Identification of cases of color blindness in the academic community: Implications for teaching-learning

Ítalo Ramon Bessa Holanda, Théo Araújo-Santos

ABSTRACT

Introduction: Color blindness continues to be a neglected condition in educational environments and there are no data available on the prevalence and characteristics of cases in the academic context. In higher education, there is a lack of data on the limitations imposed by the condition, as well as on the predilection of color-blind individuals for different areas of knowledge. **Methods:** In this work, a series study of color blindness cases was conducted in the academic community of Barreiras, Bahia, Brazil, where cases were identified using the Ishihara online test associated with symptomatologic interrogation in a single digital questionnaire. **Results:** The prevalence of color blindness within the study population was 6.38% (15/235) of participants. A greater number of cases were observed among participants who are from the area of health knowledge. Although some people with color blindness reported an impairment in their learning process, the findings indicate that this was not a determining condition for choosing an area of knowledge, but it limits the choice of acting in specific areas. The association of a symptomatologic survey allowed us to identify cases of color blindness not distinguishable by the Ishihara online test and, although considered rare, we identified cases of tritanomaly among study participants. **Conclusions:** In this way, the data points to the presence of cases of color blindness in the academic community of Barreiras in western of the Bahia and suggests that additional studies should be conducted to draw a broader profile on the consequences of color blindness in the teaching-learning processes in higher education.

Keywords: Color blindness, Higher education, Ishihara test.

INTRODUCTION

In the human eye, light is captured by two types of cells: cones and rods. Cones are responsible for capturing different wavelengths of light and are therefore responsible for color perception. Normal color vision in humans is trichromatic and is provided by cells in the retina called cones. There are three types of cones, classified according to their excitability to light in specific wavelength ranges: (i) L-cones, which are sensitive to light in the red range; (ii) M-cones, which are sensitive to yellow and green light; and (iii) S-cones, which are sensitive to blue light[1,2].

Color blindness is a condition in which an individual has difficulty seeing colors. The types of color blindness are usually the result of modifications in the opsin genes, and can be classified as: (i) anomalous trichromatism, in which the perception of red, green and blue colors is altered in some proportion; (ii) dichromatism, when perception is limited to only two colors; and (iii) monochromatism, when the perception of the image is only in black and white, in a condition known as achromatopsia. Dyschromatopsia can be classified as protanomaly, deuteranomaly and tritanomaly, causing total or partial difficulties in the perception of red, green and blue colors, respectively.

Universidade Federal do Oeste da Bahia. Centro das Ciências Biológicas e da Saúde, Barreiras, (BA), Brasil.

https://doi.org/10.11606/issn.2176-7262.rmrp.2024.217330

It is caused by mutations in the genes that code for opsins (OPN), G-protein coupled membrane receptors (GPCRs) capable of recognizing electromagnetic waves in the blue, green and red light spectrum, and is therefore a genetic condition [3,4]. The most common form of color blindness, the difficulty in distinguishing between green and red, involves the genes *opn1mw* and *opn1lw*, both present on the X chromosome, hence the X-linked inheritance mechanism. [3–5] However, it can also occur due to a mutation in the *opn1sw* gene, which is located on chromosome 7, in which case an autosomal dominant inheritance mechanism is presented [2,6,7]beginning with the L and followed by one or more M pigment genes. The L and M pigment genes are highly homologous, which predisposed them to unequal crossing over (recombination. Furthermore, cases of dyschromatopsia can be confused with rarer conditions, such as incomplete achromatopsia, which occurs more rarely in individuals carrying mutations in genes related to the cell signaling process triggered by photopsin [8] (Table 1).

Table 1. Characteristics and prevalence of diverse types of color blindness in the world population.

Color blindness type	Cell type affected	Gene	Chromosomal location	Protein mutation	Color recognition affected	Prevalence in the population	Ref.
Deuteranomaly	M-Cone	OPN1MW2 Gene ID: 728458	ChrX.q28	cys203arg	Green color	1.7 – 5%	2,6,7
Protanomaly	L-Cone	OPN1LW Gene ID: 5956	ChrXq28	gly338glu	Red color	0.76 – 1%	2,6,7
Tritanomaly	S-Cone	OPN1SW Gene ID: 611	Chr7q32.1	gly79arg ser214pro pro264ser	Yellow and Blue colors	0.001 – 0.1%	2,6,7
Typical achromatopsia	All cones	OPSIN-LCR Gene ID: 107604627	ChrXq28	cys203arg arg247	All colors	0.0001 – 0.001%	2,6,7,20
Atypical achromatopsia	All cones	RPGR Gene ID: 613	Xp22.13-p22.11	Glu967*	All colors	0.01%	2,6,7,20

The diagnosis of color blindness is performed by ophthalmologists during the routine examination of patients and is based mainly on the use of tests using colored plates, the main tests being the Ishihara test, which identifies protonomalies and deuteranomalies, and the HRR test for tritanomaly [9,10]. With the advancement of technologies, digital versions of these tests have been developed, with an online version of the Ishihara test already experimentally validated [10]. The use of digital tests to identify color blindness sufferers could help understand the prevalence of the condition in different locations with little access to medical care [11].

Dyschromatopsia affects 5% of the population [6,12], being predominant in the

male gender. If the prevalence in the male population is considered, the percentage reaches 8% and among the female population 0.5% [2,3,7].However, there is a lack of studies on the prevalence of color blindness in academic environments, as well as on the limitations in learning of students who have this alteration, because colors are of great importance as a component of communication used in the teaching-learning process [10,11,13,14].

In this study, we used the online Ishihara test associated with symptomatic questioning to identify cases of color blindness in the academic community, considering that color blindness is a genetic condition with multiple causes, but already identified. We found that the association of the test with questions related to the mechanisms of inheritance of color blindness was able to help identify cases that would not be detected by conventional diagnosis. In addition, we also identified reports from students and professionals in the academic community about the impact of color blindness on the choice of the area of knowledge to work in.

METHODS

Study design

Case series study of color blindness involving the academic community of the city of Barreiras, Bahia, Brazil. The study included teachers, administrative technicians and students. Data were collected between October 2019 and April 2020.

Data collection

Data collection was carried out using a digital form (access to the form). Community participants were invited to participate by means of posters placed around the institutions containing QR Codes directing them to the form, as well as through informative lectures on color blindness. The following information was collected: name, email, academic position, educational institution, ongoing course, age, gender, place of birth, whether they have ever taken a color blindness test, whether they have ever been seen by an ophthalmologist, family history of color blindness, degree of kinship with the color blind family member, previous diagnosis of color blindness, type of color blindness and impact of the condition on the choice of field of activity. The form then provided images for the Ishihara test [7]. The individuals' responses were analyzed using standardized procedures for analyzing the Ishihara test, which allowed individuals to be classified as having or not color blindness. Cases of color blindness that did not fall within the scope of the Ishihara test were resolved by the inheritance mechanism identified from the form data.

Statistical analysis

Descriptive statistics were performed to determine the relative frequencies of categorical variables, as well as to obtain the medians and their respective values for continuous variables. All data were analyzed using GraphPad Prism 5.0 software (GraphPad Software Inc).

Ethics

The research was submitted to the Human Research Ethics Committee for consideration via the Brasil platform, obtaining its approval with the registration number CAAE: n°18132619.5.0000.8060.

RESULTS

Characteristics of survey participants

The prevalence of color blindness within the study population was 6.38%, with a total of 15 cases. General data of the study population: 85.11% of the participants were students, 8.94% were teachers, and 5.96% were administrative technicians. 89% of the participants were from public institutions and 11% from private institutions. 69.5% of the participants were female and 30.5% were male. The mean age of the participants was 25.6 years (25.6 ± 6.26). In addition, we identified a higher incidence of cases in individuals linked to the health area (n = 8, 53.3%), followed by the humanities (n = 5, 26.7%) and exact sciences (n = 3, 20%). The general data of the participants are summarized in Table 2. There were reports of learning difficulties in 9 cases out of a total of 15, but it was not possible to identify whether color blindness was a predominant condition for interest in a specific area of knowledge. The main reports included: difficulty distinguishing colors in brushes on the board; difficulty interpreting projected or printed images in assessments; difficulty analyzing histological slides or in tests using microscopy; inability to distinguish color-dependent clinical conditions, such as jaundice and redness; difficulty in interpreting tests in psychology; difficulty distinguishing colors in graphs and spreadsheets. We identified a discrepancy of 4 cases between the previous diagnosis and that identified by our data collection instrument.

Table 2. General characteristics of research participants.

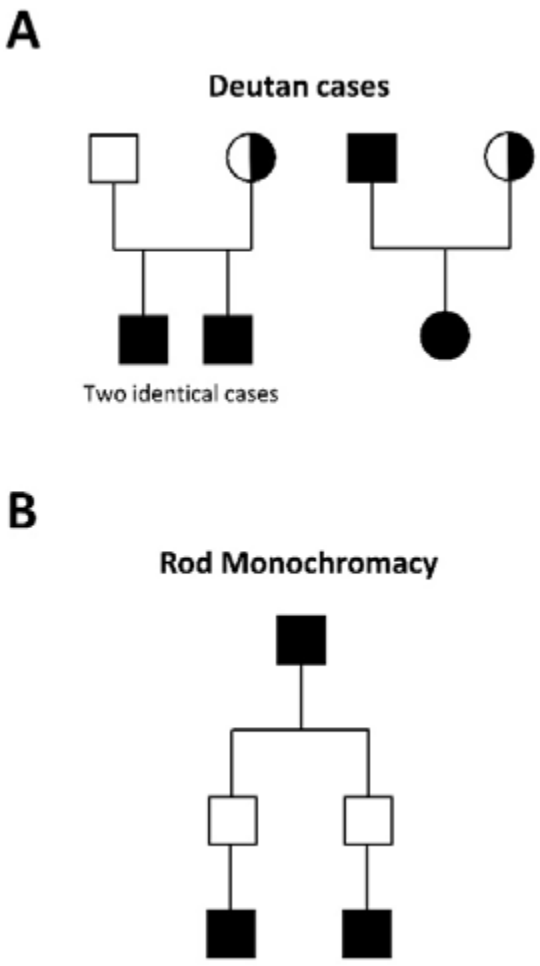
Variables	Category		
	Teachers	**Students**	**Education technicians**
No. of participants	(21) 8.94%	(200) 85.11%	(14) 5.96%
Female[#]	(12) 9.52%	(143) 71.50%	(10) 71.43%
Age in years	38±3.94	23.6±3.87	35±7.05
Color blindness[#]	(2) 9.5%	(11) 5.5%	(2) 14.3%

The absolute frequency of the variables analyzed is in parentheses, followed by the relative frequencies. Age in years is represented by the mean ± standard deviation. [#] indicates that relative frequencies were represented by category analyzed.

Deuteranomaly cases

Deuteranomaly is the most common form of dyschromatopsia [15]. In this study, we identified 7 cases of mild to severe deuteranomaly and 2 cases of deuteranopia that fit into the same spectrum, with a total of 9 cases, 2 cases concordant with a previous ophthalmological diagnosis, 2 discordant and 5 without a previous diagnosis. The mean error rate was 19.33 ± 6.63 in a total of 38 boards present in the online Ishihara test. There was a predominance of male individuals (85.7%) with a mean age of 27.2 ± 6.12 years. The use of symptomatic inheritance interrogation also allowed us to identify a characteristic pattern of inheritance linked to the X chromosome, as expected for this condition (figure 1A).

Figure 1 - Pedigree of cases of color blindness identified by the Ishihara's online test associated with the symptomatologic survey. Genealogic tree shows family members are shown according to male (□) and female (◯) genders. Fully filled symbols indicate individuals with color blindness and partially filled symbols indicate the presence of alleles for color blindness without the manifestation of the condition.



Incomplete achromatopsia case

Rare cases of color blindness can be confused with dyschromatopsia, since individuals only perceive one color [8]. The association of the Ishihara test with a symptomatic interview allowed us to identify a case of incomplete achromatopsia. A 24-year-old male individual. He was previously diagnosed with tritanopia, as he reported difficulty seeing colors from the age of 4. In the family, the paternal grandfather and a first-degree cousin have difficulty seeing colors. He reported that he cannot see the blue color, exchanging it for gray or black, and has difficulty seeing on the chart or graphs. Of the 38 questions, he answered 21 incorrectly, with an error rate of 55.26%. The inheritance analysis allowed us to identify an autosomal recessive inheritance pattern compatible with incomplete achromatopsia, also known as ROD monochromacy (figure 1B).

Achromatopsia case

Extremely rare, achromatopsia occurs at a frequency of 0.001% in the general population [6,7]. In this study, we identified a 22-year-old male individual who was previously diagnosed with deuteranopy, reported difficulty seeing colors since the age of 10, and was unable to say whether anyone in his family had any difficulty seeing colors. He also reported that the difficulties were greater when interpreting graphs and drawings. Out of 38 questions, he answered 29 incorrectly, with an error rate of 76.31%. The case is likely achromatopsia, since the individual was unable to identify the color representations in any of the test palettes.

Possible tritanomaly

The Ishihara test is only able to distinguish color blindness related to the distinction between green and red. Here, we have identified two cases of color blindness probably related to the perception of the blue color. However, the HRR test is the most appropriate to classify the three levels of color vision deficiency: mild, moderate and severe for the three most common types of color dyschromatopsia [7]. Through the online form, we were able to identify characteristics of the participants that indicate the presence of tritanomaly. The cases are described below:

Case 10 - A 36-year-old male reported not having been previously diagnosed, but only reported having difficulty seeing colors since the age of 18. He also stated that his brother also has difficulty seeing colors. The participant reported that he was unable to differentiate shades, yellowish green, and the tones of these colors. Out of 38 questions, he only got 3 wrong, with an error rate of 7.89%; this is probably a case of tritanomaly.

Case 14 - 19-year-old female who reported not having been previously diagnosed, only reported having difficulty seeing colors and was unable to say since when. It is not known whether anyone in the family has difficulty seeing colors. She reported difficulty seeing shades of gray and commonly confuses them with shades of brown and yellow. Out of 38 questions, she got 7 wrong and has an error rate of 18.42%. This is probably a case of tritanopia, but in this test applied in the research this type is not identifiable.

Both individuals answered correctly the questions related to the identification of protan and deutan color blindness, but they reported difficulty perceiving colors and answered incorrectly the questions on the online Ishihara test that allow identifying color perception difficulties. Since they were individuals of both sexes, with no previous family history of the condition, we believe these are cases of tritanomaly, since they were mild cases, and the difficulty in perceiving the blue color is often not noticeable in many individuals with the condition. They may also be cases of tritanomaly related to the presence of autosomal mutations on chromosome 7, which would justify the absence of family history (see Table 1).

Unsolved cases

The Ishihara test has limitations for identifying cases of color blindness not understood as the difficulty in perceiving red-green [10]. Here we identified 2 cases of color blindness that could not be distinguished by the test. The use of a digital data collection instrument, although it allows for a more comprehensive reach, brings limitations regarding adherence and quality of responses from some participants. Below it is a description of the cases:

Case 12 – A 22-year-old female reported having been diagnosed with unspecified color blindness since the age of 6. She was unable to report the presence of the condition in other family members. She also reported having difficulty with the colors black and white, and that she gets a headache when looking at them for more than 5 seconds in some cases. Out of 38 questions, she answered 9 incorrectly, with an error rate of 23.68%. It was not possible to determine the type of color blindness with the test alone.

Case 8 – 22-year-old female. She was diagnosed with color blindness, but she reported that the type was not reported. She was unable to say whether anyone in her family had difficulty seeing colors, or she had difficulty with the colors of the brushes used in class, viewing slides, or in practical tests. In addition to color blindness, she had a limited field of vision. Out of 38 questions, she answered 13 wrong, with an error rate of 34.21. The test was unable to identify the type of color blindness.

DISCUSSION

Color blindness is a condition that has been known for more than three centuries, yet it remains neglected in learning environments, as prevalence data in the academic population are scarce[17]. In this study, we identified cases of color blindness in the academic community of Barreiras, Bahia, Brazil, using an electronic Ishihara form associated with a symptomatologic survey. The prevalence of color-blind individuals was similar to that found in the general population. We identified cases of color blindness in individuals working in different areas of knowledge.

Regarding the implications in the academic environment and in the choice of profession, it is worth highlighting that in some choices the condition may be limiting, and it is not possible to state with precision that a colorblind person cannot perform a specific activity, for example an activity in a pathology laboratory, which has colored slides that in a more severe type are very difficult to observe [17,18] There are examples of colorblind people who work as graphic designers, which is a profession that also works a lot with colors. This confirms that it will depend on each individual, who has their own expectations and limitations [19]. In this

study, we found a higher frequency of participants from the health field, who reported a greater impact of the condition on the performance of their activities. There were also cases of people who changed their areas of study due to their color blindness, which ended up contributing to a lack of identification with the field and a feeling of not being competent to perform the activities. Among the difficulties reported were the inability to see colored brushes on the board, viewing slides, and microscope slides. In our study, we even identified a student who dropped out of a chemistry course and changed his choice to a course in the humanities area because of color blindness. Regarding the medical area, one of the main difficulties reported by students in the field is the presence of clinical signs in patients that directly depend on the interpretation of colors. The reports are very diverse in the health area [18], More specifically, in the medical course, some study participants reported difficulty in interpreting clinical signs that appear through colors, such as eye changes such as red or yellow eyes, as occurs in cases of conjunctivitis and jaundice. In addition, the interpretation of tests such as arterial blood gas analysis, at the time of collection, to differentiate bright red arterial blood from dark red venous blood.

Like other studies, this study had some limitations, such as the lack of direct contact with participants. However, previous studies have validated the online Ishihara test for diagnosing color blindness [10]. The online form may present an impediment to assisting the participant when the participant does not understand a question and is unable to know the circumstances in which the questionnaire was answered [16]. Improvements to the instrument, such as reducing the number of questions and the time required to complete the form, could result in better participant adherence, and should be carried out in future research. We found a discrepancy between the data collected through the virtual form and the diagnosis made by the ophthalmologist, but we cannot ignore the limitations of the study. When the Ishihara test is administered by a medical professional, the test administrator may influence the response to the virtual form. On the other hand, the response to a virtual form may not be sufficient to resolve possible doubts regarding the answers that should be given in a certain part of the form[10]. To reduce the bias associated with the absence of a mediator during the test, in cases where it was not possible to identify the type of alteration, the participants were contacted by the researchers. Another limitation of this study was the absence of tools capable of identifying alterations related to the perception of the blue color, tritanopia, which depends on the application of a specific questionnaire, such as the HRR. Additional validation studies of a mixed virtual questionnaire using the Ishihara test and specific tests for tritanomaly, or even cases of achromatopsia, need to be developed and validated. The inheritance mechanisms related to specific types of color blindness are already known. In this study, we identified individuals with tritanomaly using these assumptions, since family history allows us to identify the type of inheritance related to color blindness. In this study, we verified the importance of understanding the genetic inheritance mechanism related to color blindness. Although some studies have validated virtual tests for the identification of color blindness[10], This is the first study to associate information on the genetic inheritance mechanism with data from the Ishihara test, which expands the ability to identify types of color blindness beyond

those covered by the test. The use of an online form with additional questions to the Ishihara test could be an interesting tool to expand the applications of the test to other types of color blindness not covered by the conventional test.

Thus, we found that color blindness is a condition present in the academic community of Barreiras, in western Bahia. This condition is present in a wide range of institutions, and there are no reports in the literature of strategies or policies for inclusion of these individuals. Approximately 6% of the community has this condition. The data from this study will contribute to the establishment of inclusion policies and will be a good contribution to future studies on color blindness in the region.

CONCLUSION

We conclude that color blindness is a condition present in the academic community of Barreiras, in western Bahia, and is present in a wide range of institutions, which do not have any strategy or policy for inclusion of these individuals. Approximately 6% of participants have this condition. We also found rare cases that were not expected during the development of the study. The data from this study will contribute to the establishment of inclusion policies and offer a contribution to future studies on color blindness in the region.

REFERENCES

1. Deeb SS. The molecular basis of variation in human color vision. *Clin Genet*. 2005;67(5):369-377. doi:10.1111/j.1399-0004.2004.00343.x
2. Deeb SS. Molecular genetics of colour vision deficiencies. *Clin Exp Optom*. 2004;87(4-5):224-229. doi:10.1111/j.1444-0938.2004.tb05052.x
3. Bruni LF, Cruz AAVE. Sentido cromático: tipos de defeitos e testes de avaliação clínica. *Arq Bras Oftalmol*. 2006;69(5):766-775. doi:10.1590/S0004-27492006000500028
4. Lee J. Uma ferramenta adaptativa para facilitar a visualização de imagens para pessoas portadoras de daltonismo. In: 2008:435-438.
5. Casarini FC. *O daltonismo: um exemplo de herança ligada ao cromossomo x*. Monografia. Universidade Federal do Paraná; 2015. Accessed October 19, 2023. https://acervodigital.ufpr.br/bitstream/handle/1884/42326/R%20-%20E%20-%20FRANCIELE%20CRISTINA%20FANHANI%20CASARIN.pdf?sequence=1&isAllowed=y
6. Kim H, Ng JS. Prevalence of Color Vision Deficiency in an Adult Population in South Korea. *Optom Vis Sci Off Publ Am Acad Optom*. 2019;96(11):866-873. doi:10.1097/OPX.0000000000001441
7. Piccinin MRM, Cunha JF, Almeida HPD, et al. Baixa prevalência de discromatopsia, pela 4ª edição do teste pseudoisocromático HRR (Hardy, Rand e Rittler), da população indígena de etnia terena da aldeia lalima na região de Miranda: Mato Grosso do Sul. *Arq Bras Oftalmol*. 2007;70(2):259-269. doi:10.1590/S0004-27492007000200014
8. Simunovic MP. Colour vision deficiency. *Eye Lond Engl*. 2010;24(5):747-755. doi:10.1038/eye.2009.251
9. Fernandes LC, Urbano LCDV. Eficiência dos testes cromáticos de comparação na discromatopsia hereditária: relato de casos. *Arq Bras Oftalmol*. 2008;71(4):585-588. doi:10.1590/S0004-27492008000400023
10. van Staden D, Noor Mahomed F, Govender S, Lengisi L, Singh B, Aboobaker O. Comparing the validity of an online Ishihara colour vision test to the traditional Ishihara handbook in a South African university population. *Afr Vis Eye Health*. 2018;77(1). https://avehjournal.org/index.php/aveh/article/view/370
11. Jha R, Gautam Y. Prevalence of Color Blindness in Undergraduates of Kathmandu University. *J Nepal Med Assoc*.
12. CFM CF de M. Daltonismo: distúrbio atinge 5% da população mundial. Published 2004. Accessed October 19, 2023. https://portal.cfm.org.br/noticias/daltonismo-disturbio-atinge-5-da-populacao-mundial/#:~:text=Olhar%20para%20o%20sinal%20de,o%20problema%20%C3%A9%20facilmente%20contornado.
13. Khairoalsindi OA, Almasoudi BM, Bamahfouz AY, Alghamdi AA, Siddiqui MI. Prevalence and Determinants of Color Vision Defects among Preparatory University Students at Makkah, Saudi Arabia. *Middle East Afr J Ophthalmol*. 2019;26(3):133-137. doi:10.4103/meajo.MEAJO_29_19

14. Stoianov M, De Oliveira MS, Dos Santos Ribeiro Silva MCL, Ferreira MH, De Oliveira Marques I, Gualtieri M. The impacts of abnormal color vision on people's life: an integrative review. *Qual Life Res*. 2019;28(4):855-862. doi:10.1007/s11136-018-2030-1
15. Teixeira FLF, Magalhães S de A, Leite LM, Castro FM de C, Leite JÁ. Prevalência de discromatopsia congênita em estudantes do noroeste fluminese. In: 2010. https://www.inicepg.univap.br/cd/INIC_2010/anais/trabalhos_saude.html
16. Faleiros F, Käppler C, Pontes FAR, Silva SS da C, Goes F dos SN de, Cucick CD. Use of virtual questionnaire and dissemination as a data collection strategy in scientific studies. *Texto Contexto - Enferm*. 2016;25(4):e3880014. doi:10.1590/0104-07072016003880014
17. Melo DG, Galon JEV, Fontanella BJB. Os "daltônicos" e suas dificuldades: condição negligenciada no Brasil? *Physis Rev Saúde Coletiva*. 2014;24(4):1229-1253. doi:10.1590/S0103-73312014000400011
18. Viola Andin Dohvoma EE Stève Robert Ebana Mvogo, Giles Kagmeni, Nathalie Rosine Emini, Mvogo CE. Color vision deficiency among biomedical students: a cross-sectional study. *Clin Ophthalmol*. 2018;12:1121-1124. doi:10.2147/OPTH.S160110
19. Souza AS. *Estudo Sobre o Conforto Visual Nas Interfaces – Com Ênfase No Daltonismo*. Dissertação. PUC SP; 2013. Accessed October 19, 2023. https://tede.pucsp.br/handle/handle/18118
20. Maestrini HA, Fernandes LC, Oliveira ACM. Distrofias retinianas da infância: análise retrospectiva. *Arq Bras Oftalmol*. 2004;67(6):867-876. doi:10.1590/S0004-27492004000600005

Authors' contributions

IRBH and TA-S : Project design and execution

IRBH: Data Collection

IRBH and TA-S: Data Analysis

IRBH and TA-S: Materials and Software

IRBH and TA-S: Wrote the article

Acknowledgments

The authors are grateful to Professors Raphael Contelli Klein and Larissa Paola Rodrigues Venancio for the suggestions on the definitive version of the manuscript.

Conflicts of Interest

The authors declare no competing financial interest.

Autor Correspondente:
Théo Araújo-Santos,
theo.santos@ufob.edu.br

Received: oct 19, 2023
Approved: feb 19, 2024
Editor: Profa. Dra. Ada Clarice Gastaldi
