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Chromatic Perception Mediates the Response to Red, Green, Blue, and Yellow Stimuli among Children from Elementary School in Mexico[1]

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Abstract

Purpose: We evaluated the responses to chromatic perception (wavelength) stimuli in the visible spectrum among children from an elementary school in Nezahualcoyotl Country, Mexico.*Materials and Methods*: A software developed *ad hoc* was used to measure how children perceived the colors blue, green, yellow, and red. The tests were in monocular form, and responses were pooled based on their similarity according to the Pearson correlation index and cluster analysis by unweighted averages. A chi-square test was applied to the groups for significant differences. *Results*: Data from each wavelength were analyzed in relation to age, sex, and ocular laterality. At a wavelength of 450 nm, children aged 6-7 years old (group 1) of both sexes perceived the wavelength as skewed to the left -9.39 nm, while children aged 8- 11 years old (group 2) visualized a leftward skew of -4.40 nm (P < 0.0001). Then, at 530 nm, shifts of -5.39 and -6.72 nm were reported in the groups 1 and 2 (P < 0.0001), while at 580 nm, the shifts were -2.59 and -2.62 nm for both groups (P < 0.0001). Finally, at 710 nm, the shifts were +2.49 and +2.74 nm (P < 0.0001). Conclusion: At 450 nm, younger children perceived wavelengths far from normal, but, as they aged, their perceptions normalized. At 530 nm, children's perceptions shifted to the left in all cases, getting closer to normality. Finally, at 580 nm, the shift was still leftward but moved to the right at 710 nm in all cases.

Keywords: perception of color, wavelength, chromatic childhood vision, dyschromatopsia.

[1] Research article.

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INTRODUCCIÓN

Color is related to visual perception (1), which only exists in photonic environments where cones act (2). Normal human vision is called trichomata (3,4). Three types of color blindness are protan-deutan (congenital), and tritan (acquired). Blindness and its related anomaly have been previously studied (5-8).

Different available tests have been used to evaluate color blindness and alterations in chromatic perception in epidemiological studies of patients with diabetes (9-14), glaucoma (15-17), or autism (18). The tritanopes lack cones that respond to short wavelengths (7). By using common techniques to measure chromatic perception (Ishihara, Matsubara, HRR, etc.), they detected that one of the systemic diseases causing alteration in color discrimination is diabetes. There is evidence of a reduction of tritan vision in diabetic patients with macular edema (13,14). Another disease-causing color problem is glaucoma, as a sign of early damage to retinal ganglion cells (15-17). Moreover, in autist children and teenagers' impairments in chromatic perception have been detected (18). On the other hand, there are studies using computerized stimuli (color chart) that have been useful to detect congenital color vision abnormalities (19).

The visible spectrum for the human eye under normal lighting conditions ranges from 380 to 780 nm (violet to red). The receptors are the cones and rods, which make 70% of the receptors in the whole human organism (20). Since previous studies used tests that measure color perception in a very limited range of the visual wave spectrum, it is not possible to detect more subtle alterations around the central wavelength for each color. This limitation could be solved by using different tools like a software that display colors in a wider range of wavelengths.

There is still no theory that fully explains the color vision of the human being as many factors influence it, such as physiological stimuli, self-organization, learning and memory (21). Not only can physiological pathways modify the intensity of color perception, but also age, sex, and object form and distance (22). Children between 2 and 6 years old are said to discriminate more precisely tone differences rather than differences in saturation or clarity (23); in addition, that the lens and macular pigment have a lower absorption in children because the spectral sensitivities of pigments found in the photoreceptors, measured in the cornea, are different from adults. However, at wavelengths greater than 540 nm there is almost no difference between children and adults (24).

On the other hand, to explain the difference in the color preferences between men and women, theoretically we can discuss the processing of color information in the brain as well as the neurohormonal and biochemical factors of the retina, which influences the color sensitivity, located in the blue-green range in men, and in the yellow-red range in women (25). Some studies have developed methods different from those traditionally used for color perception and have proved useful for this purpose. One study showed that after 6 months children's color perception is almost the same as in adults and also reported differences by gender and age. It was concluded that there is a difference between the 9-13-yeard old and 14-18-year-old groups, which is explained by the difference in the hormonal changes existing at this age in both sexes (21). However, these results are not conclusive and further studies are needed.

In this study we evaluated responses to chromatic-perception (wavelength) stimuli in the visible spectrum among children from an elementary school, considering age, sex, and ocular laterality (right eye or left eye).

MATERIALS AND METHODS

In this prospective, cross-sectional, comparative study, a visual basic software was developed to evaluate the perception of wavelengths by displaying stimuli of different colors in the visible light spectrum (380-760 nm). With this approach, the eyes are evaluated separately and the patient is placed 50 cm away from the screen.

Figure 1 shows control stimulus in a bigger size followed by three stimuli in one column and 2 stimuli in a second column; these five stimuli of smaller sizes are the comparison stimuli, with one of them having the same wavelength as the control and is displayed randomly for each measurement. The first measurement was a 450-nm blue control and the comparison stimuli were displayed in the order 470, 460, 450, 440, and 430 nm.

Each child was asked to indicate with the mouse the small square with identical color tone to the color tone of the big square. The software recorded the nm values for the control and the comparison stimuli. The second measurement consisted in green stimuli displayed at the control wavelength of 530 nm and other ones at 560, 545, 530, 515, and 510 nm for comparison.

Next, yellow stimuli were displayed: one at the same 580 nm as the control and five at 590, 585, 580, 575, and 570 nm for comparison.

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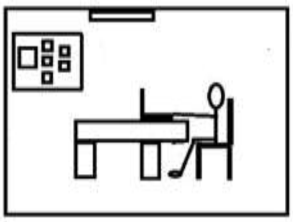
Finally, red stimuli displayed: first, one stimulus at 710 nm was the control and then five at 740, 725, 710, 695, and 680 nm were displayed for comparison.

The software was designed to scan the wavelengths that human subjects perceived with each eye at each interval. A Toshiba™ computer (Toshiba Corporation, Tokyo, Japan) was used to display the control stimulus with its five sample stimuli simultaneously; comparison stimuli were changed randomly on the right side of the screen each time the control color changed so as to avoid the subject from identifying the matching stimulus position by memory. This feature is very important to conclude that the subject looked for the correct response by the color tone instead of the stimulus position.

The monitor was placed 50 cm away from the subjects, who were asked to carefully observe the stimulus sample and indicate with the mouse which picture on the right was the same as the stimulus sample. This procedure was followed until completing the scheduled comparisons. The procedure took approximately 3 minutes per eye. The software automatically collected the subject's responses.

Figure 1. Test application.



Source: own work

The software was applied at the Isidro Fabela Primary School in Nezahualcoyotl Country to all students. Parents were informed about the project and asked to approve their children's participation by signing an informed consent form; the children also signed the form. Approval of the protocol was obtained from the Facultad de Estudios Superiores Iztacala, UNAM. A total of 162 girls and 146 boys (308 children in total) aged between 6 and 11 years were evaluated. The children were grouped by school grade (first through sixth grade). Before the evaluation all the children were examined in their vision and, when necessary, the visual disorders were corrected with eyeglasses. The children were the experimental procedure and were allowed some time to get acquainted. This stage took from July to September 2017.

Comparisons were carried out between values of wavelengths perceived by children regarding the wavelengths used as stimulation controls (DEC). A cluster analysis for the six school grades involved in the study to determine the grouping as per wavelength, and taking sex and ocular laterality into consideration, was conducted. It showed that girls aged 6-11 years viewed a control wavelength of 450 nm first with the right eye and then with the left eye. Then, the same procedure was applied to the boys. Subsequently, four groups were formed to record their perceptions at wavelengths of 450, 530, 580, and 710 nm. Pearson similarity index results were obtained according to the correlation coefficient [26] among the age groups. The grouping was performed with the unweighted average ligament method (UPGMA) (27). A chi-square analysis was then applied between the groups. In short, (1) absolute differences were obtained between 450, 530, 580, and 710 nm; (2) children were grouped according to the differences; (3) similarities between groups were measured by correlation; and (4) a cluster analysis was performed.

RESULTS

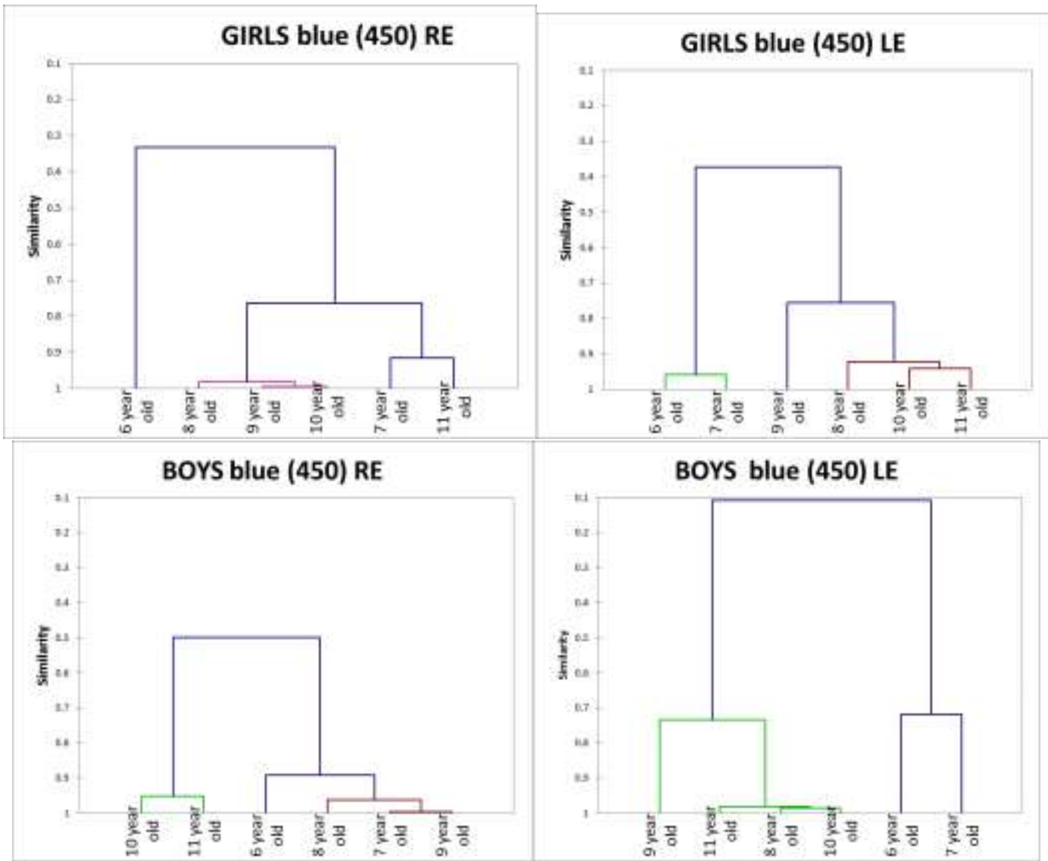
Cluster analysis findings such as dendograms including sex, ocular laterality, and evaluated wavelength are shown in Figure 2. Only groups with a similarity outcome of more than r = 0.70 were considered to show significant results.

450 NM (BLUE)

Figure 2 presents the cluster analysis of right-eye perception. Girls were grouped into 6 years old (DEC = -11.2 nm) and 7-11 years old (r = 0.765; DEC = -8.16 nm), with the latter consisting of 2 subgroups, those aged 7-11 years (r = 0.9; DEC = -11.18 nm), and those aged 8-10 years (r = 0.98; DEC = -6.15 nm). For left-eye perception, girls were grouped into 6-7 years old (r = 0.95; DEC = −6.58 nm) and 8-11 years old (r = 0.75; DEC = -2.86 nm), with the latter consisting of 2 subgroups of 9 years old (DEC = -2.61 nm) and 8, 10, and 11 years old (r = 0.92; DEC = −1.61 nm).

Regarding right-eye perception in boys, 2 groups were formed, those aged 10-11 years (r = 0.95; DEC = -7.24 nm), and those aged 6-9 years (r = 0.893; DEC = -9.78 n,), which included, in turn, 2 subgroups of those aged 6-7 years (DEC = -10.96 nm) and those aged 7-9 years (r = 0.964; DEC = -9.39 nm). Regarding their left-eye perception, the 2 primary groups were 8-11 years old (r = 0.734; DEC = +0.5 nm) and 6-7 years old (r = 0.71; DEC = -8.75 nm). Chi-square analysis revealed differences in the frequencies among the groups (P < 0.0001).

Figure 2. Response to blue color.



Girl's response to blue color: FRE 450; FLE 450. Boys response to blue color: MRE 450; MLE 450. RE, right eye; LE, left eye; M, male; F, female. Source: own work

530 NM (GREEN)

Figure 3 presents the cluster analysis indicating that, for right-eye perception, girls were divided into groups of 6, 8, 9, and 11 years old (r = 0.85; DEC = -7.96 nm), and 7 and 10 years old (r = 0.758; DEC = 4.4 nm). Regarding left-eye perception, girls were grouped into 10 years old (DEC = −3.19 nm) and 6, 7, 8, 9, and 11 years old (r = 0.832; DEC = -6.98 nm). This last group was further divided in 6 and 8years old (r = 0.90; DEC = -7.19 nm) and 7, 9, and 11 years old (r = 0.85; DEC = -6.84 nm).

Regarding right-eye perception in boys, three groups were defined: 8years old (DEC = -2.67 n), 6-7 years old (r = 0.843; DEC = -1.85 nm), and 9-11 years old (r = 0.708; DEC = -7.74). Additionally, subgroups of 10years old (DEC = -6.67 nm), and 9 and 11 years olds (r = 0.89; DEC = -8.28 nm) were defined. Regarding left-eye perception, boys were grouped into 8, 10, and 11 years old (r = 0.917; DEC = -7.41 nm); 9 years old (DEC

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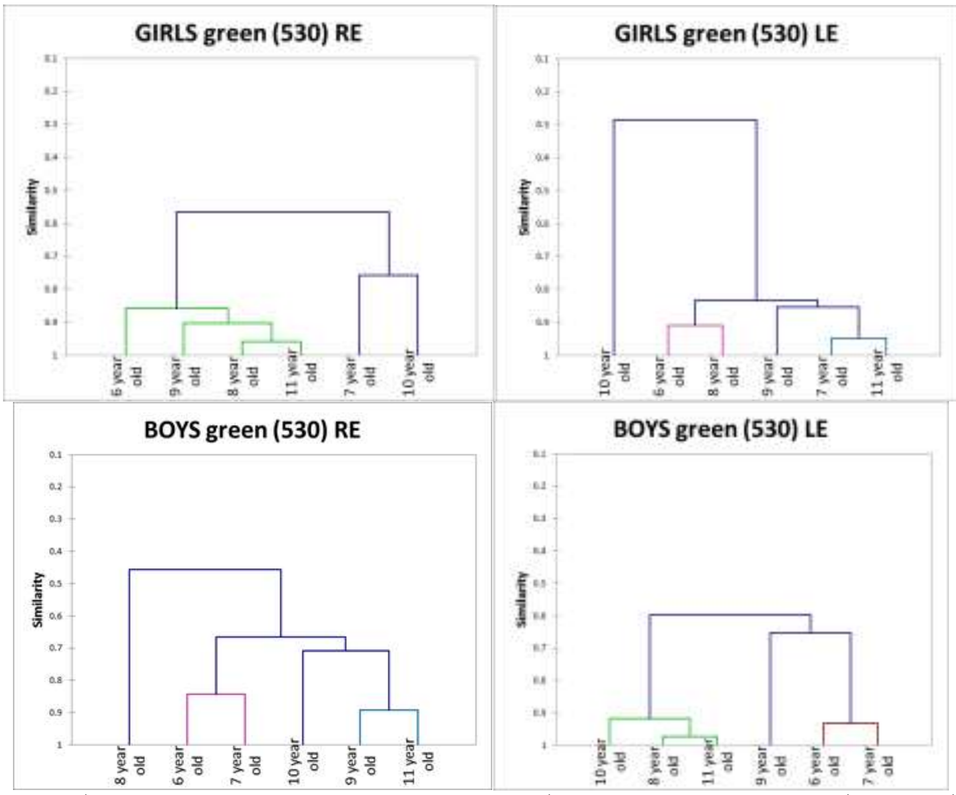
= -4.17 nm), and 6- 7 years old (r = 0.933; DEC = -6.43 nm). All groups showed differences according to chi-square test results (P < 0.0001).

Figure 3. Response to green color.



Girl's response to green color: FRE 530; FLE 530. Boy's response to green color: MRE 530; MLE 530. RE, right eye; LE, left eye; M, male; F, female.
Source: own work

580 NM (YELLOW)

Figure 4 presents the cluster analysis indicating that, for right-eye perception, girls were grouped into 10-11 years old (r = 0.728; DEC = -3.6 nm), 9 years old (DEC = -1.74 nm) and 6-8 years old (r = 0.86; DEC = -2.68 nm). Regarding left-eye perception, girls were grouped into 7 years old (DEC = -3.53 nm), and 6, 8, 9, 10 and 11 years old (r = 0.898; DEC = -1.02 nm). This last group was further divided into 10-11 years old (r = 0.99; DEC = -1.77 nm), and 6, 8 and 9 years old (r = 0.936; DEC = -0.53 nm).

Regarding right-eye perception in boys, three groups were defined: 10 years old (DEC = -5.42 nm), 11 years old (DEC = -1.96 nm), and 6-9 years old (r = 0.77; DEC = -3.40 nm), with subgroups of 7-8 years old (r = 0.91; DEC = -4.4 nm), and 6 and 9 years old (r = 0.88; DEC = -2.41 nm). Regarding left-eye perception, boys

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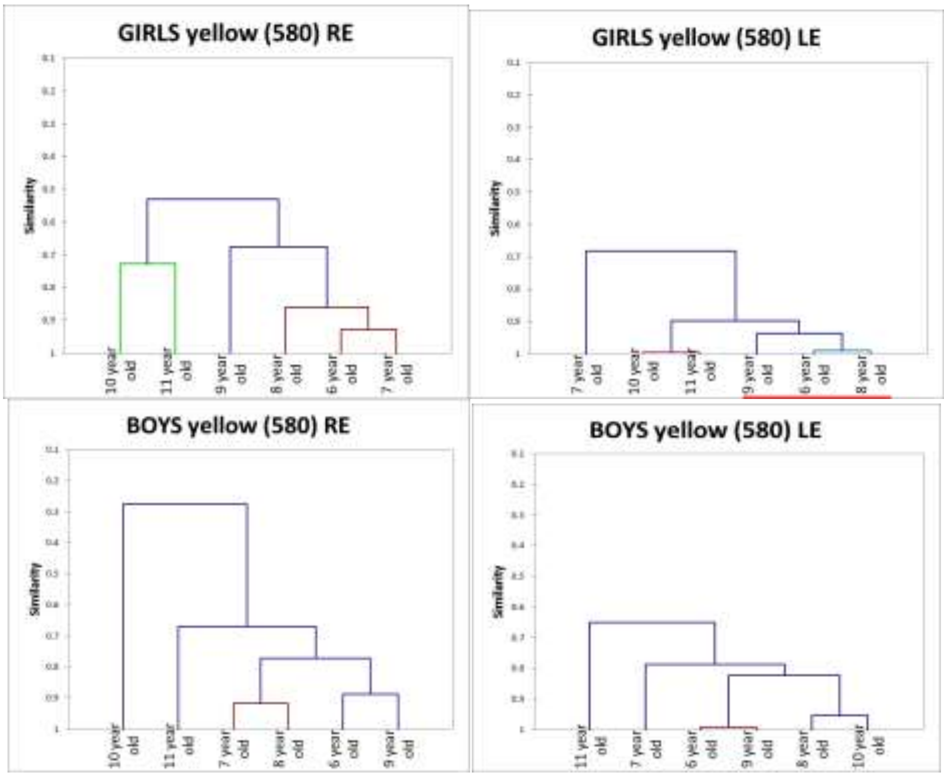
were grouped into 11 years old (DEC = -4.57 nm) and 6-10 years old (r = 0.787; DEC = -2.15 nm), and 2 subgroups of 7 years old (DEC = -2.5 nm), and 6, 8, 9 and 10 years old (r = 0.823; DEC = -2.07 nm). All groups showed differences according to chi-square test results (P < 0.0001).

Figure 4. Response to yellow color



Girl's response to yellow color: FRE 580; FLE 580. Boy's response to yellow color: MRE 580; MLE 580. RE, right eye; LE, left eye; M, male; F, female.
Source: own work

710 NM (RED)

Finally, Figure 5 presents the cluster analysis indicating that, for right-eye perception, girls were grouped into 6 years old (DEC = +5.2 nm) and 7-11 years old (r = 0.714; DEC = +2.45 nm), and 2 subgroups of 8 years old (DEC = +1.93 nm) and 7, 9, 10, and 11 years old (r = 0.821; DEC = +2.58 nm). Regarding left-eye perception, girls were grouped into 6-8 years old (r = 0.853; DEC = +0.95 nm) and 9-11 years-old (r = 0.797; DEC = +2.69 nm), and this last group was subdivided into 11 years old (DEC = +3.33 nm) and 9-10 years old (r = 0.88; DEC = +2.37 nm).

Regarding right-eye perception in boys, 2 groups were defined: 10-11 years old (r = 0.984; DEC = +6.04 nm) and 6-9 years old (r = 0.719; DEC = -1.88 nm); additionally, subgroups of 7 years old (DEC = -1.88 nm) and

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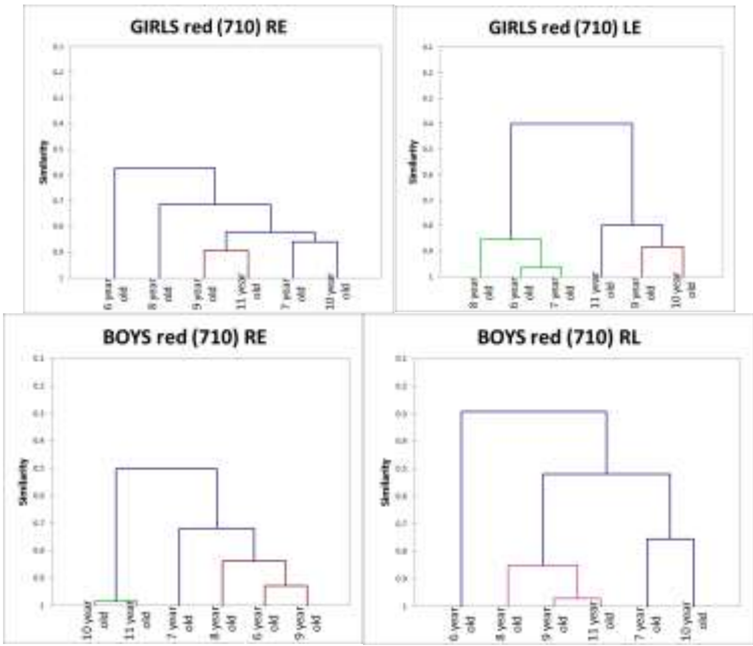
6, 8, and 9 years old (r = 0.839; DEC = -1.88 nm) were also defined. Regarding left-eye perception, boys were grouped into 6 years old (DEC = +5.71 nm); 8, 9, and 11 years old (r = 0.851; DEC = +6.59 nm); and 7 and 10 years old (r = 7.56; DEC = +3.435). All groups showed differences based on the chi-square test (P < 0.0001).

Figure 5. Response to red color



Girl's response to red color: FRE 710; FLE 710. Boy's response to red color: MRE 710; MLE 710. RE, right eye; LE, left eye; M, male; F, female.
Source: own work

DISCUSSION

Deficiencies in color vision in humans are explained by dyschromatopsia (color blindness) (3-8) or are associated with various ocular and/or systemic diseases (13-17). Most of the existing tests do not measure wavelength and we agree with researches indicating that there is not yet a theory to explain the mechanism of color vision because of the multiple factors involved (9). Meanwhile, some authors have mentioned age and sex as influential factors (10), indicating that, from 6 months onward, color perceptions in children are the same as those in adults (21). However, in this work, we found that many perception changes happen between 6 and 11 years of age; children who are 6-7 years old show differences as compared to those who are 8 years old regarding the laterality intervention in the perception of different colors. This comparison can be further extended to 2-6-year-old children, who precisely discriminate color tone better than saturation (11).

We found that perceptions vary at different wavelengths and, in addition, we managed to establish those ages when changes thereof occur (24).

In this vein, blue color (450 nm) at the age of 6 years is perceived at 439 nm in average, getting closer at the age of 11 years with 444 nm in the right eye and 448 nm in the left eye, i.e., as a child gets older, he/she reaches the blue color perception as the control stimulus; while when younger he/she perceives blue darker. Regarding green color (530 nm), perception is similar in both eyes in girls, i.e., they perceived it at 522 nm at the age of 6 years, and at 525 nm at the age of 11, getting closer to the control stimulus when growing in age. However, boys had a different perception in both eyes and difference got bigger at older ages, i.e., in the right eye at the age of 6 years they perceived it at 528 nm and 519 nm at the age of 11; in the left eye 524 nm and 523 nm, respectively, and accordingly with age they perceive the green darker.

Regarding yellow color (580 nm) perception is very similar in girls and boys with minimal ocular dominance because the right eye at the age of 6 years in both sexes perceived at 578 nm, and at the age of 11, they did at 577 nm, while the left eye perceived 579 nm at the age of 6 years and 577 nm at 11. Again, yellow was darker as they grew older.

Lastly, regarding red color (710 nm) in girls both eyes perceived at 711 nm during ages 6-9 years, while at 10 in the right eye, the color was perceived at 715 nm and in the left eye at 713 nm, i.e., they perceived red darker as they aged. Regarding boys, perception was different because the right eye perceived it at 708 nm and 716 nm at the age of 11 years; while the left eye perceived at 713 nm at the age of 6 years, and 717 nm at the age of 11 years, showing red darker as boys grew older.

Previous authors have indicated that, in wavelengths greater than 540 nm, there are no differences between children and adults (24). In this work, it was found that under the examined wavelengths, a similar appreciation is seen from third grade of primary school, with no significant differences in perceptions between both sexes. In addition, the perceptions among first- and second-grade children are similar, while those from third grade onward begin to change, eventually correlating with those in fourth, fifth, and sixth grades. In other words, the perceptions of children change starting from 8 years of age and increasingly match the perceptions of adults.

Several works have reported the effect that age and sex have on color perception, but they have not studied the influence of the ocular laterality on this process. Although some authors have indicated that sex influences color perception (22). this work showed that in general terms, at ages from 6 to 11 years, color perception is similar in both sexes. Moreover, our results showed that ocular dominance also influences the chromatic perception in interaction with sex and wavelength. For example, girls' perception of blue in the right eye is closer to the color of the control stimulus from 7 years of age, while boys do so from the age of 10, although in both cases there are significant deviations towards wavelengths shorter than the control stimulus color. In contrast, in the left eye girls approach the correct perception from 8 years of age and keep significant deviations towards shorter wavelengths, while boys, at the same age, almost perceive the same color as the stimulus control and at the age of 6-7 years they have similar deviations towards shorter wavelengths as the girls. In contrast to the other colors, including blue, in the red color boys and girls showed perceptual deviations towards wavelengths larger than the control stimulus color.

Since our paradigm appropriately detects perceptual errors around the central wavelengths for each eye in healthy children, we propose as a useful tool to detect perceptual disturbances in people with any pathology in color perception.

Limitations of this study include the small sample size and the fact that only children from one school were evaluated. However, this study shows that measuring color might be useful to diagnose pathologies due to perception changes.

CONCLUSION

In this work, the chromatic perception of stimuli with different wavelengths (including blue, green, yellow and red) in children aged 6-12 years were analyzed considering also the influence of sex and ocular laterality on color perception. The main contribution by this work was to demonstrate that age, sex and laterality are factors that influence significantly to color perception, showing that around 11 years of age, the chromatic perception is very similar to that of adults. It differs from findings reported in other studies, indicating that at 8 months of age, an individual already perceives the color as he/she will perceive it in adulthood.

The degree of human perception cannot be evaluated only based on dyschromatopsia; individuals with this condition can perceive all colors but not at the same degree as other individuals. In children, a difference was detected in the perceptions from one eye to the other depending on the color, meaning that ocular dominance in addition to the sex also modifies this perception. Finally, age is a very important factor because it was found that in most of the colors, perceptions were very similar in those aged 6-7 years, with perceptions of blue, green, and yellow shifted to the left, while there was a change among 8-11-year-old children, where perceptions approach those of the control colors. However, it did not occur with the red, when all ages perceived this color as shifted to the right.

This work found some changes existing during childhood such that different age groups should be further evaluated to elucidate whether more changes exist. The software used in this work is proposed as a useful tool when detecting perceptual disturbances in people with any pathology in color perception and when detecting perceptual errors in normal people.

It is suggested that studies exploring alterations in color perception should take into account factors such as sex, age, environment, ocular laterality and ocular/systemic pathologies to elucidate alterations in the perception at different wavelengths and then adopt the best measures for a better diagnosis of visual impairments. We hope to encourage new researches in areas related to variables interfering with color perception modifications.

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REFERENCES

1. Santosjuanes B. Estudio del anomaloscopio Heidelberg multicolor como test de detección de defectos cromáticos rojo-verde y azul-amarillo. Tesis de master en optometría avanzada y ciencias de la visión. 2010. Vision Assambly of Behavioral, 1981.
2. Atchison DA, Pedersen CA, Dain SJ, Wood JM. Traffic signal color recognition is a problem for both protan and deutan color-vision deficient. Hum. Factors. 2003; 45: 495–503.
3. Simunovic MP. Acquired color vision deficiency. Surv. Ophthalmol. 2016; 61: 132–155.
4. Urtubia C. Neurobiología de la visión. 2da ed. España: Universidad Politécnica de Cataluña, 1999.
5. Huang JT. Image recolorization for the colorblind. IEEE International Conference on Acoustics, Speech and Signal Processing 2009; 1: 1161–1164.
6. Valenzuela GM. Anomalías en la visión del color. Ittakus. 2008.
7. Matlin MY, Foley H. Sensación y percepción (3rd Ed). México: Prentice Hall Hispanoamericana S.A. 1996.
8. Pardo FP. Realización y validación de un programa informático para la detección de deficiencias en la visión de los colores. Tesis de licenciatura. Universidad de Extremadura. Badajoz. 2000.
9. Castro L. Estudio epidemiológico de las discromatopsias congénitas en escolares. Rev San Hih Pub. 1992; 66: 273–279.
10. Quispe A. Usabilidad Web para usuarios daltónicos. Memoria en Congreso Iberoamericano SOCOTE, Universidad de San Martín de Porres. 15–16. 2013.
11. Xie JZ, Tarczy-Hornoch K, Lin J, Cotter SA, Torres M, Varma R, et al. Color vision deficiency in preschool children: the multi-ethnic pediatric eye disease study. Ophthalmology 2014; 121: 1469–1474.
12. Mota MM, Roldán MI, Trujillo JA, Uribe JR. Prevalencia de las discromatopsias en la zona metropolitana de la Ciudad de México. Ciencia UANL. 2019; 22: 10–25.
13. Al Saeidi R, Kernt M, Kreutzer TC, Rudolph G, Neubauer AS, Haritoglou C. Quantitative computerized color vision testing in diabetic retinopathy: A possible screening tool? Oman J. Ophthalmol. 2013; 6: S36–S39.
14. Bresnick GH. Diabetic macular edema: A review. Ophthalmology. 1986; 93: 989–997.

Ciencia y Tecnología para la
Salud Visual y Ocular
Science and Technology in Ocular Health and Vision

15. Cabrera Martínez JA, Martínez Ribalta J, Márquez Fernández M, Cabrera Martínez A. Comportamiento de la visión de color en pacientes sospechosos de glaucoma y glaucomatosos como daño precoz de las células ganglionares de la retina. Rev. Cubana Oftalmol. 2007; 20.
16. Niwa Y, Muraki S, Naito F, Minamikawa T, Ohji M.. Evaluation of acquired color visión deficiency in glaucoma using the rabin cone contrast test. Invest. Ophthalmol. Vis. Sci. 2014; 55: 6686–6690.
17. Gella L. impairment of color vision in diabetes with no retinopathy: Sankara Nethralaya diabetic retinopathy epidemiology and molecular genetics study (SNDREAMS-II, report 3) 2015.
18. Zachi EC, Costa TL, Barboni MTS, Costa MF, Bonci DMO, Ventura DF. Color vision losses in autism spectrum disorders. Front. Psychol. 2017; 8: 1127
19. Miyahara E, Pokorny J, Smith VC. Incremento de umbral y la discriminación pureza sensibilidades espectrales de colores observadores defectuosos cromosoma X-ligado. Vision Research. 1996; 36: 1597–1613.
20. Urtubia C. Fisiología de la retina: el mensaje de la primera sinapsis. Rev. Ver. y oír. 2004; 288-291.
21. Muñoz R. Caracterización física de la percepción de colores digitales. Órgano de divulgación científica y tecnológica de la Facultad de Ingeniería de la Universidad de Carabobo. 2001.
22. Correa V, Estupiñán L, Garcia Z, Jiménez O, Prada LF, Rojas A, et al. Percepción visual del rango del color: diferencias entre género y edad. Revista Med. 2007; 15:7-14.
23. Camps. Memoria de color en niños. Memoria en Congreso Alicante, España (sin año).
24. Werner J. Sensitivity of human foveal color mechanisms throughout the life span. J. Opt. Soc. Am. 1988; 12: 2122-2130.
25. Ellis L, Ficek C. Personality and individual differences. Pergamon. 2001; 1375-1379.
26. Sokhal RR, Rohlf FJ. Biometry: The principles and practice of statistics in biological research. WH Freeman. 1995.
27. Orlocci L, Kenkel N. Introduction to Data Analysis. International Cooperative Publish House. Springer. 1985.