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REVIEW

The impacts of abnormal color vision on people's life: an integrative review

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Abstract

Background This article shows an integrative review on the impact that abnormal color vision may have on the daily routine of individuals.

Purpose We followed the PRISMA guidelines for reviews and carried out researches in four databases (Pubmed, Lilacs, Scopus, and Web of Science) using keywords related to the impact of abnormal color vision.

Method Initially, 805 articles were retrieved and after a first filtering stage, we selected 74 articles for a detailed analysis of the abstracts in which it was found that a total of 20 studies were in fact related to the topic of this review. We then read the selected studies in full and those included in the final selection were analyzed and categorized into specific topic groups of findings. Seven categories were created in total: "impact on daily routine activities", "occupational impact", "impact on product choice motivation", "emotional impact", "impact on school or professional qualification", "impact on self-care and health", and "advantages".

Results From the definition of these categories we could understand that people with some degree of color vision loss face challenges in different aspects of their daily life, especially in their work activities. Still, the amount of research and hence technical support which could be offered to this population is restricted. Additionally, the scarce availability of publications on the topic and the fact that they include very specific groups of people, such as drivers and medical students, allow us to draw only partial conclusions about the all possible impacts yield by such perceptual difference since they observe the impact of the color-vision deficiency in their daily routine from a specific and precise point of view.

Conclusions A broader view of the impact of this problem on the daily life of its carriers is fundamental for implementing strategies that allow such people to be included in all sorts of activities or for the impact of this sensory change to be decreased or treated in a way that would reduce the detrimental impacts.

Keywords Color vision · Color perception · Dyschromatopsia · Color blindness · Impact · Visual function · Color vision defects

Introduction

Color is a powerful tool for encoding and emphasizing visual information present in our life routine despite culture or life style or. It is putative that anomalous color vision impacts qualitatively on individuals' lives and this impact probably occurs in an unique and personal way. Such repercussions are present even when the color vision losses are barely consciously noticeable. To those of us who experience some degree of color vision loss or dyschromatopsia it may be due to congenital or acquired conditions. According to previous studies, the prevalence in cases of congenital dyschromatopsia is approximately 7% of the male population and 0.5% of the female population [43].

Color processing is related to both subjective and more concrete aspects of human life. On one hand it is important to emotional response such as mood in situations of esthetic experiences [7, 8, 36] and on the other it conveys specific

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information, such as map readings, where level curves, road and relief characteristics are color-coded [6]. A further example for objective color coding is among pharmaceuticals. For elderly people making continuous and intense use of numerous medications, colors may facilitate their identification more efficiently or quickly than by means of tags and labels, improving agility in the use of medications. Aging is, however, often associated with changes in color vision. Ishihara et al. [14] pointed out that medicine colors tend to be confused by the elderly and suggested changes in color combinations and special products for this age group. Even though color seems to be related to a broad range of aspects in modern life, little is known about how that impact can influence the daily routine of people with changes in this visual attribute.

Regarding acquired color vision alterations there are studies such as thesis from Piro et al. [27, 28] in which acquired color vision alterations can be a biological marker to distinguish the beginning of Parkinson's disease or the prognosis of multiple sclerosis. Studies on other neurological disorders follow the same pattern showing that color vision defects could be one of the earliest signs of visual loss in the evolution of Leber hereditary optic neuropathy (LHON) on the studies of Ventura et al. [38] or even precede the diabetic retinopathy [10, 12].

Despite the limited number of studies on the impact of abnormal color vision, there is currently great interest in improving the quality of life of people who have such losses. Initiatives from the academy, industry, and organized groups of patients include attempts to cure or correct abnormal color vision by the means of gene therapy, adaptive lenses, digital simulation tools, and color transformation methods [2, 19, 26, 32, 34, 42].

Technological strategies allow individuals with altered color vision to find information within images or pictures which would be very difficult without it [18, 24]. A few technology companies have identified that this visual change may influence the use of their products by dichromat consumers and developed changes in the color palette of their products in order to correct or minimize those problems. Also, lenses which increase color saturation have been developed by Tanuwidjaja et al. [37], in their study they discuss that the deleterious impact of color vision changes the routine of people with this deficit.

Contrary to the majority of studies that find negative results connected to the impact of altered color vision, a study deals with the thresholds of detection of contours or better definition of contrasts in some luminance frequencies, reporting a better adaptation of dichromats to environments with low contrast in those frequencies [33]. Other studies report the advantages that some people with color vision changes could have related to the recognition of camouflage, that is, these people would recognize this color pattern more efficiently than people with normal color vision. These studies suggest that dichromat people are less susceptible to focusing on the color interference and are prone to focus on the texture detection [22, 25].

Almost 10 years ago an important study has been published bringing the ambitions idea of a possible cure for the congenital types of color blindness. The study of Mancuso et al. [19] successfully employed a gene therapy protocol that allowed dichromat squirrel monkeys (*Saimiri sciureus*) to perform a series of electrophysiological and behavioral tests as a trichromat animal would. This study represented a milestone in the study of color vision and the possible implications it might have for the people carrying congenital dyschromatopsia have been speculated ever since.

Regardless of the nature of the change in color vision, whether congenital or acquired throughout life, and regardless of how one has sought to correct those visual changes—with gene therapy, technological resources, or physical devices—it is evident that changes in color perception have an impact on the daily routine of its carriers. We believe an important achievement such as this could be better employed if it were based on consistent research assessing the impacts that different degrees of color vision could bring to the people who have it. This prompted us to the question motivating this paper. Thus, we present a joint analysis of the data obtained so far, as well as a reflection on the prospect in the area based on a broad review.

He we present an integrating review in this study aiming at the following question: what is the impact of anomalous color vision on people's lives?

Method

For the present review we followed the method proposed by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) in search flowchart and determination of relevant points [21]. This method proposes a standardization of literature reviews with a transparent and accessible method for other researchers [39]. In order to obtain as many relevant articles as possible, we used a search strategy adapted to the operation of each of the electronic bases, that is, using similar words, but observing the field completion system according to the structure of the website.

Our integrative review began with the identification of the problem and clear definition of the initial question: What do studies about the impact on the daily routine of people with anomalous color vision reveal? Researches were performed between February and April 2018 and the criteria for inclusion of the papers were: studies published in English, Portuguese, or Spanish languages and within the last 10 years.

Initial searches were performed in four electronic bases: Web of Science, Scopus, Lilacs, and Pubmed by two

reviewers (authors MS and ML), using specific keywords as listed on Table 1, below.

After this first searching step, the team of six authors was divided into three pairs that separately analyzed potentially relevant titles and abstracts in order to choose the articles that would integrate this review. Exclusion criteria were texts describing color change alone, prevalence studies, technology development studies that did not mention impact on any part of their content. When there were discrepancies on the decision regarding one article's inclusion to the review they were settled by including a third reviewer.

The articles selected were those containing research results related to the impact on the daily routine of individuals with abnormal color vision. The criterion used to include articles for analysis and categorization was the presence of experimental results and/or the clear discussion about the impact on the daily routine of individuals with altered color vision. Then, after selecting the articles considered relevant, the full texts were analyzed by all authors. The papers presenting aspects related to the guiding question were organized into thematic categories established according by the authors as it seemed necessary throughout the studying of the texts. The process of defining the categories is described in the "Results" section of this paper.

Results

The initial search on all four databases returned 809 titles, 554 from Scopus, 161 from Web of Science, 33 from the Pubmed platform, and 61 from the Lilacs platform. At the first screening, it was considered if the title was coherent

Table 1 Summary of the research strategies applied in each of the databases used for this review

Database	Research strategies
Lilacs (bvs)	Visão de cores and Defeitos da Visão cromática (título, resumo e assunto) and Humanos
	Defeitos da Visão Cromática (título, resumo e assunto)
	Dicromatopsia (Titulo Resumo ou assunto)
	Percepção de Cores (Tit, Res, Assun) and Humanos
	Função Visual (Titulo, Resumo, assunto) and cores
Pubmed	Color Vision Defects/congenital[Mesh] AND "Color Vision Defects/psychology"[Mesh]
	color vision defects[MeSH Terms] AND impact[Title/Abstract]
	(blindness, color[MeSH Terms]) AND quality of life[Title/Abstract]
	(color blindness[MeSH Terms]) AND Psychology[Title/Abstract]
	(color blindness[MeSH Terms]) AND Questionnaire[Title/Abstract]
	(color blindness[MeSH Terms]) AND everyday tasks[Title/Abstract]
	(blindness, color[MeSH Terms]) AND everyday work[Title/Abstract]
	(color blindness[MeSH Terms]) AND general practitioners[Title/Abstract]
	(blindness, color[MeSH Terms]) AND occupational handicap[Title/Abstract]
	(color blindness[MeSH Terms]) AND (vision[Title/Abstract] AND sport[Title/Abstract])
	((blindness, color[MeSH Terms]) AND sports[Title/Abstract])
Web of Science	Tópico: (color blindness) Refinado por: Categorias do Web of Science: (PSYCHOLOGY) Tempo estipulado: 2008–2018
	Tópico:("color blindness")Refinado por: Tópico: (humans)Tempo estipulado: 2008–2018
	Tópico: ("color blindness") AND Tópico: (impact) Tempo estipulado: 2008–2018
	("color blindness") and ("everyday work")
	("color Blindness") And (quality of life)
	Tópico: (color blindness) AND Tópico: ("everyday tasks") Tempo estipulado: 2008–2018
Scopus	key ("color blindness") and (limit-to (pubyear, 2018–2009)) and (limit-to (exactkeyword, "color blindness") or limit-to (exactkeyword, "human") or limit-to (exactkeyword, "color vision defects") or limit-to (exactkeyword, "humans")) and (limit-to (language, "english") or limit-to (language, "spanish"))
	(key ("color blindness") and title-abs-key (questionnaire))
	(key ("color blindness") and title-abs-key ("everyday work"))
	(key ("color blindness") and title-abs-key ("quality off life"))
	(key ("color blindness") and title-abs-key ("occupational handicap"))
	(key ("color blindness") and title-abs-key ("everyday tasks"))
	(key (color and blindness) and title-abs-key (impact)) and (limit-to (pubyear, 2018–2009))

The keywords were chosen from the specific descriptors list from each of the databases

regarding the proposed topic and 75 articles were selected for abstract reading and a brief analysis of the text. At this stage six texts were excluded, as they had no cohesive references on the impact of abnormal color vision. A total of 49 papers were read in full and, finally, we elected the 20 papers that were indeed pertinent to this review. The flowchart (Fig. 1) below summarizes the steps involved.

Related subjects

We categorized the research findings into seven categories describing the nature of impact assessed by the studies. As a result, we had a total of seven categories: "impact on daily routine activities", "occupational impact", "impact on product choice motivation", "emotional impact", "impact on school or professional qualification", "impact on self-care and health", and "advantages in altered color vision". According to the range of results described in each paper, one same article could fit into more than one category, as the Table 2 shows below.

Seventeen out of 20 studies had finding categorized as *impact on daily routine activities*, making it the more frequently observed topic. Daily routine activities were considered as all daily actions not related to study or work that included: driving vehicles under abnormal color vision and its risks [2]; difficulties in sports-practice requiring color

Table 2 Categories established as the reviewers carefully analyzed the 20 papers included in the present review

Category	Total number of articles	Representativeness (%)
Impact on daily routine activities	17	85
Impact on product choice motivation	2	10
Impact on school or professional qualification	7	35
Occupational impact	10	50
Emotional impact	1	5
Impact on self-care and health	4	20
Advantages in altered color vision	0	0

The amount of studies presenting results in each of the categories gives an idea of the whole range of subjects color vision deficits are considered to have an effect upon

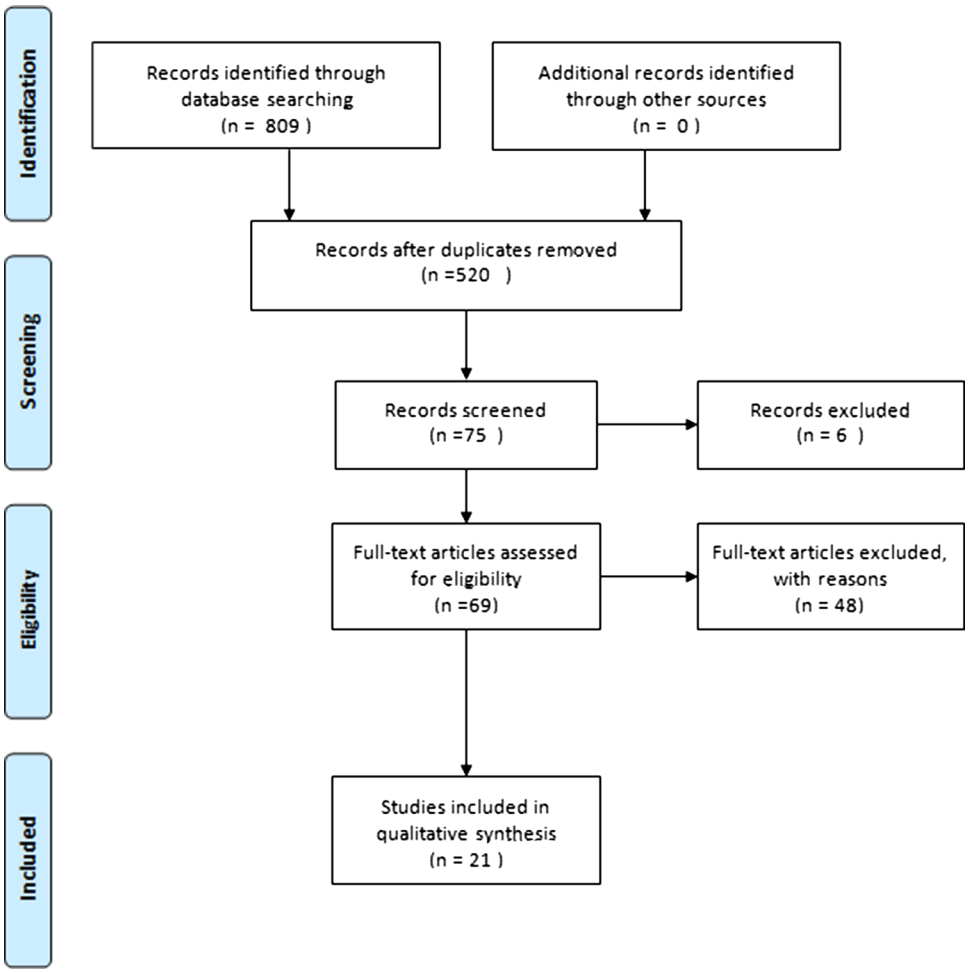

Fig. 1 Flowchart representing all stages included in the present study. Our search method included four main steps beginning with the identification of the potential studies, followed by a screening phase, a eligibility verification instance and finally the selection of the articles to be included in the review

recognition for performance. Long and Junghans [17] mention this issue with the use of maps for guidance in orienteering races and the disadvantages some athletes have due to the colors commonly used on the map.

Under daily routine there are also studies on the difficulty that color blind people have in reading texts on either print or electronic media [6, 11, 16, 23, 30, 31, 42] besides focusing on the description of such difficulties, also discuss the development of a software to change colors of texts in order to make the reading easier to colorblind people.

As publications related to the development of both hardware and software technology to facilitate access to information and entertainment by the colorblind we found. The studies for Ribeiro and Gomes [30], Lau et al. [16], Chaparro and Chaparro [6] which present algorithms digital image adjustments in a variety of digital resources.

The category *occupational impact* included studies referring to the effects of color perception on occupational performance. Among all the occupations presented, the most frequently studied are medical and medical-related careers as shown in the article by Dargahi et al. [9] which deals with the impact altered color vision of laboratory technicians and physicians can have on the potential of errors in exam reports and analyzes. Pathologists are also mentioned in relation to the diagnostic difficulties they face in their routine [1]. A questionnaire applied during a pathology conference assessed the opinion of medical pathologists on the impact of altered color vision and the professional relationship and almost two-thirds answered that people with altered color vision should not practice pathology and no pathologist out of the 93 respondents confessed having any difficulty with color viewing. Also related to this topic, the article by Rubin et al. [32] deals on the use of monitors to make viewing histology slides easier for histologists with altered color vision, linking once again the diagnostic capacity of this group to the color spectrum they are able to see.

Some of the papers, also selected under the occupational category, refer to the difficulty in reading texts in scientific journals featuring charts and graphs that do not fit this population. Those articles suggest colors causing less visual confusion and the authors' attention to this matter [31, 42].

The category "impact on school or professional qualification" is related to the difficulties experienced by individuals in the school routine in both basic and vocational education. In this category, studies such as Rubin et al. [32] raised the main difficulties medical students have to view laboratory slides and argues that removing color from some histology images may help a student with altered color vision to discern the images. Also, studies reflecting the difficulty of reading texts, graphs, and images, both in journals and electronically, were included in this category as school education is closely related to those studies. The text by Frane [11] describes that graphs printed in magazines do not take those with color vision deficits into consideration, demonstrating a frequency of 8% of the analyzed images containing problems to be identified by altered color vision individuals. In contrast, the articles by Ribeiro and Gomes [30] and Chaparro and Chaparro [6] discuss about the difficulties dichromats find to access images on the computer and propose developments of hardware and software to adjust colors for dichromats.

When analyzing articles related to the "impact on product choice motivation" we find studies such as Tanuwidjaja et al. [37], Steward and Cole [36] and Witter and Ramos [40] reporting the influence colors can have on the decisions to buy or choose products. Ramos' article [40] describes this relation in the influence colors can have on the motivation to read works of children's literature. In the article, children connect the choice of stories with colors related to them, but they do not relate the children's attention at the moment the story is being told or the assessment of the story. The article Tanuwidjaja et al. [37] brings up the use of technology once more with the pretense of helping colorblind people tackle obstacles in their daily activities such as how to choose fruits, flowers and clothes using a color-signaling device.

The category "emotional impact" presents results referring to social situations of prejudice, ridicule, mockery, or other behaviors which have had emotional impact on altered color vision individuals or that refer to their relationship with people that are part of their routine. The article by Melo et al. [20] brings up mainly the curiosities of third parties with respect to color vision and the social interaction resulted from this.

On "impact on self-care and health" articles were included that reveal difficulties of recognizing blood in body fluids, difficulties with the use of medications or skin characteristics [15, 29]. The most striking study on this issue is Katmawi-Sabbagh et al. [15] which discusses male colorblind patients who had bladder cancer and the relationship with the more severe forms of the disease in this group associated with the difficulty of identifying blood in the urine due to their altered color vision.

After meditating on the selected articles the group realized that no study in that specific period reported advantages in altered color vision, even though some articles would have already mentioned this previously. Still, we found it was relevant to create the category "advantages in altered color vision" to numerically describe this fact.

Considering a general scenario of the topic categories studied, we observed that most of the papers—17 out of a total of 20 (85%)—are related to impacts on daily life activities, especially regarding traffic and direction signs. The second most studied category is the one referring to occupational impact: 10 out of 20 papers discuss this issue (50%), mainly about the occupational risks due to dyschromatopsia.

Table 3 Year of publication of the twenty studies included in this review

Publishing year	Number of articles	Representativeness (%)
2008	3	14
2009	2	10
2010	0	0
2011	2	10
2012	0	0
2013	1	5
2014	3	14
2015	5	24
2016	0	0
2017	4	19
2018	0	0

The listing reveals the throughout the course of 10 years the amount of papers related to the impacted of color vision losses and its impact was never higher than five papers in a year

Table 4 Listing of the countries where the reviewed articles were came from

Country	Number of articles	Representativeness (%)
Australia	1	5
Brazil	2	10
USA	8	38
India	1	5
Iran	1	5
Israel	1	5
Portugal	1	5
Sweden	1	5
Turkey	1	5
UK	3	14

Almost half the publications came from American institutions. Europe summed one-fourth of the studies and the remaining publications represented studies carried out in South-America or the Middle-East

Time and place

Regarding the year of publication, most studies were published between 2014 and 2015, accounting for 38% of the articles found. The Table 3 below shows the distribution.

About the articles' publishing country, ten different countries were found. Most of them were published in the United States—38% (8 out of 21 articles) [2, 6, 11, 16, 31, 32, 37, 41]. The second country with most publications was the United Kingdom with 14% of articles selected [3, 15, 42]. Then we have two Brazilian articles [20, 40] and the rest found are from Australia [17], India [23], Iran [9], Israel [4], Portugal [1], Sweden [34], and Turkey [1]. The Table 4, below illustrates the outcome more clearly.

Discussion and conclusion

Despite the fact that we started the search process with a large number of studies listed (809), we verified throughout our process of material selection that only 20 studies were in fact pertinent to the topic of this review and indeed were related to the impacts that color vision losses may have on people's lives. This is probably due to a relative unspecificity of the descriptors available on each database as well as due to the scares amount of specific studies concerned with the impacts of color vision losses on the daily routine. Although the number of publications on this subject is quite small, it has increased in the last years and we considered it may be due to gradual increase in the realization of the scientific community about the relevance of this topic in the last 10 years.

In the current development of visual sciences and technology It is not only reasonable but also necessary to have a growing body of knowledge regarding how color vision losses can impact one's life. As we present here, it was in the last decade that we had studies aiming a possibility of a cure of color blindness as well as the largest number of research on assisting technology for this population Mancuso et al. [19] and Shayeghpour et al. [34], improving information perception from digital images for users with dichromatic color vision; Rubin et al. [32] in using color and grayscale images to teach histology to color-deficient medical students; Wong [42] in reply to "more on color blindness"; Almagambetov et al. [2] in mobile standards-based traffic light detection in assistive devices for individuals with color-vision deficiency; Shayeghpour et al. [34] in improving information perception from digital images for users with dichromatic color vision; Ohkubo et al. [26] in development of a time-sharing-based color-assisted vision system for persons with color-vision deficiency.

It is important to mention that there are studies related to this subject that were published over 10 years ago and therefore were not included in our review. These papers discuss the effects of abnormal color vision with the development of self-esteem, personality [7], challenges and difficulties faced by professionals in the medical field [5, 35] and difficulties in sports-practice [13]. This, even though we decided for a more restrict time window for our search, we believe our results provide an accurate scenario of the current research in the field of assessment of impact caused by color vision blindness or losses.

The importance of such sensory changes on people's lives is quite evident when we analyze the studies. From our research we believe it is possible to draw a conclusion that

having abnormal color vision may affect virtually all facets of modern human life. Despite the presence of individual differences that make each individual situation a unique one, a person might have problems in fundamental activities or dimensions such as occupational performance, education, social and emotional relationships, personal care, and access to entertainment and information.

Building knowledge on the subject of the impacts of abnormal color vision is essential to guide the development of further assisting technologies for those who deal with this sensory condition on a daily basis. Mapping and understanding the levels effects of this sensory loss for each individual, considering interpersonal differences it is mandatory for safely consider the prescription or use of assisting apparatus and therapeutic resources developed for this population.

However, the current evidence base is still limited. In a scenario of reduced number of studies on the subject we can conclude that having some degree of color vision loss impacts the lives of individuals in different and significant manners. However it is important to emphasize we draw a general picture based in a rather small amount of studies, not due to an issue of method but rather due to this being a subject studied by only a small amount of groups worldwide. We believe the identification of which are and at what levels the impacts occur is still a topic of research in need of growth. Thus, it seems ideal that further studies dedicated to systematically and comprehensively assess those possible impacts be carried out.

Compliance with ethical standards

Conflict of interest I certify that all authors to this manuscript have no conflict of interest to declare.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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