SYSTEMATIC REVIEW OF COLOUR BLINDNESS

BY

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Abstract:

Background: Colour blindness stems from the lack of colour vision and highlights the lack of the functioning of the eyes to see colour or perceive colour due to the loss of the different types of cones so there is an inability to see certain wavelengths of light.

Aim: To systematically review studies on colour blindness.

Method: A systematic review was done to critically appraise research studies, and synthesize findings qualitatively or quantitatively [17]. A complete exhaustive summary of current evidence was used from 33 articles, both published and unpublished; they were methodical, comprehensive, transparent, and replicable.

Results: Colour blindness was found to be prevalent globally and deuteranomaly was the most prevalent form of colour blindness. There was a higher prevalence of colour blindness in the Non-Hispanic White ethnicity. Males have a higher prevalence of colour blindness than females and Muslims tend to have a higher prevalence of colour blindness than other religions. There is no evidence to show that colour blindness impacts academic performance and ability to drive although it was found to affect quality of life. Colour blindness is managed through providing awareness, adjusting teaching methods at schools, providing counselling and using optical methods.

Conclusion: Colour blindness is a very serious problem that could affect children adversely, provisions should be made for colour blindness to be screened early in school children for better management.

TABLE OF CONTENTS

CHAPTER ONE: Introduction:

1.0 Introduction

Colour blindness, once referred to as Daltonism, stems from the lack of colour vision or perception and was discovered by David Brewster in 1798 [1]. Though discovered since 1798, many are unaware of how it came about, how it can affect our signals for detection and ways in which it can hamper our daily functions and future endeavours in life. This review study seeks to educate those affected and unaffected by colour blindness by highlighting its prevalence around the world and summarizing studies conducted concerning its cause, impact on academics, quality of life and methods of management. Each study has its strengths and weaknesses and they will be highlighted along with recommendations for the enhancement of future studies.

1.1 Background of study

Colour vision is the ability of the eyes to discriminate the different wavelengths of light by establishing its corresponding colour[2]. At the back of the eye, there are photoreceptors called cones. These cones are light sensitive pigments that allow for the perception of three wavelengths of light: short, medium and long, and they correspond to three particular colours: blue, green and red respectively. This aids in the detection of objects that we would perceive as we are able to tell the difference in the saturation and intensity of colour and perceive shadows and borders [3]. Colour blindness stems from the lack of colour vision and highlights the lack of the functioning of the eyes to see colour or perceive colour due to the loss of the different types of cones so there is an inability to see certain wavelengths of light. This can be broken down to a person lacking the ability to see specific colour, discriminating between colours and some unable to see any colour[4] .It is most often of genetic nature, but may also occur because of eye, nerve, or brain damage, or due to exposure to certain chemicals.

1.1.1 Causes of colour blindness

There are a number of ways in which someone can become colour blind and there are various factors that need to be considered and are responsible for colour blindness[5] .

Congenital Colour Blindness

This occurs when there is a mutation of combined genes inherited from both parents leading to the person being born colour blind. The arrangement of these genes forms the classes of colour blindness. This disorder is X-link recessive as it presents itself on the X chromosome of males and females. In that case, colour blindness can be congenital, and spans across the two major classes of red-green colour blindness and blue-yellow colour blindness[6]. Blue-Yellow colour blindness is a bit different from red-green colour blindness. It is a rare form of colour blindness and both men and women have an equal chance of getting this type of colour defect as the gene that it is found on cause's mutation of the chromosome 7 [7].

Acquired Colour Blindness

Despite the genetic disorder, colour blindness can be acquired as well. Primarily, persons can acquire colour blindness when there is a change in their chromosomes in the early developmental stage. Secondarily, colour blindness can be acquired as a result of diseases, trauma or injury[7]. It presents itself in various conditions where the retina is affected because of the disease or when there is some form of casualty that affects the cones directly or indirectly. It can also be in the form of ocular diseases like optic atrophy, retinal disorders etc [8-10]. Other causes of acquired colour blindness are drugs like digoxin (used in heart failure), ethambutol (used in tuberculosis), chloroquine (used in malaria treatment), hydroxychloroquine, phenytoin (used in treatment of epilepsy) and sildenafil or viagra (used in erectile dysfunction). Certain chemicals and pollutants such as carbon disulfide and styrene may also affect colour vision. In addition, aging also causes deterioration of colour vision[11].

1.1.2 Types or classification of colour blindness

When there is a lack of cone pigmentation, this causes a lack of colour perception. Primary colour can either be anomalous or anopia. This can be further broken up into dychromatopsia and achromatopsia. Dyschromatopsia refers to anomalous trichromacy or dichromacy. Anomalous trichromacy is expressed by three colour vision deficiencies. According to the National Eye Institute anomalous trichromacy branches into protanomaly, deuteranomaly and tritanomaly where there is a deficiency in red, green and blue cones respectively [12].

Dichromacy occurs when one of the cone pigments are non-functioning so an affected person would be unable to see that particular colour. Likewise, in dichromacy there can be protanopia, deuteranopia and tritanopia where there are non-functioning red, green and blue cones

respectively. Red-green colour blindness stems from dichromacy where the affected would experience the effects of either protanomaly or deuteranomaly[12].

Where there are effects of protanomaly objects that are red would look green and dull, however with effects of deuteranomaly objects that are green tend to look more red due to an imbalance of cone pigmentation. Total red-green colour blindness means that the affected would experience the effects of both protanopia and deuteranopia where they are unable to perceive or distinguish red and green coloured objects [12]. Red-green colour blindness is revealed to be the most common form of colour blindness.

Blue-yellow colour blindness also stems from dichromacy and is less common of the two. When affected, one would be unable to distinguish blue from green and yellow from red. They can either experience tritanomaly where there is difficulty in differentiating blue from green and yellow from red or tritanopia, differentiating between blue and green, purple and red and yellow and pink is almost impossible[12]. Any colour perception would also tend to look dull.

Achromatopsia, also referred to as Monochromacy, is the type of colour blindness where a person is unable to perceive any colour and would see objects in black and white[12]. This is very rare and often times the affected is unable to see clearly and is more sensitive to light due to the lack of cones in the fovea of the macula[12].

1.1.3 Methods of testing for colour blindness

There are a variety of colour vision tests that can be performed to help in the identification of these types of colour blindness. Some of these tests are the Ishihara plates test, Farnsworth D-15 colour vision test and the City University Colour Vision test to name a few. The more popularly used form of testing would be the Ishihara plates test which consist of 38 pseudoisochromatic plates and identifies red-green colour blindness. Each plate contains a number or line around a series of colourful dots. The booklet is held 75cm away from the patient and tilted so that the booklet is at a right angle to the views line of sight. The patient is asked to state what is on the plate within three seconds[6]. This is usually done binocularly but can sometimes be done monocularly if one suspects that the colour vision defect is acquired.

The Farnsworth D-15 colour vision test is a modified version of the Farnsworth-Munsell 100 hue test. It is mostly used as a screening test for colour vision and is made up of 15 coloured caps. The patient is asked to arrange the caps in order of their hues. They are given 1-2 minutes to do so. This test identifies a number of colour vision deficiencies[13].

Lastly, the City University colour vision test comprises of a booklet of coloured samples. There are four coloured samples on each page surrounding a sample at the centre of the page. The patient is asked to choose 1 of the coloured samples that would match the sample in the centre of that page. The booklet is held at 35cm away from the patient and they are given 3 seconds to respond. This test is used to identify protanopes, deuteranopes and tritanopes[13] .Other methods of colour vision tests not commonly used are Colour Vision Testing Made Easy (CVTME) [14] and Richmond Hardy-Rand-Rittler pseudoisochromatic test[15].

1.1.4 Advantages of testing colour vision

When persons are tested for colour blindness, there is now an ability for their colour blindness to be identified, classified and even graded; that is the only way the prevalence can be measured. With more awareness of colour blindness among children, parents become more aware and teachers are given the opportunity to make adjustments to their teaching methods to cater to their children and reduce their alienation in the classrooms. Counselling is advised for colour blind children along with their parents to give proper holistic guidance as they may face various problems throughout their life pertaining to their daily activities, possibly future jobs and the chance of genetic inheritance of their offspring in the future[16].

1.1.5 Impact of colour blindness on an individual

The impact of colour blindness varies in different individuals as it depends on the extent of colour blindness that they would be facing. Studies have shown that colour blindness could affect children's academic performance and career choice for employment. When colour vision deficiency is severe, the condition can have a significant impact on a person's life. When the deficiency is mild, on the other hand, the symptoms may often go unnoticed until colour vision is tested. Some of the ways in which deficient colour vision can affect a person's life include:

Restricted career options – Colour blind individuals are prohibited from certain professions that involve being able to differentiate between colours. Examples include careers where it is necessary to accurately interpret coloured signals or warnings such as careers in aviation, jobs that involve operating heavy machinery and transportation jobs. Artistic or creative occupations involving interior design, painting, or even cooking may also be difficult to pursue.

Limited driving rights – In some countries such as Romania, Turkey and Singapore, colour blind individuals are prevented from obtaining a driving license in case they are unable to see and recognize colour-coded traffic symbols, signals and warning lights. A colour vision

deficiency can impair a person's ability to read and interpret various diagrams and graphics such as maps, pie charts and slides used in presentations. Colour deficiency can also interfere with the interpretation of advertisements and graphics on websites. Special colour scheme generators are available that individuals can use to create a colour scheme that is easier to interpret.

Most colour blind individuals identify objects by their texture, shape and other features instead of their colour. In mild cases, individuals may be able to see a dulled version of a colour which can help them identify the colour to some extent. For many people, a colour is easier to identify if it is present over a large area rather than in the form of a line, which may simply appear as black.

1.2 Problem Statement

Currently, there may not be any treatment method for colour blindness but there is treasure in being knowledgeable and aware of this situation that children are put into. There are many disadvantages to being colour blind and there are many factors to be considered when it comes to hampering the lifestyle of a child. However, being knowledgeable about colour blindness can provide a better coping mechanism for the affected children. Parents and by extension teachers, when made more aware can be better equip and assist in the betterment of their lives, primarily in their academics and future careers. This study seeks to review studies conducted on colour blindness in order to know areas where more studies are needed to be done.

1.3 Aim of study

The purpose of this study is to systematically review studies on colour blindness.

1.4 Objectives of study

1. To determine the prevalence of colour blindness.
2. To ascertain the causes or factors responsible for colour blindness.
3. To understand the impact of colour blindness on academic performance.
4. To evaluate the implication and the impact of colour blindness on the quality of life.
5. To explain the methods of managing colour blindness.

1.5 Significance of study

1. This study will serve as a guide and reference for further studies.
2. It will also help create awareness to the public on the area where much needs to be done regarding CVD.

1.6 Delimitation of study

This review was delimited to studies on colour blindness, the causes, impact and methods of managing colour blindness.

CHAPTER TWO: Method

2.0 Introduction

This chapter reviewed the methodology used in this study including research design, study population, sample size, inclusion and exclusion criteria, and data collection procedure.

2.1 Research design

The research design used in this study was a systematic review. Systematic review is a type of literature review that uses systematic methods to collect secondary data, critically appraise research studies, and synthesize findings qualitatively or quantitatively [17]. Systematic reviews formulate research questions that are broad or narrow in scope, and identify and synthesize studies that directly relate to the systematic review question. They are designed to provide a complete, exhaustive summary of current evidence, published and unpublished, that is "methodical, comprehensive, transparent, and replicable.

2.2 Study population

This included all studies done in different parts of the world on colour blindness.

2.3 Inclusion criteria

Studies like cohort-case, experimental, cross-sectional and longitudinal research articles, and review papers on topics related to colour blindness that are specific to the prevalence, causes, implications and impact on the quality of life and methods of managing colour blindness published within the last 10 years.

2.4 Exclusion criteria

Researches on colour blindness that are related to its prevalence, causes, implications and impact on quality of life and methods of managing colour blindness that are not in English and or not published within the last 10 years.

2.5 Sample size

After using the electronic databases and sifting through a variety of reference lists and search engines on the world wide web using the key words such as colour blindness, colour vision, colour vision defect, impact, implication, quality of life, causes and prevalence, a total number of fifty-three (53) studies were retrieved. Two of the studies were duplicated and after removal, fifty-one (51) studies remained. Eighteen (18) of the chosen studies were removed because

they fell into the exclusion criteria. This review was inclusive of the remaining thirty-three (33) studies. Of the 33 studies, 13 journals were reviewed and 33 articles were drawn from it to use as the database for this review study. The 33 articles included different types of studies like cohort-case studies, experimental studies, cross-sectional studies, longitudinal studies and review studies as they covered the basis of the objectives of this study. A number of the articles came from journals covering medical and health-related research, for example International Journal of Medical and Health Research, Clinical and Experimental Optometry and Orphanet Journal of Rare Diseases to name a few.

2.6 Data collection procedure

The collection of data was done by firstly inputting various terms which included “Children with colour blindness”, “Prevalence of colour blindness”, “Impact of colour blindness”, “Acquired colour blindness” and “Management of colour blindness” into search engines like “Pubmed” and “Google Scholar” so that studies along the objectives of this review can be retrieved. Secondly, the studies were analysed according to the socio-demographic background of those affected by colour blindness and its prevalence in the various regions. The data were then categorized according to the causes, implications and impact on quality of life and method of managing colour blindness. Lastly, the studies were compared, contrasted and evaluated based on their results and new conclusions were made for the enhancement of future studies.

CHAPTER THREE: Results

3.0: Introduction

This chapter presented the results of studies on colour blindness done in different parts of the world according to the objectives.

3.1 Prevalence and Distribution of colour blindness

Ireland, Europe has the highest prevalence of colour blindness (5.4%), followed by North-West Ethiopia (4.3%) and Southern Ethiopia (4.2%) (Table 3.1.). Deuteranomaly was the most prevalent colour vision defect (Table 3.1.1).

Table 3.1: The Prevalence of Colour Blindness.

Authors	Year Study was done	Place of Study	Total Population Assessed	Age Range Assessed in years	Prevalence of Colour Blindness (%)	Prevalence of Colour Blindness (%)		Method of Colour Vision Testing
						Male	Females	
Xie et al[19]	2014	Southern California, North America	4005	1.54-3	1.6	1.5	0.1	CVTME & Waggonner HRR Diagnostic test
Pitchi Reddy et al[16]	2017	Andhra Pradesh, India	1629	10-15	1.9	1.7	0.2	Ishihara 38 plate edition
Agarwal & Bandsod[21]	2014	Pune, India	595	9-16	2.4	2.1	0.2	Ishihara 38 plate edition
Gupta et al[1]	2017	Southern Bhopal, India	738	11-15	2.6	2.3	0.3	Ishihara 38 plate edition
Thomas et al[22]	2018	Kuala Lumpur, Malaysia	1732	8-11	2.7	2.6	0.1	Ishihara 24 plate edition & Farnsworth D-15
Wale M et al[5]	2018	North-West Ethiopia	850	8-18	4.3	3.2	1.1	Ishihara 24 plate edition
Woldeamanuel & Geta[6]	2018	Southern Ethiopia	844	7-12	4.2	3.6	0.6	Ishihara 38 plate edition
Mashige & van Staden[14]	2019	Durban	1305	7-17	2.2	1.9	0.3	Ishihara 24 plate edition & CVTME
Oduntan et al[15]	2019	Lagos State, Nigeria	2326	7-22	2.5	2.1	0.4	Richmond-HRR
Harrington et al[20]	2020	Ireland, Europe	1626	6-13	5.4	4.6	0.8	Richmond-HRR

Tables 3.1.1 Distribution of Colour Blindness

Author	Place of Study	Method of Colour Vision Testing	Number of Colour Blind Persons	Type of Colour Blindness				
				Protan	Deuteran	Tritan	Unclassified (Combination of Protan and Deuteran)	Achromatopsia
Xie et al[19]	Southern California, North America	CVTME & Waggonner HRR Diagnostic test	63	20	32	0	11	0
Pitchi Reddy et al[16]	Andhra Pradesh, India	Ishihara 38 plate edition	31	28	3	0	0	0
Agarwal & Bandsod[21]	Pune, India	Ishihara 38 plate edition	12	9	2	0	0	0
Gupta et al[1]	Southern Bhopal, India	Ishihara 38 plate edition	19	13	6	0	0	0
Thomas et al[22]	Kuala Lumpur, Malaysia	Ishihara 24 plate edition & Farnsworth D-15	46	11	33	0	0	0
Wale M et al[5]	North-West Ethiopia	Ishihara 24 plate edition	36	7	15	0	14	0
Woldeamanuel & Geta[6]	Southern Ethiopia	Ishihara 38 plate edition	35	15	20	0	0	0
Mashige & van Staden[14]	Durban	Ishihara 24 plate edition & CVTME	29	10	19	0	0	0
Oduntan et al[15]	Lagos State, Nigeria	Richmond-HRR	58	17	38	0	3	0
Harrington et al[20]	Ireland, Europe	Richmond-HRR	87	16	48	5	17	1

3.2 Causes or factors responsible for colour blindness

There was a higher prevalence of colour blindness in Non-Hispanic Whites (36.5%) than Hispanics (27%) and Asians (22.2%) with the lowest prevalence being found in Blacks (14.3%). Males have a higher prevalence of colour blindness than females and Muslims tend to have a higher prevalence of colour blindness than other religions (Table 3.2).

Table 3.2 Causes or Factors Responsible for Colour Blindness

Author	Place of Study	Causes/ Factors	Population Assessed	Prevalence of colour blindness(%)			
Xie et al[19]	Southern California, North America	Ethnicity	4005	Black	Asian	Hispanic	Non - Hispanic White
				14.3	22.2	27	36.5
		Sex		Males		Females	
Xie et al[19]	Southern California, North America		4005	1.5		0.1	
Pitchi Reddy et al[16]	Andhra Pradesh, India		1629	1.7		0.2	
Agarwal & Bandsod[21]	Pune, India		529	2.1		0.2	
Gupta et al[1]	Southern Bhopal, India		738	2.3		0.3	
Thomas et al[22]	Kuala Lumpur, Malaysia		1732	2.6		0.1	
Wale M et al[5]	North-West Ethiopia		850	3.2		1.1	
Woldeamanuel & Geta[6]	Southern Ethiopia		844	3.6		0.6	
Mashige & van Staden[14]	Durban		1305	1.9		0.3	
Oduntan et al[15]	Lagos State, Nigeria		2326	2.1		0.4	
Harrington et al[20]	Ireland, Europe		1626	4.5		0.8	
		Religion		Muslim			
				Males		Females	
Shah et al[23]	Manipur, India			8.73		1.69	
Woldeamanuel & Geta[6]	Southern Ethiopia		844	2.6			

3.3 Impact of colour blindness on academic performance

Colour blindness impacts learning ability, with problems in mathematics and science as well as poor grades (Table 3.3).

Table 3.3: Impact of colour blindness on academic performance

Author	Year of Study	Impact on Academic Performance(Yes/No)	How Colour Blindness Impacted/Did not Impact
Chakrabarti[24]	2018	Yes	Slow Learning
Bailey[9]	2013	Yes	Problems in mathematics
Bailey[9]	2013	Yes	Problems in Sciences
Barry et al[25]	2017	Yes	Poor Grades
Ramachandran et al[26]	2014	No	Educational achievements

3.4 Impact and implications on quality of life

The quality of life of individuals affected with colour blindness are impacted in a variety of ways which include team sports, conversations that include the topic of colour, food choices, cooking and fruit ripeness. Their emotions are affected negatively, there is limitation of career choices, difficulty when completing tasks and the lack of appreciate for art and design. There is controversy as to whether their driving ability is affected by colour blindness. Implications are put in place for colour blind individuals like providing colour vision screenings in schools. Where employment is concerned, there are limited career choices but still access to jobs with risk of facing difficulties. Some jobs make accommodations for their colour blind employees (Table 3.4).

Table 3.4: Impact and the Implications of Colour Blindness on the Quality of Life

Impact/Implication due to Colour Blindness		Author	Year of Study
Impact			
Team Sports		Barry et al[25]	2017
Conversations that include colour		Barry et al[25]	2017
Food choices		Barry et al[25]	2017
Cooking		Barry et al[25]	2017
Fruit ripeness		Barry et al[25]	2017
Negative Emotions		Barry et al[25]	2017
Limited career choices		Barry et al[25]	2017
Difficulty completing tasks		Barry et al[25]	2017
Art/Design		Chakrabarti[24]	2018
Driving Ability	Impact	Chakrabarti[24]	2018
	Impact	Bailey[9]	2013
	No Impact	Pepple & Adio[27]	2014
Implications			
Limited career choices		Chakrabarti, Barry et al, Bailey[9,24,25]	2018, 2017,2013
Access to jobs with risks of difficulty		Barry et al[25]	2017
Colour vision screenings at schools		Wale M et al[5]	2018
		Mashige & van Staden[14]	2019
		Woldeamanuel & Geta[6]	2018
		Agarwal & Bandsod[21]	2014
		Harrington et al[20]	2020
		Chakrabarti[24]	2018
Accommodation in job place		"Business - Colour Blind Awareness"[29]	Not dated

3.5 Methods of managing colour blindness

Methods used to manage colour blindness were providing awareness about colour blindness, adjusting teaching methods at school to accommodate children with colour blindness and providing counselling for those affected with colour blindness. Two optical methods of filter spectacles and dyed contact lenses are also used to manage colour blindness (Table 3.5).

Table 3.5: Methods of Managing Colour Blindness

Author	Year of Study	Methods of Management
Gupta et al[1]	2017	Awareness
Gupta et al[1]	2017	Adjust teaching methods
Pitchi Reddy et al[16]	2017	Counselling
Gómez-Robledo et al[31]	2018	Filtered Spectacles
Badawy et al[33]	2018	Dyed Contact Lenses

CHAPTER FOUR: Literature review and discussion

4.0: Introduction

This chapter reviewed and discussed studies done in different parts of the world on colour blindness including the causes, implications and impacts of colour vision on quality of life and methods of managing colour vision defect

4.1 Global prevalence of colour blindness

Globally, there are approximately 300 million people with colour blindness, almost the same number of people as the entire population of the USA[18]. Colour blindness affects approximately 1 in 12 men (8%) and 1 in 200 (0.5%) women in the world. Studies showed that almost 6% of Caucasian boys had colour blindness, compared with 3% of Asian boys, almost 3% of Hispanic boys and less than 2% of African-Americans[6] .The most common form of colour blindness globally is red-green colour blindness because its cause is X-linked recessive.

There is a variation in the prevalence of colour blindness in the different geographical locations with the highest prevalence in Europe and lowest prevalence in North America. This can be due to racial or ethnic and religion differences.

4.1.1 Colour blindness studies in America

A school-based study[19] conducted in Southern California, North America on children between the ages of 37-72 months old using Colour Vision Test Made Easy (CVTME) plates and Waggonner HRR Diagnostic plates recorded a prevalence of 1.6% among the children. Of this 1.6% prevalence, 1.5% were males and 0.1% were females.

4.1.2 Colour blindness studies in Europe

In another study in Ireland among children 6 to 13 years old using Richmond Hardy-Rand-Rittler (HRR) pseudoisochromatic test a prevalence of 5.4% was recorded[20]. Of the 5.4%, 4.6% were males and 0.8% were females. Similar study[10] conducted on male population of Calabria, Southern Italy using the Farnsworth test along with the Ishihara test and City University test showed a high prevalence of tritanopia among males with Type 2 Diabetes. Most children had Dominant Optic Atrophy and tritanopia and cases of acquired colour blindness was also reported.

4.1.3 Colour blindness studies in Asia

Colour blindness prevalence was also recorded in various parts of Asia including India and Malaysia [1,16 ,21-22]. School-based studies conducted in India specifically Guntur City, Andhar Pradesh, Pimpru, Pune, and Southern Bhopal, Madhya Pradesh as well as Kuala Lunpur, Malaysia recorded prevalence of 1.9%, 2.0%, 2.6% and 2.7% respectively[1,16,21-22]. The Ishihara pseudoisochromatic colour vision test was used to assess all schools and the prevalence of colour blindness was significantly higher in males than females. Also in another study in Kuala Lumpur, Malaysia, the Farnsworth D-15 test was also used to assess colour vision and a higher prevalence was recorded in males than females. Variations in the findings could be due to the use of more than one colour vision test in some studies which could have increased the accuracy of testing and provided them with a lesser chance of missing any colour blind children. Also variations in the age groups assessed in the studies could have affected the results recorded too.

4.1.4 Colour blindness in Africa

School-based studies conducted in various parts of Africa including North-west Ethiopia[5], Amhara regional state, Wolkite, Southern Ethiopia[6], Durban, South Africa[14] and Lagos State, Nigeria[15] recorded prevalence of 4.2%, 4.1%, 2.2% and 2.5% colour blindness respectively with a significant higher prevalence in males than females. The Ishihara pseudoisochromatic plates was used in the studies in Ethiopia while in Durban and Lagos State, Nigeria studies Colour Vision Teste Made Easy (CVTME) and the Richmond-HRR were used. Variations could be due to the type of colour vision test done.

4.1.5 Distribution of colour blindness

Deuteranomaly was found to be the most prevalent form of colour blindness in the school-based studies conducted in North America, Europe and Africa [5, 6,14,15,19, 20]. Also a school-based study conducted in Kuala Lumpur, Malaysia recorded a higher prevalence of deutroanomaly too.[22] However, in school-based studies conducted in Andhra Pradesh, Pune and Southern Bhopal, India in Asia, a higher prevalence of protanomoly colour blindness than deuteranomoly was found[1, 16 , 21].

4.2 Causes or factors responsible for colour blindness

Colour blindness varies significantly according to ethnicity[19]. They recorded a prevalence of 1.6% colour blindness in a school-based study with populations of different races including Black, Asian, Hispanic and Non-Hispanic White subjects. Among the colour blind individuals,

14.3% were black, 22.2% were Asian, 27% were Hispanic and 36.5% were Non-Hispanic White. There was a lack of the breakdown of the predilection of colour blindness of the different races and ethnicities in a number of studies.[1, 5, 6, 16, 20, 21] More studies should seek to break down the colour blind individuals by race and ethnicity to see the correlation and make a more accurate statement concerning its relationship.

4.2.1 Relationship between sex and colour blindness

While colour blindness has a varying prevalence around the world, there is a prediction of the disease affecting more males than females because of the recessive trait linked to the X chromosome. Females are often carriers of the disease but with males having only one X chromosome they are more likely to have it. School-based studies conducted in different parts of North America, Asia, Africa and Europe showed that there is a higher prevalence of colour blindness in males than females despite the size of the population assessed [1, 5, 6,8,10,14,16,19, 22,

4.2.2 The relationship between religion and colour blindness

It was also observed that colour blindness is prevalent in young males and females within the Muslim faith due to consanguineous marriage among themselves. This is because there is not a variety of genes inherited by their offspring and that led to a spread of inherited colour blindness easily. A population-based study[23] conducted in the Muslim population of Manipur, India to assess colour blindness in males and females using the Ishihara pseudoisochromatic plates test showed that 8.73% of males and 1.69% of females were colour blind. Similar study in Southern Ethiopia, Africa recorded 45.9% Muslim population and there was a prevalence of 2.6% colour blindness in males and females[6].

4.3 To determine the impact of colour blindness on academic performance

Colour is introduced to students from a very young age and applied in various teaching methods. A Psychiatrist evaluated some of the psychosocial aspect of colour blindness and stated that colour blindness is often present in childhood and these children are labelled as slow learners causing them to lag behind in various subject areas [24]. Children have difficulty in subjects like mathematics due to coloured graphs and sciences which deal with chemical reactions or scientific outcomes like that of a litmus test used to teach principles[9] and that makes learning difficult for colour blind children. Also simple things like the use of coloured chalk on a white board can affect their understanding which could lead to poor grades[25].

On the contrary, a review study conducted stated that the level of educational achievement is not hampered by colour blindness and were in favour of discontinuing colour vision screening for school students[26]. It was concluded that there was no clear interrelation between academic performance and colour blindness because while some studies agree to a negative impact on academic performance, a number of studies disagree with this statement[24].

4.4 The implication and the impact of colour blindness on the quality of life

Studies showed that the quality of life of all colour blind patients are affected in some way or the other[25]. Children in "play age" are hampered when playing team sports as there will be difficulty in differentiating their team from their opposing team. By extension, children are turned off from joining conversations concerning anything regarding colours because they are embarrassed because they cannot relate. Their choice of food is also affected, as their food would tend to look unappetizing because of the lack of colour. These problems transgressed into their adolescent and adult lives and manifest in the larger scale of their lives in various ways. An online survey[25] conducted using both non-colour blind and colour blind individuals and devised a questionnaire to assess the quality of life of those with colour blindness and those without using an online Ishihara pseudoisochromatic plates test. Three aspects of their lives were assessed: quality of life for health & lifestyle, for work and for their emotions. Colour blind individuals scored lower in the three subscales of their quality of life than those with normal colour vision. In the quality of life for health and lifestyle aspect, they experienced a number of complications including not noticing when they are sunburnt or experiencing difficulty when taking colour coded medication. In the food and cooking aspect, they had difficulty in choosing groceries, understanding when food is fully cooked or even notice when a fruit is ripe. These could lead them to feel a range of negative emotions like anxiety, depression, humiliation or low self-esteem where colour is concerned. In their work life they could also be limited in career choices and experience difficulty completing tasks on their job places. Another study also showed that colour blindness could have a range of psychological and psychosocial effects on individuals.[24] For example the ability to match or differentiate colours when painting or even decorate a house or appreciate an art is crippled.

4.4.1 Impact of colour blindness on driving ability.

Safe driving involves the recognition of traffic signals, road signs and colour-coded lights. Studies revealed that colour blind individuals have problems in identifying these traffic signals and tend to have a slow response rate to these signals and need to be closer to the signs to better

understand them[24]. They also noted that there is a higher risk for rear-end collisions when there is lack of sensitivity to colours like red. Many persons think that they can adapt to colour-coded traffic lights because of its position unknown to the fact that in larger cities and other countries traffic lights are not universal.[9] It was suggested that the traffic light should be hung horizontally as opposed to vertically and there should be three-five different signals shown on it at once in order to help colour blind persons.

A population-based study conducted in Nigeria, Africa to assess the visual function of drivers and its relationship to road traffic accidents using Ishihara pseduoisochromatic plates recorded a prevalence of 4.5% for colour blindness[27]. Of the 18 persons detected with colour blindness, 10 had experienced road traffic accidents. However, the colour vision defects were not found to be statistically significant in the causes of the road traffic accidents due to the subjects also having other visual anomalies like glaucoma, cataract and presbyopia. This study did not specify the other visual anomalies that each colour blind subject had and did not specify the type of colour blindness that they possessed but concluded that it did not significantly impact the cause of road traffic accidents.

4.4.2 Implications in terms of employment for colour blind children

An online survey conducted in the UK found that when children are colour blind, as they grow into adults, there is restriction in career choice and this limits their means of employment because of the level of difficulty that they can face according to their level of colour blindness[25]. Some of these career choices that are limited for colour blind individuals were highlighted[24]. They include the armed forces who rely on colours for signalling and even regarding sciences ranging from chemists to medical practitioners. This is because there is said to be a reduction in precision where safety and quality assurance on the jobs places are concerned. Occupations like those involved in transport, particularly aviation which is prohibited for practice of colour blind individuals, electronic and electric industries exclude persons that have colour blindness because of the high risk that these companies would be taking for their mandates to be fulfilled [9,24,28]. The authors explained that those with severe forms of colour blindness would have poor performance on the job and fail to complete certain tasks but there is equal opportunity for employment and even stretched to say that various occupations may have relaxed their requirements regarding colour vision standards. Because there is not much literature on this topic there was no evidence that colour blind people are restricted from employment in any chosen field[24]. Some school-based studies conducted in North-West and Southern Ethiopia,

Durban Africa, Pune India and Ireland Europe, stated that generally, precaution should still be taken in order to make children with colour vision defect aware of this disability[5,6, 14, 20-21,24].They concluded that colour vision screening should be put in place in the school system to not only make the children, their parents and the teachers aware but to give them better guidance for future. There are means for employers to accommodate their colour blind customers and employees by avoiding colour-coding in charts for example and use a non-colour coded alternative where possible[29].

4.5 Methods of managing colour blindness

Currently, there is no treatment method to cure colour blindness but there are several ways to manage it. A school-based study[1] conducted in Southern Bhopal, India concluded that with more awareness of colour blindness among children, teachers are given the opportunity to make adjustments to their teaching methods to cater to their children and reduce their alienation in the classroom[1]. Another study conducted in Andhra Pradesh, India advised that counselling should be given to the colour blind children along with their parents to give proper holistic guidance as they may face various problems throughout their life pertaining to their daily activities, possibly future jobs and the chance of genetic inheritance of their offspring in the future[16].

In addition, studies have shown that the use of coloured filters and contact lenses can assist in distinguishing some colour combinations[30]. Scientist at the University of Granada stated that the colour filtered spectacles do not help colour blind persons to see colours like normal colour vision[31-32]. Companies like Enchroma provide these spectacles but when evaluating the effectivity of the glasses they realised that it was not guaranteed to work on all colour blind individuals as there is a limitation to red-green colour blindness and was not effective when there is severe colour blindness and in some cases even mild colour blindness[31]. This is because the colour corrective spectacles filter out a narrow range of wavelength of approximately 545-575nm[31].

Dyed contact lenses were also recommended to be used to provide slight enhancement of colour perception for those that are affected by colour blindness and those that are not but persons that are colour blind will not have comparable colour enhancement to normal colour vision[33]. The dyes used for these contact lenses were nontoxic to human corneal fibroblasts and human corneal epithelial cells reducing the level of risk for use. Due to its customizability, low

cost of the dye, and the ease of the production process, the dyed contact lenses give a measure of hope for the management of colour blindness.

CHAPTER FIVE: Conclusion, Limitations and Recommendations

5.1 Conclusion

In conclusion, colour blindness was systemically reviewed and it was highlighted that colour blindness is prevalent around the globe, with the highest prevalence in Ireland, Europe and lowest prevalence in Southern California, North America. Deuteranomaly was found to be the most prevalent type of colour blindness. The causes or factors responsible for colour blindness were race/ethnicity, gender and religion. Colour blindness was most prevalent in Non-Hispanic whites and least prevalent in Blacks. There was a significantly higher prevalence of colour blindness in males compared to females and in the Muslim religion due to consanguineous marriages. There was no conclusion regarding the impact of colour vision defect on academic performance although it was found to affect learning, the ability to play team sports, cook, and choose food as well as emotions. There is contradictions as to whether driving ability, career choice and employment are affected by colour blindness. Optical methods of managing colour vision defect were the use of filtered spectacles and dyed contact lenses for colour vision enhancement.

5.2 Limitation of study

- The lack of literature in this research area in many regions which include Asia, Australia, Oceania and the Caribbean. An example of this would be that in the continent of Asia, majority of studies were conducted in India and Malaysia rather than the other areas of Asia so the accuracy of a statement of colour blindness in Asia would be limited to India and Malaysia rather than the entire continent.
- There are no studies based on colour blindness in the Caribbean and a lack of studies in the continent of Australia and Oceania so there is not an accurate estimate of global prevalence of colour blindness. In some studies, there was a lack in the measurement of the demographics of those tested so an accurate value of males to females assessed, race and ethnicity were not collected.
- There was no standard data collection method for all studies; various colour vision test were used in different regions and many of these colour vision tests are only subject to certain types of colour blindness. For example, the Ishihara pseudoisochromatic plates test assess red-green colour blindness and increases the predilection of one or two types of colour blindness more than another However, the Richmond-HRR test would assess protanopia, deuteranopia and tritanopia. In a number of studies, after an individual was

said to be colour blind using one type of colour vision test, they were not retested with another more sensitive colour vision test to confirm the results.

5.3 Recommendations

Some recommendations can be made for the enhancement and accuracy of studies in the future. They include:

- Studies should be conducted in South America, Australia, Oceania and the Caribbean as well as in parts of Asia, Africa, North America and Europe where there is a lack of research on colour blindness.
- When studies are being conducted, they should include more of the demographic information of the subjects being analysed like religion, race and ethnicity so that there can be a comparison or contrast when the data is collected and a conclusion can be made as to whether there is any relation between those demographics and colour blindness.
- Further studies should include magnitude and severity of colour blindness
- A longitudinal study should be done on individuals who were said to have any form of colour blindness to get an idea as to how they managed their colour blindness using the methods of management that are available and measure the effectivity of the methods.
- Colour vision screenings are recommended to be put in schools as a measure to create awareness in order to reduce the impacts on quality of life.
- Awareness on methods of managing colour blindness should be made and materials for the management made available and affordable.

References:

1. Gupta S, Saxena S, Gupta S, Saxena R, Sharma S. The prevalence of colour blindness in middle school student of southern Bhopal. International Journal of Medical and Health Research [Internet]. 2017 [cited 25 May 2020];3(5):111-113. Available from: http://www.medicalsciencejournal.com/download/449/3-5-66-356.pdf .

2. Colour Vision | Encyclopedia.com [Internet]. Encyclopedia.com. [cited 11 June 2020]. Available from: https://www.encyclopedia.com/science/dictionaries-thesauruses-pictures-and-press-releases/colour-vision

3. Colour | Encyclopedia.com [Internet]. Encyclopedia.com. 2020 [cited 27 May 2020]. Available from: https://www.encyclopedia.com/science-and-technology/astronomy-and-space-exploration/astronomy-general/colour

4. Turbert D, Mendoza O. What Is Color Blindness? [Internet]. American Academy of Ophthalmology. 2019 [cited 27 May 2020]. Available from: https://www.aao.org/eye-health/diseases/what-is-color-blindness

5. Wale M, Abebe Y, Adamu Y, Zelalem A. Prevalence of color blindness among school children in three primary schools of Gish –Abay town district, Amhara regional state, north-west Ethiopia. BMC Ophthalmology [Internet]. 2018 [cited 27 May 2020];18(1). Available from: https://bmcophthalmol.biomedcentral.com/articles/10.1186/s12886-018-0970-4

6. Woldeamanuel G, Geta T. Prevalence of color vision deficiency among school children in Wolkite, Southern Ethiopia. BMC Research Notes [Internet]. 2018 [cited 27 May 2020];11(1). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6263558/

7. Color Blindness Facts & Statistics: Prevalence [Internet]. Color Blindness. [cited 11 June 2020]. Available from: https://www.colour-blindness.com/general/prevalence/

8. Lenaers G, Hamel C, Delettre C, Amati-Bonneau P, Procaccio V, Bonneau D et al. Dominant Optic Atrophy. Orphanet Journal of Rare Diseases [Internet]. 2012 [cited 27 May 2020];9(7):46. Available from: https://pubmed.ncbi.nlm.nih.gov/22776096/

9. Bailey J. Color Blindness: Psychological Effects [Internet]. Sites.psu.edu. 2013 [cited 27 May 2020]. Available from: http://sites.psu.edu/jessikabailey/wp-content/uploads/sites/19553/2014/10/Psychological-Research-Paper_Color-Blindness_Bailey-Jessika.pdf

10. Piro A, Tagarelli A, Lagonia P, Nicoletti G, Quattrone A. Color vision study to assess the impaired retina-brain cortex pathway in type 2 diabetes: a pilot study in Calabria (Southern Italy). Neurological Sciences [Internet]. 2019 [cited 27 May 2020];40(9):1939-1942. Available from:https://pubmed.ncbi.nlm.nih.gov/31054066/?from_term=acquired+colour+blindness+in+diabetics&from_filter=ds1.y_10&from_pos=4

11. Mandal A. Color Blindness Prevalence [Internet]. News-Medical.net. 2019 [cited 10 June 2020]. Available from: https://www.news-medical.net/health/Color-Blindness-Prevalence.aspx

12. Types of Color Blindness | National Eye Institute [Internet]. Nei.nih.gov. [cited 27 May 2020]. Available from: https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/color-blindness/types-color-blindness

13. Dahal H. Colour vision examination [Internet]. Slideshare.net. 2017 [cited 6 June 2020]. Available from: https://www.slideshare.net/hiranathdahal/colour-vision-examination

14. Mashige K, van Staden D. Prevalence of congenital colour vision deficiency among Black school children in Durban, South Africa. BMC Research Notes [Internet]. 2019 [cited 27 May 2020];12(1). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6558866/

15. Oduntan O, Mashige K, Kio F. Colour vision deficiency among students in Lagos State, Nigeria. African Health Sciences [Internet]. 2019 [cited 27 May 2020];19(2):2230. Available from: https://www.ajol.info/index.php/ahs/article/view/189175

16. Pitchi Reddy A, Babu G, Prasad K. Prevalence of Colour Blindness in School Children in Guntur City, Andhra Pradesh. Colour Blindness in School Children [Internet]. 2017 [cited 27 May 2020];4(11):2266-2268. Available from: https://www.ijcmr.com/uploads/7/7/4/6/77464738/ijcmr_1751_v1.pdf

17. Siddaway A, Wood A, Hedges L. How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses. Annual Review of Psychology [Internet]. 2019 [cited 14 June 2020];70(1):747-770. Available from: https://pubmed.ncbi.nlm.nih.gov/30089228/

18. Birch J. Worldwide prevalence of red-green color deficiency. Journal of the Optical Society of America A [Internet]. 2012 [cited 27 May 2020];29(3):313. Available from: https://www.osapublishing.org/josaa/abstract.cfm?uri=josaa-29-3-313

19. Xie J, Tarczy-Hornoch K, Lin J, Cotter S, Torres M, Varma R. Color Vision Deficiency in Preschool Children. Ophthalmology [Internet]. 2014 [cited 27 May 2020];121(7):1469-1474. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4839481/

20. Harrington S, Davison P, O'Dwyer V. Prevalence of colour vision deficiency in the Republic of Ireland schoolchildren and associated socio-demographic factors. Clinical and Experimental Optometry. 2020;. Available from: https://pubmed.ncbi.nlm.nih.gov/32285548/

21. Agarwal S, Bansod N. Prevalence of Colour Blindness in School Children. International Journal of Science and Research (IJSR) [Internet]. 2014 [cited 27 May 2020];7(4):175-177. Available from: https://pdfs.semanticscholar.org/6ba6/98fd889c049e5c44647adfef113343fe7ea1.pdf

22. Thomas B, Kaur S, Hairol M, Ahmad M, Wee L. Behavioural and emotional issues among primary school pupils with congenital colour vision deficiency in the Federal Territory of Kuala Lumpur, Malaysia: A case-control study. F1000Research [Internet]. 2018 [cited 27 May 2020];7:1834. Available from: https://f1000research.com/articles/7-1834/v1

23. Shah A, Hussain R, Fareed M, Afzal M. Prevalence of Red-Green Color Vision Defects Among Muslim Males and Females of Manipur, India. [Internet]. 2013 [cited 28 May 2020];42(1):16-24. Available from: https://pubmed.ncbi.nlm.nih.gov/23515069/?from_term=prevalence+of+red-green+colour+vision+defects+in+muslims&from_filter=ds1.y_10&from_pos=1

24. Chakrabarti S. Psychosocial aspects of colour vision deficiency: Implications for a career in medicine. The National Medical Journal of India [Internet]. 2018 [cited 28 May 2020];31(2):86-96. Available from: http://www.nmji.in/article.asp?issn=0970-258X;year=2018;volume=31;issue=2;spage=86;epage=96;aulast=Chakrabarti

25. Barry J, Mollan S, Burdon M, Jenkins M, Denniston A. Development and validation of a questionnaire assessing the quality of life impact of Colour Blindness (CBQoL). BMC Ophthalmology [Internet]. 2017 [cited 28 May 2020];17(1). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5625603/

26. Ramachandran N, Wilson G, Wilson N. Is screening for congenital colour vision deficiency in school students worthwhile? A reviewa. Clinical and Experimental Optometry [Internet]. 2014 [cited 28 May 2020];97(6):499-506. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/cxo.12187

27. Pepple G, Adio A. Visual function of drivers and its relationship to road traffic accidents in Urban Africa. SpringerPlus [Internet]. 2014 [cited 27 May 2020];3(1). Available from: https://springerplus.springeropen.com/articles/10.1186/2193-1801-3-47

28. Colour blindness in the classroom : Fizzics Education [Internet]. Fizzics Education. [cited 28 May 2020]. Available from: https://www.fizzicseducation.com.au/articles/colour-blindness-in-the-classroom/

29. Business - Colour Blind Awareness [Internet]. Colour Blind Awareness. [cited 29 May 2020]. Available from: http://www.colourblindawareness.org/business/

30. Treatment - Colour Blind Awareness [Internet]. Colour Blind Awareness. [cited 29 May 2020]. Available from: http://www.colourblindawareness.org/colour-blindness/treatment/

31. Gómez-Robledo L, Valero E, Huertas R, Martínez-Domingo M, Hernández-Andrés J. Do EnChroma glasses improve color vision for colorblind subjects?. Optics Express [Internet]. 2018 [cited 29 May 2020];26(22):28693. Available from: https://www.osapublishing.org/oe/abstract.cfm?uri=oe-26-22-28693

32. Scientists debunk the effectiveness of EnChroma glasses for colorblind people [Internet]. Phys.org. 2018 [cited 29 May 2020]. Available from: https://phys.org/news/2018-10-scientists-debunk-effectiveness-enchroma-glasses.html

33. Badawy A, Hassan M, Elsherif M, Ahmed Z, Yetisen A, Butt H. Contact Lenses for Color Blindness. Advanced Healthcare Materials [Internet]. 2018 [cited 29 May 2020];7(12):1800152. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6691754/