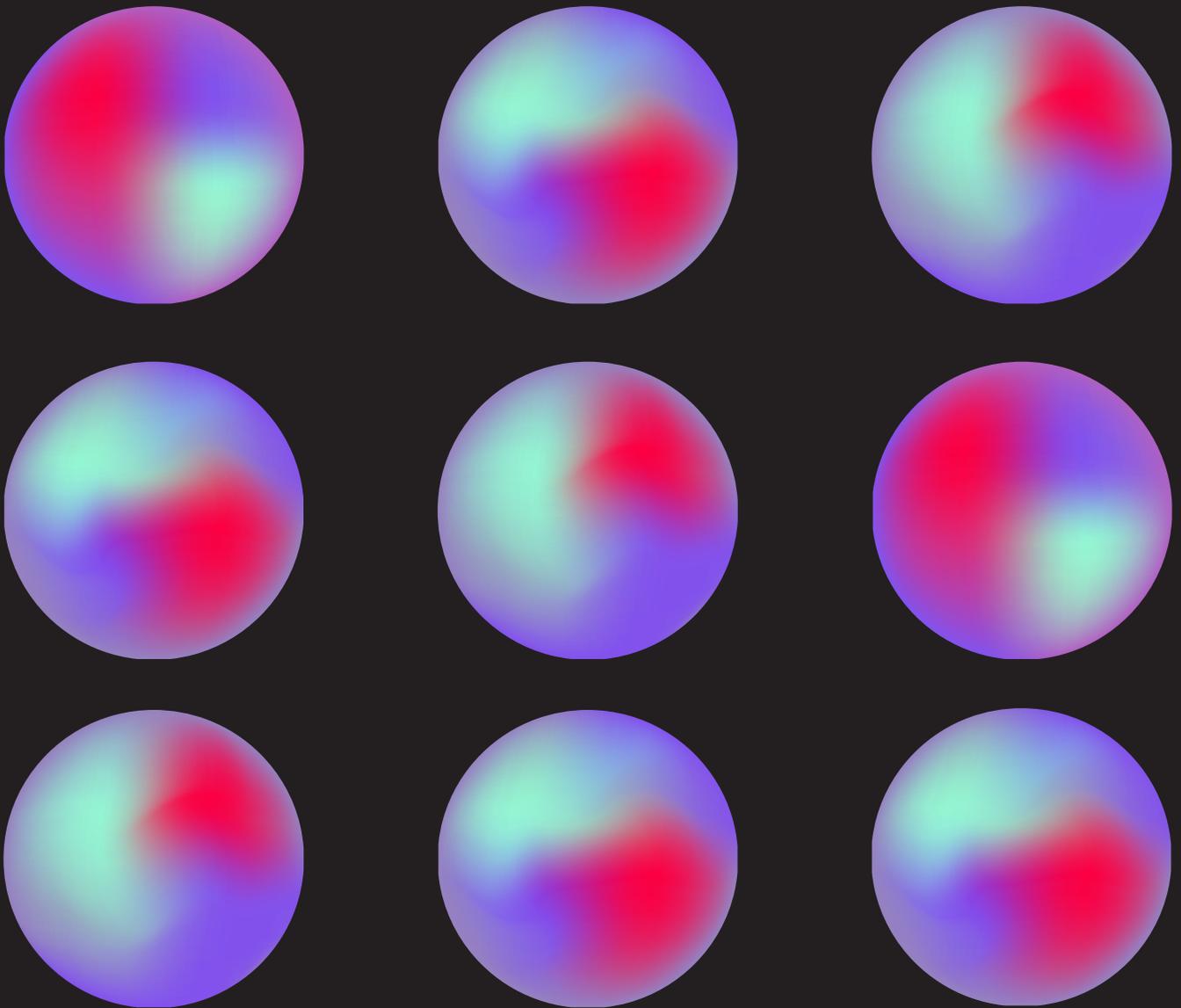


AN
INVESTIGATION
INTO
INCLUSIVE
DESIGN
FOR

COLOUR VISION DEFICIENCY



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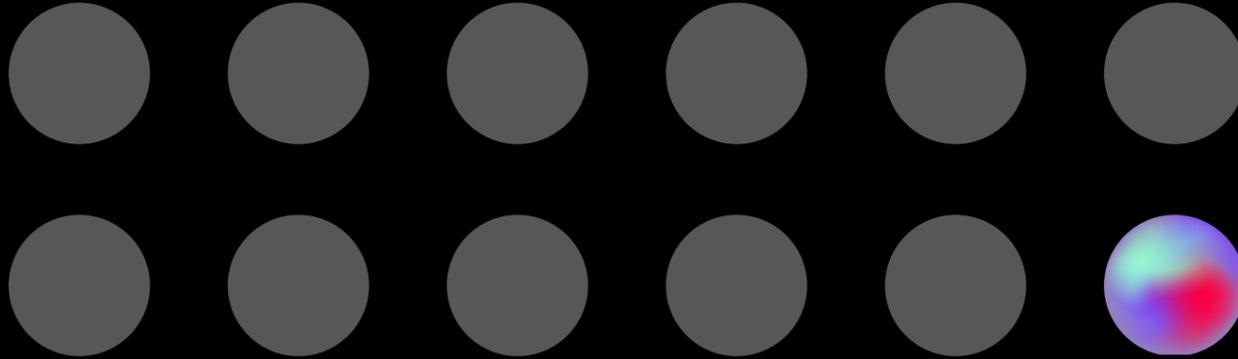
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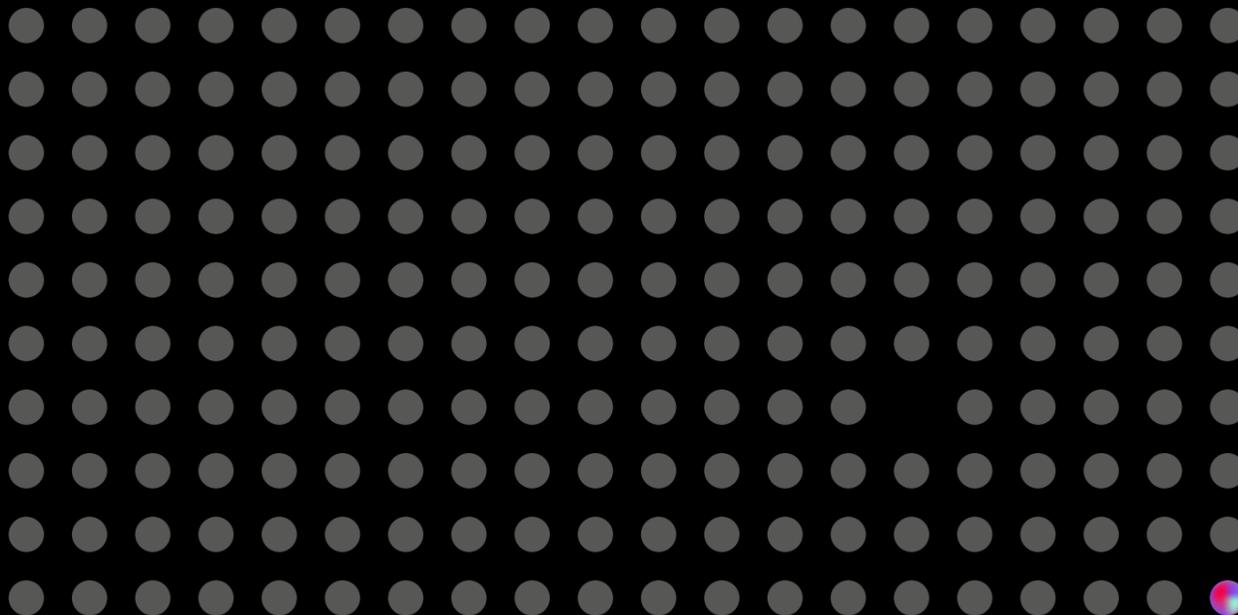
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INTRODUCTION

1 in 12 Males



1 in 200 Females



Colour is ubiquitous and it plays an important design element to convey information and transmit messages across through various communication platforms. Moreover, with technological advancements continuously evolving in today's society, this means that we as human beings are constantly being exposed to new types of information and new knowledge every single day. But does everyone acquire knowledge and perceive visual communication equally and in the same way?

According to Colour Universal Design Organisation (2006), In Europe and the US, 1 in 12 males and 1 in 200 females are experiencing colour blindness or colour vision deficiency (CVD). This leads to a total of over 10 million people in the US and around 2 million people in the UK. Because of this, it is often challenging for this demographic to read and understand certain information since most of the systems are designed for people who can distinguish colours (Lee et al, 2020). This means, there are approximately 200 million people who potentially do not receive equal access to information.

Even though Barry et al (2017) claimed since only around 5% of the world population are affected by CVD, therefore, its impact on everyday life is not generally considered a topic of importance. Another reason why the condition remains an unnoticed problem is also that people are not aware of their CVD conditions (Munawar et al, 2018). However, according to The Colour Blind Awareness Organisation, this number might seem insignificant but this subject is crucial for designers. This is because designers must consider and ensure that people with CVD are not excluded from the information as any information provided by colours alone can potentially alienate this group of demographic (The Colour Blind Awareness Organisation).

Therefore, this subject needs to be explored further to measure the extent of the issues faced by those with colour vision deficiency and whether designers should adopt design practices to ensure that there is a degree of accessibility and inclusivity for this demographic.

200 million

are potentially inheriting colour vision deficiency.

4.2 Million

Canada

7.8 Million

Great Britain

1.8 Million

Russia

1.7 Million

China

1.3 Million

Mexico

10 Million

United States

9 Million

Australia

Colour Vision Deficiency in
Different Countries.

AIMS AND OBJECTIVES

Aim 1:

To understand the term colour vision deficiency (CVD).

Objective 1:

Secondary research methods such as scientific insight reports and publications will be utilised to ensure a degree of reliability.

Aim 2:

To explore the importance of colour function and colour connotations.

Objective 2:

Secondary research will be used to explore how colours are being employed to convey information and create emotional responses.

Aim 3:

To recognise the effects of CVD on various disciplines of visual communication.

Objective 3:

Secondary will be utilised to explore different perspectives and investigate various experiences. Surveys will be conducted to gain in-depth insights about challenges people with CVD experience.

Aim 4:

To measure designers' awareness regarding CVD.

Objective 4:

Surveys will be carried out to find out about designers' general knowledge surrounding CVD. This will allow problems and misconceptions regarding the topic to be further analysed.

Aim 5:

To find out whether supports are currently available to assist people with CVD.

Objective 5:

Interviews will be conducted to analyse whether professional advice from the optometrists is available to the public.

Aim 6:

To evaluate whether design can be pushed beyond using colours.

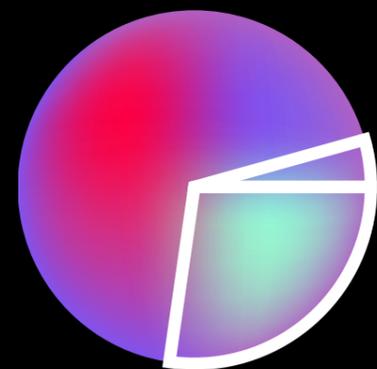
Objective 6:

Secondary research will be used to evaluate possible design solutions that can be adopted to help this demographic.

METHODOLOGIES

Surveys refer to a research method which involves a process of collecting and gathering data from a sample group of demographic. In this report, a survey was conducted and divided into the following sections:

- The impacts of CVD.
- Society's awareness and misconceptions about CVD.
- Designers' awareness and knowledge of CVD.



68.8%

Not colourblind

27.1%

Colourblind

4.1%

Do not know

Overall, 48 people have responded to the survey in which 41% were males and 59% were females. The age range from 17-71 years old and out of all the respondents, 27% were colourblind and were males. While 73% were not colourblind and the majority were females.

Secondary research refers to a method that involves using already existing data. This report utilised the following secondary research methods to gain insights and explore different perspectives regarding CVD:

- Articles
- Journals
- Insight reports
- Publications
- News articles

Interviews refer to a qualitative research technique that involves collecting and gathering data from individuals in order to explore their perspectives to gain deeper insights. In this report, a structured interview technique was implemented so that the contrast of answers given to the same questions can be compared.



Image: (Kurnaz, 2017)

DISCUSSIONS

WHAT IS CVD?

According to the NHS (2019), CVD or also known as colour blindness refers to the inability to differentiate certain shades of colours due to the perceptions of colours getting affected.

The cone cells in the retina act as an input to help our brain determine the colour perception. There are three types of cones that see and detect colours: red, green and blue. These three receptors interact with each other to form and combine any visible colours in the spectrum. The functions of these three receptors result in trichromatic theory or also known as a normal colour vision in humans in which this allows humans' brains to interpret and perceive up to over 100 million shades of colours (Turbert, 2019). However, not everyone can see up to these significant shades of colours as CVD occurs because one or more of these receptors or colour the cone cells "are absent, not working

or detect a different colour than normal" (Turbert, 2019). Because the severity of the conditions depend on how the receptors in the cone cells are affected, therefore, the common misconception of "individuals with CVD can only see in black and white" found when conducting the survey suggests that there is a lack of awareness and knowledge about CVD within the society. Furthermore, this shows that CVD is a condition that is currently being misunderstood by normal trichromats (people with normal colour vision). In addition, Rauch (2017) explained that the condition where individuals can only see the world in grayscale is the most severe condition called monochromacy or achromatopsia and this condition is significantly rare. This is the reason why it only affects 1 in 30,000 people which is a very small percentage when compared to how common other forms of CVD occur (BBC Bitesize).

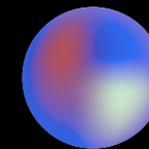
Deuteranomaly:

Green-deficiency. Difficult to distinguish green as it looks redder.



Protanomaly:

Red-deficiency. Difficult to distinguish red as it looks greener and less bright.



Protanopia and Deuteranopia:

Unable to tell the difference between red and green at all.



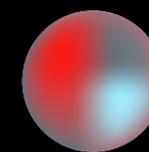
Tritanomaly:

Difficult to tell the difference between blue and green, and between yellow and red.



Tritanopia:

Unable to tell the difference between blue and green, purple and red and yellow and pink. Colours look less bright.



Achromatopsia

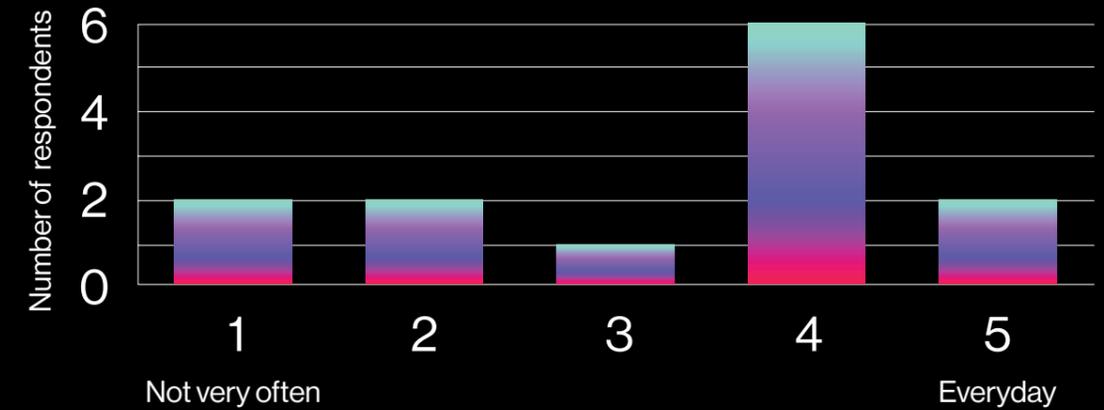
Or Monochromacy: Individuals lose their colour vision completely and can only see in black and white.



WHO IS AFFECTED BY CVD?

CVD is one of the world's most common genetic conditions that affects more males than females because CVD is mainly carried on the X-chromosomes. Males only have one X-chromosome whereas females have two X-chromosomes. This means that a female must inherit CVD on both of their X-chromosomes in order to experience the condition (The Colour Blind Awareness, 2018). CVD can also be acquired through conditions such as ocular disease or injury or disease of the retina by trauma, chronic diseases, drugs, toxins, alcoholism and ageing (Wale et al, 2018). However, these acquired conditions are much less common. Wale et al (2018) further expressed that even though CVD "is not physically debilitating, but it can still have a major impact on one's day-to-day life". (Wale, 2018).

On a scale of 1-5, how often do colour-related problems occur?



This is the reason why 55% of those with CVD that responded to the survey have admitted that colour-related problems exist constantly in their day-to-day lives. The common everyday tasks found in the survey are:

- Reading charts, maps and infographics
- Picking colours for the furniture
- Matching clothes
- Setting up monitors
- Fixing wires within electronic instruments
- Identifying ripe fruit and cook meat
- Buying food in supermarkets
- Identifying the signals and signage when driving
- Keeping up in the classroom environment

“People decide whether or not they like a product in 90 seconds or less. 90% of that decision is based solely on colours.”

To truly measure the extent of the issues faced by people with CVD, it is crucially important to understand how colours are being utilised to create meanings and convey information. Individuals with CVD stated in the survey that CVD would not be considered a problem “if colour-coding systems are not being implemented for example, why only red and green are being used as signals for everything from flying planes to fixing wiring electrics?”. They also believed that “if other combinations of colours are being utilised instead such as blue and yellow, the term CVD would not exist”. The response shows that this demographic felt excluded from society. Therefore, a question of whether utilising other colour-coding systems would have any impact and would be successful in the long term needs to be analysed.

According to Lee et al (2020) colour can be used to serve a variety of important functions and colour is a powerful non-verbal form of language that serves communication between humans and their surroundings.

“People decide whether or not they like a product in 90 seconds or less. 90% of that decision is based solely on colours.”
(Decker, 2017)

Decker (2017) explained that colour selection is often a critical factor which influences whether a design is successful or not. Because of this, designers employ colour as a strong tool to impact, engage and influence impact viewers' perceptions.

COLOUR FUNCTION

Several researchers discussed the various functions of colour and how it plays the role within the design (Lee et al, 2020). Portillo and Dohr's theory focused on the five important functions of colour and what designers should consider when conducting colour planning:

- **Composition:** space within Interior design
- **Communication:** colour meanings and colour interpretations
- **Preference:** subjective views that affect the design process
- **Response:** human behavioural responses are influenced by colour
- **Pragmatics:** practical situations such as resource constraints, preconditions, maintenance and sustainability must be considered when conducting colour planning.

(Lee et al, 2020)



Image: (Lam, 2018)

Kim discussed the eight functions of colour in visual communication:

- **Safety:** colour can be used to signify danger and alert physical hazards
- **Identification:** colour can be used as a tool to distinguish and highlight objects or information.
- **Aesthetic:** colour can be used to evoke feelings and emotions.
- **Symbolic:** colour can be used to convey symbolism and meanings.
- **Physical, physiological-psychological, and therapeutic:** colour can be used to improve emotions, health and well-being.
- **Camouflage:** changing colour to create protection by blending into the environment.

(Lee et al, 2020)

Designers must consider these functions of colour and carefully consider them in the colour planning process. This is because appropriate functions of colour must be utilised depending on the specific target audience or discipline of design since each one serves different purposes.

From this, the most crucial functions for CVD can be identified. It can be determined that safety, identification and symbolism are the top essential functions when designing for CVD. This is because safety is a vital function to be considered in order to avoid accidents. Information needs to be communicated clearly and easily to avoid confusions through identification function. As well as information should serve meaningful and purposeful messages through the use of symbolism.

COLOUR CONNOTATIONS



According to Oxford Reference (2016), colours can have different connotations for different audiences. This is because many influences affect how people perceive colours. Therefore, designers need to be aware of colour meanings so that they can use appropriate colours for a specific target audience.

Factors such as psychological effects, biological condition and cultural developments can affect the meanings of colours (Lundberg, 2020). Colour meanings generated from cultural and contemporary context are not universal, because of this, the same colours can evoke different emotions. However, some colours are universally recognised due to the natural associations or occurrences of colours in nature. As such, these colours are being utilised within public spaces to create a common understanding among a wide range of audience. The two common universal colours are red and green, the two colours that are difficult to be distinguished by red-green colour deficient.

The reasons why these two colours are universally recognised is because red is associated with heat or fire, therefore, it is being used to stimulate people to make quick decisions, evoke erotic feelings and indicate danger. In contrast, green universally represents nature and growth. This is why green, opposed to red is being used to convey safety.

However, Lundberg (2020) conveyed yellow as a colour that grabs attention and “can be used to signify caution, like red and orange”. Lundberg (2020) also conveyed blue as a colour that represents nature and responsibility. Since the connotations for both yellow and blue are very similar to red and green, it can be argued that there is a possibility in which blue and yellow can be used instead in order to accommodate people with CVD. But the adaptation can be difficult since this will mean that the other 90% of audiences would have to adapt and alter their systems completely. This will not be feasible in the long term because the alterations will create confusion among the vast majority of people since the universal colour systems (like red and green) are already deeply embedded in people’s psyche.

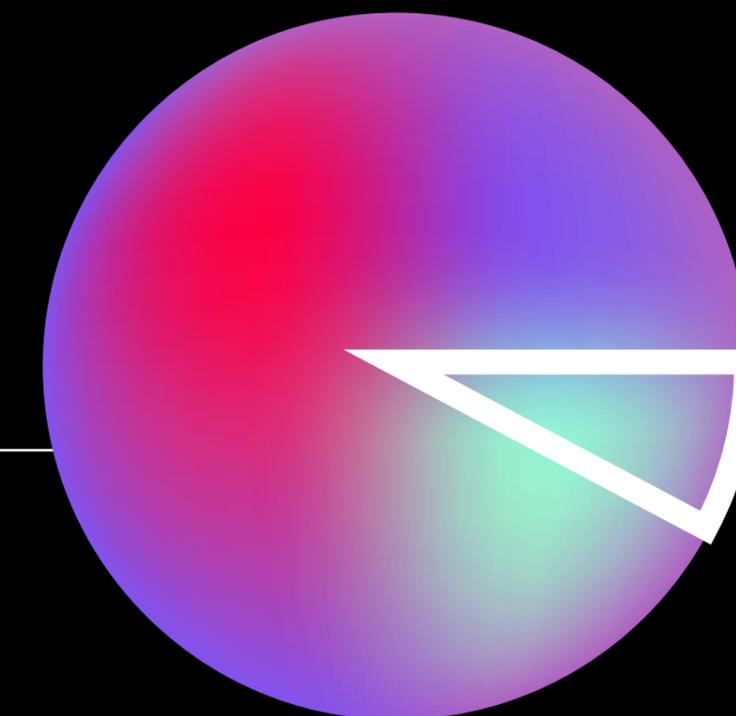
Therefore, it might not be possible to alter the colour-coding systems completely since visual communication still has to be understandable for 90% of those without CVD. However, it can also be argued that since designers still require carefully selecting appropriate colours even when designing for the vast majority of people, this means, taking CVD into an account will not affect the timeline of their design processes.

IMPACTS OF CVD ON WAYFINDING AND SIGNAGE

The Society for Experiential Graphic Design (SEGC) defined wayfinding and signage as information systems that guide and navigate people through a physical environment. However, people with CVD claimed that current wayfinding and signage exhibited some challenges (Lee et al, 2020). This is because certain combinations of colours applied to wayfinding and signage are difficult to be distinguished. Lee et al (2016) stated further that this demographic struggles with both internal and external wayfinding, for example, difficulty interpreting GPS maps, coloured bus routes, campus maps and stop signs. In addition, some individuals cannot distinguish the colours of traffic lights and road signs due to a lack of contrast.

Mulligan (2019) further expressed that the reasons why driving a car can be difficult for people with CVD is because green light appears pale while red appears similar to orange. This is the reason why they rely on the traffic lights' positions rather than the actual colours represented. Cole (2016) claimed that between the 1960s and 1980s and most recently in 2014, six research papers explored the relationship between abnormal colour vision and road accidents. However, five out of six reports identified that there was no association between abnormal colour vision among accidents caused by drivers or that there was no increase in accident rate for drivers who have abnormal colour vision.

92.3%
Never experienced accidents



7.7%
Experienced accidents

Alongside this findings, over 90% of individuals with CVD who have responded to the survey claimed that they have never experienced accidents caused by colour confusion but The Colour Blind Awareness Organisation explained that it is still important to consider creating wayfinding and signage that are colour blind friendly because if this demographic is unable to understand a colour coded signage or map easily and quickly in case of emergencies, this could lead to serious accidents or repercussions.

IMPACTS OF CVD ON UX/UI

The number of commercial web pages is growing rapidly worldwide. But, according to Sik-Lanyi (2012, p. 610), most websites do not develop for special needs users. This is because they do not see any potential in this limited market.

The Colour Blind Awareness Organisation explained further that CVD individuals have been forgotten in the race for progress in a digital world. This is because designers, especially web designers are often focusing firstly on the aesthetic as a main function of colour to ensure that visually appealing content is achieved. However, connotations of colours and messages can be misunderstood since CVD individuals may not interpret those colours the same way.

The Colour Blind Awareness Organisation reported common problems individuals with CVD found within websites such as:

- Unable to identify invisible links which are colour coded.
- Inability to buy tickets because available or unavailable seating information is given in colour only.
- Inability to read the informational text because of the lack of contrast between text and background colour.
- Inability to buy products due to lack of accessible information about the colour of the product, no exploratory text except poor colour baking which means nothing to people with colour vision deficiency.

The Colour Blind Awareness Organisation admitted that it is crucially important for UX/UI designers to consider design for accessibility and inclusivity. This is because businesses can lose up to 5% of their target markets if they are not aware of the effects of CVD.

IMPACTS OF CVD ON DATA STORIES

According to Daddow (2017), current data representations which are increasingly shared via social media and other platforms cannot be indecipherable to those with CVD. As such, this leads this demographic struggling to process the data efficiently and unable to learn something new and valuable quickly compared to those with normal colour vision. This problem occurs because data is often being presented through only the use of colours. An article by BBC Bitesize demonstrated the difficulties Dr Daddow encountered during election times where the colours were used to distinguish different political parties..

“If you are only relying on colour alone to convey meaning, you are in trouble.”

(BBC Bitesize)

The lack of secondary labelling means that he cannot access and understand information. He expressed further that those with CVD who have little knowledge in the field will also be excluded from the informational charts completely. Which means that they will not be exposed to the new type of knowledge.

IMPACTS OF CVD ON BRANDING

A ccording to Sykes (2017), packaged goods brands do not take CVD into account. This is because similar to driving, nutritional information on food packaging is being provided via a traffic light coding system. As such, many individuals with CVD have to rely on utilising text as a way to understand the information. But another problem occurs when the text if the colours for the backgrounds are not appropriate for the text. For example, if the black text is being used against a red background then

it would not be feasible for people with CVD.

Sykes (2017) further explained that by heavily relying upon using different colours to distinguish information and between similar products, a colourblind person can be confused and therefore this can lead them to put off making purchases. Designers need to take into account designing to be colourblind friendly because of the safety aspect where it can be dangerous if the allergen information on food packaging cannot be identified by individuals with CVD .

IMPACTS OF CVD ON EDUCATION

The Colour Blind Awareness (2019), suggested in an interview with the BBC that even though the department of education does not label CVD as a special educational need or disability but the condition has a lot of consequences for children in terms of their personal self-development and their education. This is because all the learning and education resources are colour-coded. Problems often encounter within the school environment are:

- Difficulty reading texts, graphics and images both in printed and in online resources.
- Difficulty identifying colour slides and lab instruments.
- Difficulty understanding exam papers and exam questions.

Another study by Barry et al, 2017 expressed further that since colours are being utilised in all aspects of learning resources, children with CVD will experience impaired social play where colours are often being used to divide teams in sports. The children might even experience behavioural issues due to the embarrassment and social withdrawal since colourblindness is often being treated as “something of a joke”.

However, The Colour Blind Awareness (2019) argued those difficulties do not conclude that these children are naughty, slow or unruly. As such, it is important to get tested for CVD at an earlier age so that more help, support and advice can be offered.

IMPACTS OF CVD ON DIGITAL GAMES

Digital games are considered to be one of the largest sectors of the entertainment industry with over \$21 billion in value in 2020 (Clement, 2021). However, according to Plothe (2018), the digital game industry excludes a significant portion of consumers and players with disabilities. Although, different technologies such as Tanuwidjaja, HueVue, Chroma and Google glasses are being developed as add-ons or as Retrofitting to help assist players with CVD.

Retrofit means “to add a component or accessory to something that has already been manufactured or built. This does not necessarily make the product function, does not necessarily fix a fault product, but it acts as a sort of correction”. (Plothe, 2018)

However, they still do not solve the underlying problem completely, being that digital games are still inaccessible (Plothe, 2018). Furthermore, another factor such as the price and additional cost of these add-ons secondary assistants can demotivate players with CVD which means a portion of the market can be lost significantly.

Common problems encountered by people among CVD within the gaming industry are:

- Unable to identify teams quickly since the majority of them mainly utilise red and green, therefore, struggle to keep up with the pace.
- Unable to interpret and understand guide for the racing game since brakes information changes from red to green regularly during the game.
- Difficulty carrying out puzzles due to colour confusion and lack of numbers labelling.

Hue is a puzzle platform game developed by Henry Hoffman. Originally, the core concept of the game relied heavily on colour theory such as using the colour red for danger (Plothe, 2018). However, during the testing and development stage, Hoffman realised that a large portion of people struggled to play his game due to CVD. Because of this discovery, Hoffman developed his game further by using patterns and symbols in the aesthetic. By making the game more accessible for people with CVD as well as those without the condition, Hoffman was able to obtain a solution that was flexible, intuitive and easy to use, three crucial principles that inform universal design.

“While building accessibility accommodations into digital games can open them to a different audience, they can also make the games more marketable.”

(Plothe, 2018)

Furthermore, Hoffman, also found accessible features were incredibly successful this is because the number of players adopting the feature was high as well as the feature was being utilised not just by players with CVD but also those without the condition as well. He also believed that designing for accessibility can gain financial benefits because it allows developers to perform successfully within a competitive market (Plothe, 2018).

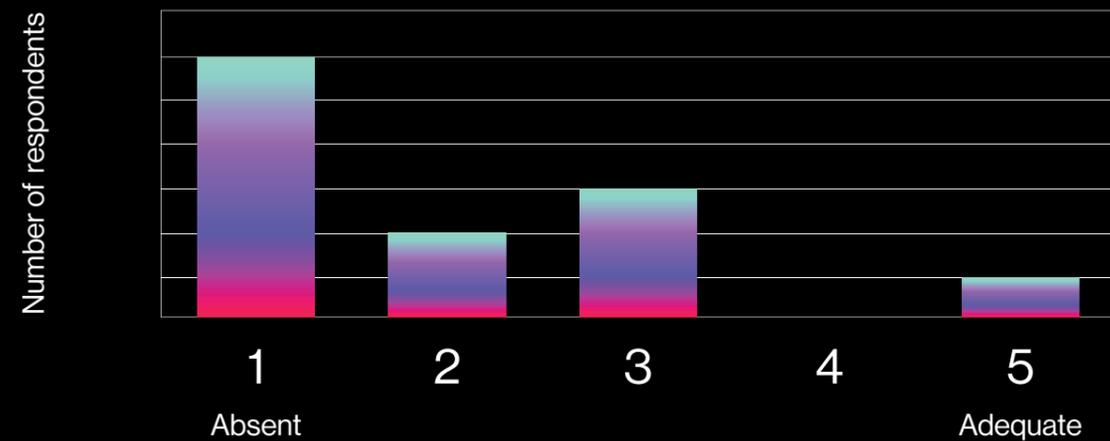


Image: (Taylor, 2019)

SURVEY

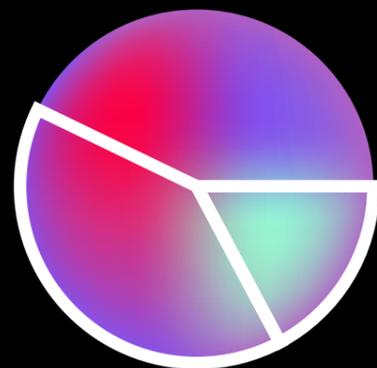
Individuals with CVD:

Due to all the problems that this demographic encountered within visual communication as such, 70% of the respondents agreed that visual designers currently have a lack of understanding that their designs might be viewed by individuals with CVD.



Individuals without CVD:

When asked whether individuals without CVD view the topic negatively or positively, 40% viewed the topic negatively, while 43% did not know the answer to this. They admitted they "did not know enough information about the topic to make a decision" which indicates that there is currently a huge lack of awareness about the topic.



42.9%

Do not know what to think

17.1%

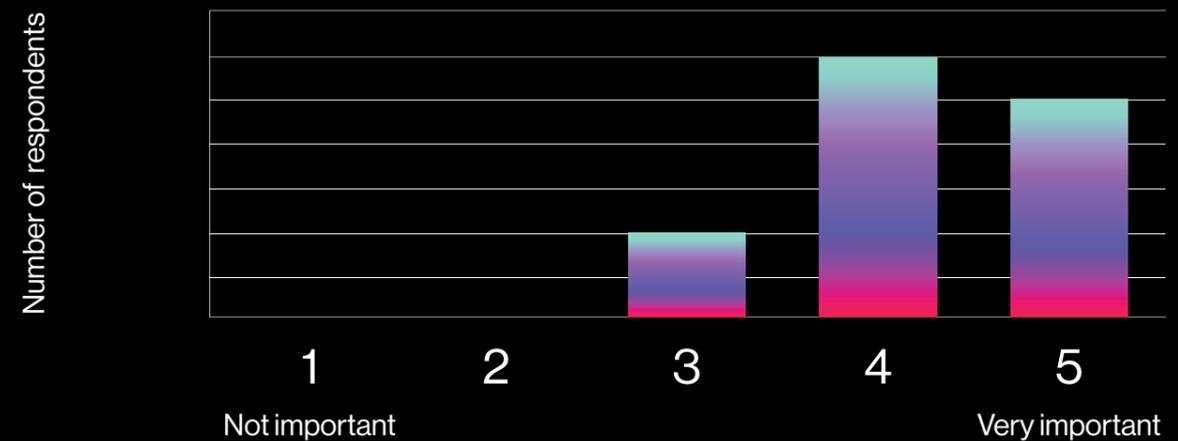
Think of CVD positively

40%

Think of CVD negatively

Designers:

15 out of 48 respondents or 31% of those who have responded to the survey were designers or students pursuing careers in the design industry.



When asked whether it is important to design for people with CVD, 86% were leaning towards important and significantly important. However, when designers were questioned whether they have ever considered that their products or services might be viewed by individuals with CVD, 73% stated no while 27% said yes. Designers commented further that the reasons why they have said no were because "the awareness of the topic has never crossed my mind" or that "I have never thought about it" so, therefore, they concluded that this topic was not considered an issue previously. In contrast, some designers stated yes because they were either colourblind or knew someone with the condition, therefore, they explained that if their designs were not colour blind-friendly, then they would not be able to use or interpret them. The results for this indicate that awareness and knowledge about CVD associated with the availability of accessible designs.

INTERVIEWS

A structured interview was conducted with two optometrists to find out more about the topic and whether supports are available to guide this demographic.

“It is not an important issue, because the condition does not affect their prescriptions so they can still read everything up to standard.”

(Herbert Chan, 2021)

Chan indicated that CVD only affects colours, therefore, it does not affect an individual's vision and their ability to perceive their surroundings. Chan also suggested that since CVD has nothing to do with vision, he cannot give treatments and “individuals cannot be recovered from taking medications” because “colour blindness just simply cannot be removed”.

These are the reasons why Chan's optician does not currently provide any learning and educational resources for those with CVD. Therefore, it can be pointed out that the lack of educational and reliable resources from the professional point of view contributes to the lack of society's awareness about CVD. This could be another reason which contributes to why the topic has been considered unimportant.

“This is an important issue because it can affect daily lives and even careers in the future.”

(Winnie Lo, 2021)

Lo mainly focused on the impact of career options for those with CVD. She further expressed that the optician is prepared to provide advice to those with CVD, especially for young children to “be aware that certain occupations such as designers, pilots, electricians etc. may be limited to them”. A UX designer with CVD, Noah Glushien disagreed and believed that being a colourblind designer actually helped with his work. This is because he could bring in a different perspective into the projects and offer insights that others within the team do not necessarily have (Glushien, 2020). For example, Glushien could suggest to the team whether the information is getting lost, he could point out poor contrast and identify elements which could be difficult to interpret. From gaining feedback through Glushien, the team will be able to make designs more

inclusive for CVD demographic (Glushien, 2020). Cole and Harris (2009) explained further that optometrists should not advise individuals against choosing a career in the design industry. This is because there are many designers with CVD and there is no evidence which indicates that the condition precludes their successes. Instead, suggested that optometrists should advise patients that while CVD may introduce some difficulties (Cole and Harris, 2009).

The interviews suggested that although CVD might not majorly impact some individuals, it is still important to consider offering and providing support for this demographic so that they do not feel precluded. Furthermore, through learning and understanding the topic, individuals with CVD can understand and can be aware of the limitations.

SOLUTIONS

Colour Universal Design (CUD) was developed in Japan in 2001 with its aim of including people with various types of CVD into the design process.

“Colour-coding shall not be used as the only means of conveying information, indicating an action, prompting a response or distinguishing a visual element.”

(Jane and Kelso, 2007)

Through following CUD principles, designers will be able to use colour effectively and create colourful designs that are visually appealing for everyone while still conveying information accurately to people with difficulty distinguish between different colours.

“Colour-coding shall not be used as the only means of conveying information, indicating an action, prompting a response or distinguishing a visual element.”

(Jane and Kelso, 2007)

This means that designers should ensure that they are not only relying on colour alone to convey information. Jenny and Kelso (2007) suggested that a combination of different shapes, positions and patterns can ensure that information can be delivered to individuals with CVD. This is because designing products and services for everybody (including disabled and those with CVD) is not only morally correct but can increase financial advantages too. If access is not barrier-free a large number of users can be lost. Therefore, designers must be constantly testing their designs with those users to ensure accessibility, usability and overall user satisfaction.

CONCLUSION

“There has been surprisingly little research on the quality of life impact of congenital colour blindness.”
(Barry et al, 2017)

Throughout this report, although it can be determined that individuals with CVD encountered many issues and challenges within visual communication. Therefore, designers can adopt CUD principles into their design process to provide a more inclusive and accessible experience for individuals with colour vision deficiency without ignoring the need for the rest of the populations. However, the extent of the issues faced by individuals with CVD cannot be measured properly due to the variation of the severity. This means that since each individual encountered different types of problems, each person had different opinions on how much CVD impacted them. Hence, this is why there were conflicting perspectives on the issue. Therefore, this area will need to be explored further through a quantitative system where figures and numbers can be compared.

Therefore we cannot assume the extent of the issues as the vast majority of CVD individuals will need to be taken into consideration. For example, only 15 respondents in the survey are colourblind, therefore, the information given can only be used to determine potential issues, but it cannot be utilised to conclude that all colourblind people experience the same issues to the same degree. Because of this, it can be established that the degree of the topic's importance is dependent on the severity and type of CVD. It can also be determined from the survey and interviews conducted that lack of knowledge, awareness and understanding among designers, and society, contributed to why the topic has not been considered as important. Therefore, it is another factor which is dependent to the degree of the topic's importance.

**CAN DESIGN BE USED
TO RAISE AWARENESS
AND THE ADOPTION
OF ACCESSIBLE DESIGN
PRACTISES FOR
COLOUR VISION
DEFICIENCY?**

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