-isochromatic dots of different sizes and colors, which present single or double-digit numbers to people with normal color vision. Color blind people find it difficult or impossible to identify the numbers on certain plates. The test can be used to identify whether or not the subject is red-green color blind, but an instrumental anomaloscopic examination is required to determine the extent of the color blindness. The Ishihara test book does not provide information on color blindness involving other colors, such as blue or yellow. In summary, the Ishihara test book can be used to perform an easy-to-understand, simple and quick test to screen for and identify red-green color blind individuals. Today, this is the most widely used color blindness test in daily clinical practice. Since its publication, many adaptations of the original Ishihara test have been developed for illiterate children **[11]**, as well as several versions in Eastern Arabic **[12]**.

In addition to standard methods, there are other pseudo-isochromatic tests. The condition for using pseudo-isochromatic diagrams is that the subject knows the objects to be recognized, therefore, modified or special tests have been developed to test the color vision of children or illiterate people: geometric shapes (Neitz color vision worksheet), familiar objects (Kojima–Matsubara Test), geometric shapes and familiar objects (Color Vision Testing Made Easy (CVTME) **[15]**, for the illiterate (Velhagen Pflugertrident, Ishihara test for Unlettered Persons) **[9, 16]**. The following pseudo-isochromatic tests are also widely used in international practice: American Optical Hardy-Rand-Rider plates (AOHRR) (USA), ColorLite color vision test (Hungary), Cambridge Color Test (UK), Standard Pseudoisochromatic Plates (SPP) (USA).

The Hardy Rand Ritter Test (HRR) is very similar to the Ishihara test in terms of the test method. In the printed pseudo-isochromatic test book, simple geometric shapes must be distinguished from the background: circles, triangles or Xs. In addition to red-green color blindness (protanomaly – red color blindness – and deuteranomaly – green color blindness), the test can also be used to determine tritanomaly (blue color blindness), and it also provides information on the extent of color blindness, so it is recommended as a supplement to the Ishihara test **[17].**

The Colorlite color vision test is also a printed collection of pseudo-isochromatic images that can be used to determine whether a subject has normal color vision or is color blind. The test is able to distinguish between people with deuteranomaly and protanomaly, and to classify the extent of color blindness into 3 categories. In the test book, there are color series: a red-green series (16 images), a purple-green series (11 images) and a purple-blue series (11 images). The test must be performed with all three series. Each series begins with the highest contrast (easiest) task and becomes harder with each step. Within the series, each page shows a Landolt C image that is different in color from the background. During the test, the subject has to perform a simple task. The task of the subject is to determine where the break is in the ring (letter C) in the test image. The images become progressively harder, so after the test subject's correct answer, they see increasingly difficult images, until they can no longer give a correct answer. The test is quick, objective and simple, and the diagnosis takes only 5 to 10 minutes to establish. In case of a disorder, the test can be used to classify subjects into categories with severe, moderate or mild deuteranomaly or protanomaly (***Figure 6***) **[18]**.

The Colorlite color vision test system is complemented by a correction system. The complete set includes 10 pairs of differently tinted corrective eyeglass lenses. The spectrum of the color stimulus that reaches the eye can be altered with colored lenses, so colored lenses are a feature of color loss correction technology. The lenses are made by a special thermodiffusion process to achieve the most appropriate effect. The lenses can be placed in a test frame to perform the color test. An important and necessary condition of the color blindness correction mechanism is that the eye can adapt to the given color lens and ambient light conditions. When wearing the lenses, chromatic adaptation occurs within 2 to 3 minutes in a well-lit environment, a sign of which is that a white sheet appears again white when viewed through the colored lens. If there is a possibility of color blindness, the pseudo-isochromatic color test must be repeated using the colored lens selected on the basis of the description. Reassessment with corrective lenses helps to select the most effective corrective lenses and the color vision enhancing effect of the lenses can be checked. In addition to the Colorlite test, it is advisable to check the effect with the Ishihara test as well. The colored correction layers can be applied to so-called "plano" lenses similar to no diopter sunglasses, as well as to lenses diopter lenses, i.e., the existing glasses of a color blind subject can also be corrected **[18]**.

A common computer adaptation of pseudo-isochromatic tests is the Cambridge Color Test (CCT), one of the biggest advantages of, compared to the tests presented so far, is that it does not work with pre-painted images, but with images that can be displayed on the monitor, with significantly more color combinations. For this reason, the list of test conditions is longer: it is extremely important that the measurements be performed using a calibrated monitor, and the test has special hardware requirements, meaning a resolution that is better than the standard 8-bit color depth, making it possible to measure even differences between people with normal color vision. Similar to the Colorlite test, the orientations of Landolt C images have to be recognized during the examination, with the difference that there are only 4 options here: top, bottom, right and left (***Figure 7.***) **[19]**.

The test should be performed in a dark room in such a way that the person performing the measurement sees the break in the Landolt C image at a visual angle of 1°. The result of the test is the smallest color difference observed by the subject compared to a reference color along the directions defined in the CIE 1976 uniform color chart. The reference color is the background color of the pseudo-isochromatic images. The test is adaptive: based on the subject's responses, the difference between the color of the background and the sample is continuously decreasing or increasing, thus ultimately determining the lowest detectable threshold. The test has two modules: by performing the Tritan test, we can carry out a fast (2 to 3 minutes) examination along the three directions, while the Ellipse test is longer (20 to 30 minutes), the areas around the reference color points within which the subject cannot distinguish between color shades can be characterized by an ellipse fitted to the threshold values, based on measurements in several directions compared to the 3 reference points. The default setting for the 3 test directions of the Tritan test are the 3 confusion directions, along which the color discrimination abilities of deuteranomalous, protanomalous and tritanomalous color blind people are significantly worse than that of people with normal vision. The limit of color blindness was determined by the preparers of the test at the neutral reference point (0.1977; 0.4689) in the protan and deutan directions at $100x10^{-4}$, while in the tritan direction at $150x10^{-4}$ u'v' value **[19]**, but more stringent recommendations can also be found in the literature **[20]**. When evaluating CCT results, it should be taken into account that the color discrimination ability is age-dependent **[21]**, and also that the native color system of CCT, the CIE 1976 color chart is not uniform in terms of color perception, therefore, a change in the reference color leads to a change in the expected value of the results. The ellipses fitted to the results of the ellipse test elongate significantly along the confusion direction characteristic of the type of color blindness (***Figure 8.***).

With the variability of its reference points and the luminance levels and measurement directions characteristic of the pseudo-isochromatic images, as well as its color depth exceeding 8 bits, in addition to screening for and categorizing color blindness, CCT also provides an opportunity to compare the results of people with normal color vision, with a task-specific experimental design, such as one fitted to the colors of the products to be tested and the adaptation state of the test conditions.

The most accurate method for determining the type of color blindness is the instrumental examination with an anomaloscope. Nagel's anomaloscope uses the color matching method. In the field of view of 2°, a circle is divided into an upper and a lower part. The task is always the same, the red ® and green (G) monochromatic light projected on the upper semicircle must be mixed so that it appears to be the same as the target color projected on the lower semicircle (yellow monochromatic light, Y). Color mixing in the upper semicircle actually results in additive color mixing, and the brightness of the lower semicircle can be adjusted until the subject sees both semicircles as the same (identical) both in terms of color and brightness. Based on the test results, subjects can be classified into different areas (color vision types and subtypes): normal color vision, protanomaly, protanopia (red color blindness), deuteranomaly (green color blindness), deuteranopia, achromatopsia (grayscale only) vision. By repeating the anomaloscope examination, the so-

SCIENCE

called color stability of color blind people can also be determined from the uncertainty of the results, which is an important characteristic in addition to the type of color blindness and in some jobs criteria are defined on the basis of this **[10]**.

One of the most commonly used standard methods for testing color hue discrimination is the Farnsworth-Munsell 100 color hue test (FM-100 HUE). The test was developed by Dean Farnsworth in the early 1940s, along with other classification tests, such as the D-15 panel, B-20 and H-16, which, however, have not gained widespread use. The Farnsworth-Munsell-100 test is based on the consistency of the Munsell hue, the color intensity and the Munsell values. What makes the procedure special is that the colors used have the same Munsell value and intensity, they only differ from each other in hue **[8, 23]**. Initially, tests consisting of 100 disks were constructed, but research has shown that arranging 100 disks is too difficult a task for the judges, so the number of disks was reduced to 85. Thus, today the Farnsworth-Munsell 100 color hue test consists of only 85 hues, containing four different color series of similar hue. The colored test disks (Ø=2.54 cm) have black edges on the outside and a colored inner part. The ends of the color series are fixed, the task is to arrange the hues between them, so that each disk is between the two disks most similar to it. The numbers in the frame indicate the fixed disks, which are the endpoints of the scale (***Figure 10.***) **[24]**.

Disorders of color vision can be assessed simply by summing up the errors, as well as by the differences between the chosen and actual locations of the color hues. several versions of the system are available on the internet, typically small squares have to be arranged instead of disks, but in the case of tests performed using monitors, it is important to note that the accuracy of the results cannot be guaranteed without calibration. The great advantage of the test is that the assessment is extremely simple: errors can be evaluated simply by summing up the mistakes or even by the differences between the chosen and actual locations of the color hues. Based on the evaluation results, judges can be classified into three categories **[25]**:

- Excellent (good) result: This requires that a maximum of 4 swapping type of errors can occur in each color series, i.e., the number of errors is in the 0-16 range. ~16 % of the population falls into this category.
- Average (normal) result: a result between 16 and 100 errors. ~66% of people fall into this category.
- Poor (reduced) result: a result above 100 errors. In the case of these results, it is recommended to perform further vision and color blindness tests. ~16% of the population falls into this category.

The evaluation of computer-based tests can be called up in the form of an impressive chart. It consists of two concentric circles. Along the larger circle, the colors and numbers of each color disk are displayed (1-85). The smaller circle shows the initials of the colors, corresponding to the outer circle. The degree of error is indicated by a black curve returning to itself. Where the black curve fits the outline of the inner, smaller circle, the judge gave the correct answer, i.e., the color disk was placed in the right place. Where, on the other hand, the black curve points in the direction of the outer circle, a mistake has been made. The degree of error is shown by the extent to which the black line approaches the arc of the outer circle. The greater the degree of error, the further away the black marker is from the inner circle (***Figure 11.***) **[24]**.

The color mixing method is mainly used to examine color hue discrimination. The first step in the tests is the preparation of stock solutions using analytical grade chemicals: water (deionized or distilled), yellow color substance (quinoline yellow), blue color substance (patent blue V), red color substance (crimson red), graphite and corn starch. The finished color scale is thus two color series of 11 members each presented in test tubes. One of the series ranges from yellow through green to blue, while the other from red through purple to blue. The task is to select the colors and arrange them in order. Two errors are allowed in each series. For the examination of grayscale distinction, the blending method is used. During the 10-member grayscale test presented in test tubes, a continuously increasing amount of graphite powder is added to a continuously decreasing amount of corn starch. The test tubes are presented in a random order. The task is to put the shades of gray in order **[1]**.

The quality of product profiling performed using descriptive sensory methods depends primarily on the perceptions and descriptive abilities of the judges. In connection with the description of the color of the products, color identification, i.e., the determination of the color description of the product is necessary. Even though descriptive ability is essential for objective color designation, international standards do not contain any testing or methodology requirements in this regard. Based on English names, 11 of the designations in the different languages can be considered as commonly used (Red, Yellow, Green, Blue, Purple, Brown, Orange, Pink, Black, White, Gray). Most research on color identification is also based on the above designations **[26]**. Most research identifies color stimuli based on their color coordinates in different color rendering systems (Munsell (World Color Survey), Natural Color System, DIN-system, NF-AFNOR-system) **[27]**. Color identification tests today are essentially used through calibrated digital displays. One possible approach to human color identification is spectral differentiation of stimuli and classifying them into color concept categories, which can be used to specify color perception wavelength ranges associated with the colors, which can be characterized by different uncertainty bands for each color **[28]**.

A number of online tests and applications have been developed to test normal color vision, often by adapting the original tests. However, it is important to stress that computerized online color vision tests are not suitable for clinical diagnosis. The original image collections, disks, printed tests give different results, because the results of the tests are significantly influenced by the display device and its settings (monitor resolution, color-correct calibration), as well as the testing conditions: the test geometry (relative position of the light source, the test book and the eye), the photometric and spectral nature of the light source and the monitor, and the adaptation state of the eye **[6]**.

5. Summary

In sensory examinations, judges must be in good general health. They should not have any deficiencies that could affect their perception or adversely affect their sensory performance, and thus can affect the reliability of their judgments. The vision of a judge is basically determined by three factors: visual acuity, contrast sensitivity and color vision. In the international practice of sensory analyses, color vision is generally examined. Color blindness is typically tested using the Ishihara pseudo-isochromatic color test, while color discrimination ability is examined using the Farnsworth-Munsell 100 hue test **[1]**. The most accurate tool to detect color blind people is the anomaloscope. Screening for color blind people is important because they have both poorer color discrimination abilities and poorer color identification abilities. The results of online color vision tests are significantly affected by the display device and its settings (monitor resolution, color-correct calibration), as well as test conditions: test geometry (relative position of the light source, the test book and the eye), photometric and spectral nature of the light source and the monitor, and the adaptation state of the eye. Unfortunately, standard sensory tests do not specifically mention the visual acuity and contrast sensitivity testing of sensory judges, however, these properties obviously affect visual perception, so testing them is necessary.

6. Acknowledgment

The research was supported by the János Bolyai research bursary. The project is supported by the European Union, co-supported by the European Social Fund (ESF) (grant agreement number: EFOP-3.6.3-VEKOP-16-2017-00005). Ákos Nyitrai and Dániel Szabó express their gratitude to the Doctoral School of Food Science.

7. References

[1] MSZ EN ISO 8586:2014 Érzékszervi vizsgálat. Általános útmutató a kiválasztott bírálók és az érzékszervi szakértő bírálók kiválasztásához, képzéséhez, valamint folyamatos ellenőrzéséhez (ISO 8586:2012 2014-06-15-i helyesbített változat).

[2] Davson, H. (1980): Front Matter. Physiology of the Eye, iii. https://doi.org/10.1016/b978-0-12-206745-7.50001-4. (Hozzáférés / Aquired: 12.07.2020)

[3] Jindra, L. F., Zemon, V. (1989): Contrast sensitivity testing: a more complete assessment of vision. Journal of Cataract & Refractive Surgery, 15(2), 141-148.

[4] Liu, G. T., Volpe, N. J., Galetta, S. L. (2019): The Neuro-Ophthalmic Examination. Liu, Volpe, and Galetta's Neuro-Ophthalmology, 7–36. doi:10.1016/b978-0-323-34044-1.00002-x (Hozzáférés / Aquired: 09.09.2020)

[5] Schinzel, J., Zimmermann, H., Paul, F., Ruprecht, K., Hahn, K., Brandt, A. U., & Dörr, J. (2014): Relations of low contrast visual acuity, quality of life and multiple sclerosis functional composite: a cross-sectional analysis. BMC neurology, 14(1), 31.

[6] MSZ ISO 11037:2014 Érzékszervi vizsgálat. Irányelvek a termékek színének érzékszervi bírálatára.

[7] Luo, M. R. (2016): Encyclopedia of Color Science and Technology. https://doi.org/10.1007/978-1-4419-0851-3. (Hozzáférés / Aquired: 25.09.2020)

[8] Dain, S. J., (2004): Clinical colour vision tests. Clinical and Experi-mental Optometry, Volume 87, Issue 4-5, 276-293.

[9] Birch. J. (2001): Diagnosis of Defective Colour Vision, 2nd edn. Butterworth Heinemann, Oxford.

[10] Wenzel, K. (2013): Színtan. Budapesti Műszaki és Gazdaságtudományi Egyetem, Gépészmérnöki Kar, Mechatronika, Optika és Gépészeti Informatika Tanszék. 1-192.

[11] Choi, S.Y., Hwang, J. (2009) : Ishihara test in 3- to 6-year-old children. Jpn. J. Ophthalmol. 53, 455–457.

[12] Heidary, F., Gharebaghi, R. (2013): A modified pseudoisochromatic ishihara colour vision test based on eastern arabic numerals. Med. Hypothesis Discov. Innov. Ophthalmol. 2(3):83-5.

[13] Schiefer, U., Wilhelm, H., Hart, W., & Editors. (2007): Clinical Nuro-Ophtalmology - A Practical Guide. Springer.

[14] https://lombartinstrument.com/store/ishihara-38-plate-book-test (Hozzáférés / Aquired: 22.04.2020)

SCIENCE

SCIENCE

[15] Neitz, M., Neitz, J. (2001): A new mass screening test for color-vision deficiencies in children. Color Res. Appl. 26, S239–49.

[16] Velhagen, K., Broschmann, D. (2002): Tafeln und Prüfung des Far-bensinnes. 29 Auflage. (Színlátásvizsgáló táblák). Budapest, Medicína.

[17] Birch, J. (2010): Identification of red-green colour deficiency: Sensitivity of the Ishihara and American Optical Company (Hard, Rand and Rittler) pseudo-isochromatic plates to identify slight anomalous trichromatism. Ophthalmic and Physiological Optics, 30(5), 667–671. https://doi.org/10.1111/j.1475-1313.2010.00770.x. (Hozzáférés / Aquired: 04.15.2020)

[18] https://www.colorlitelens.com/ (Hozzáférés / Aquired: 17.05.2020)

[19] Mollon, J. D., & Regan, B. C. (2000): Handbook of the Cambridge Colour Test. London, UK.

[20] Ventura, D. F., Silveira, L. C. L., Rodrigues, A. R., De Souza, J. M., Gualtieri, M., Bonci, D., & Costa, M. F. (2010): Preliminary Norms for the Cambridge Colour Test. In John D Mollon, J. Pokorny, & K. Knoblauch (Eds.), Normal and Defective Colour Vision.

[21] Paramei, G. V, Oakley, B. (2014): Variation of color discrimination across the life span. Journal of the Optical Society of America A: Optics and Image Science, and Vision, 31(4), A375–A384.

[22] Samu, K. (2005): Világosság észlelet kompenzált színlátás-vizsgáló tesztek megvalósítása számítógéppel vezérelt CRT képernyőn. Doktori értekezés, Budapesti Műszaki és Gazdaságtudományi Egyetem. 1-103.

[23] Farnsworth, D. (1943): The Farnsworth-Munsell 100-hue and dichotomous tests for color vision. JOSA, 33(10), 568-578.

[24] https://munsell.com/faqs/what-does-score-farnsworth-munsell-100-hue-test-mean/ (Hozzáférés / Aquired: 19.10.2020)

[25] Lausegger, G., Spitzer, M., & Ebner, M. (2017): Omnicolor–a smart glasses app to support colorblind people. *International Journal of Interactive Mobile Technologies*, 11(5), 161-177.

[26] Le Rochellec, J., Viénot, F. (1995): Contribution of two colour opponent mechanism to Fechner-Benham subjective colours. In B. Drum (Ed.), *Colour Vision Deficiencies XII. Documenta Ophthalmologica Proceedings Series, vol 57.*, (pp. 251–258): Dordrecht: Springer. https://doi.org/10.1007/978-94-011-0507-1_30 (Hozzáférés / Aquired: 16.05.2020)

[27] Kay, P., Berlin, B., Maffi, L., Merrifield, W. R., Cook, R. (2009): *The world color survey.* Stanford: Centre for the Study of Language & Information.

[28] Nagy, B.V., Németh, Z., & Ábrahám, Gy. (2009): Human wavelength identification testing and numerical analysis. *Periodica Polytechnica, 52*(2), 77–81. https://doi.org/10.3311/pp.me.2008-2.07. (Hozzáférés / Aquired: 14.04.2020)