

Colour Vision Deficiencies in the Digital Age: A Survey of User Experiences with Digital Displays

by

Sandra Mazur

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Introduction: Approximately 90% of dichromats and 67% of anomalous trichromats experience difficulty performing colour-related tasks daily (Steward & Cole, 1989). As technology becomes more prevalent, examining whether this condition impacts their use of digital displays is increasingly essential. Limited studies analyze the relationship between colour vision deficiencies (CVD) and digital displays. Mashige (2019) found that 63.2% of schoolchildren with CVD reported challenges when “working with computers,” suggesting that this condition may have some effect.

Purpose: The purpose of this study is to examine the impact that congenital red-green CVD has on an individual’s interaction with digital displays in different areas of their daily life, such as “school,” “work/volunteering,” “gaming and eSports,” “driving/motorized vehicle,” and “travelling.”

Materials and Method: An online survey was administered to people with CVD from Canada and the United States of America (USA). In addition to collecting demographic information and awareness of their CVD, information regarding difficulties carrying out colour-related tasks was collected. Because several software and filter options may improve performance on colour-related tasks, we asked whether they tried any and to rate their effectiveness.

Results: A total of 381 individuals with CVD (280 males) completed the survey. Nearly 100% reported some difficulty with one of the tasks in most areas of life, individually, except for travelling (54.1%). For most tasks, there were no significant differences in the rankings based on sex and/or age group. Still, some tasks showed significant differences based on severity, primarily between mild and severe defects. Some examples included “colour-coded diagrams” at school, work/volunteering, and recreation/hobbies; “editing photos or other coloured images” at school, recreation/hobbies, and social media; and “reading coloured letters on various backgrounds” in gaming/eSports, online shopping/banking, and in-person shopping/banking.

Nearly 65% of respondents reported making changes or implementing modifications to their displays, but there were 35% who did not. The most popular aid was “trial-and-error adjustments” of the colour and brightness of the display. Of the individuals who tried an aid, approximately 90% reported a modification to be at least a little effective, less than 3% reported at least one aid as ineffective, and only 25% rated the modifications as highly effective. There was no significant difference based on sex, age group, or severity for most modifications, except for passive aids (“coloured filters”) where youth found them more effective than adults.

“Desktops/laptops,” “cell phones,” and “tablets” were the displays that people with CVD most frequently encountered difficulty and modified. The displays showed significant association with age group for some areas of life (work/volunteering, recreation/hobbies, gaming & eSports, and online shopping/banking) and modifications. This was probably due to the greater use of displays or differences in content, with youth having more problems with tablets and adults more with cell phones.

Conclusion: Most respondents encountered some difficulty with at least one task, indicating that CVD had some effect on their ability to use digital displays. Although most respondents have tried some modifications to their displays, some respondents reported that at least one modification was ineffective and only 25% found an aid to be highly effective. Software developers should focus on making aids more accommodating and customizable to individual preferences.

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Dedication

I dedicate this work to my loving parents, Sam and Violet, and my sister, Venessa.

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Chapter 1

Introduction

1.1 Colour Vision

1.1.1 Photoreceptors in the Retina

Visual perception begins with the translation of radiant energy into neural impulses, which occurs at the photoreceptor level of the retina. There are two types of photoreceptors: rods and cones. Each photoreceptor has its own unique functions within the retina. Rods are activated in low-light conditions (scotopic) and are the most numerous outside the central visual area (fovea). They do not mediate colour vision or fine spatial resolution. Cones are activated in brighter light conditions (photopic). They are most numerous in the fovea and mediate high spatial acuity and colour vision.

1.1.2 Opponent Colours Theory

Although the neural processes underlying colour vision are not fully understood, it is clear that the cones, themselves, do not code colour. Colour perception likely arises through the neural mechanisms that compare the output of the various types of cones. One model that compares the cone responses is the opponent colours model, based on Hering's opponent colours theory (Figure 1.1).

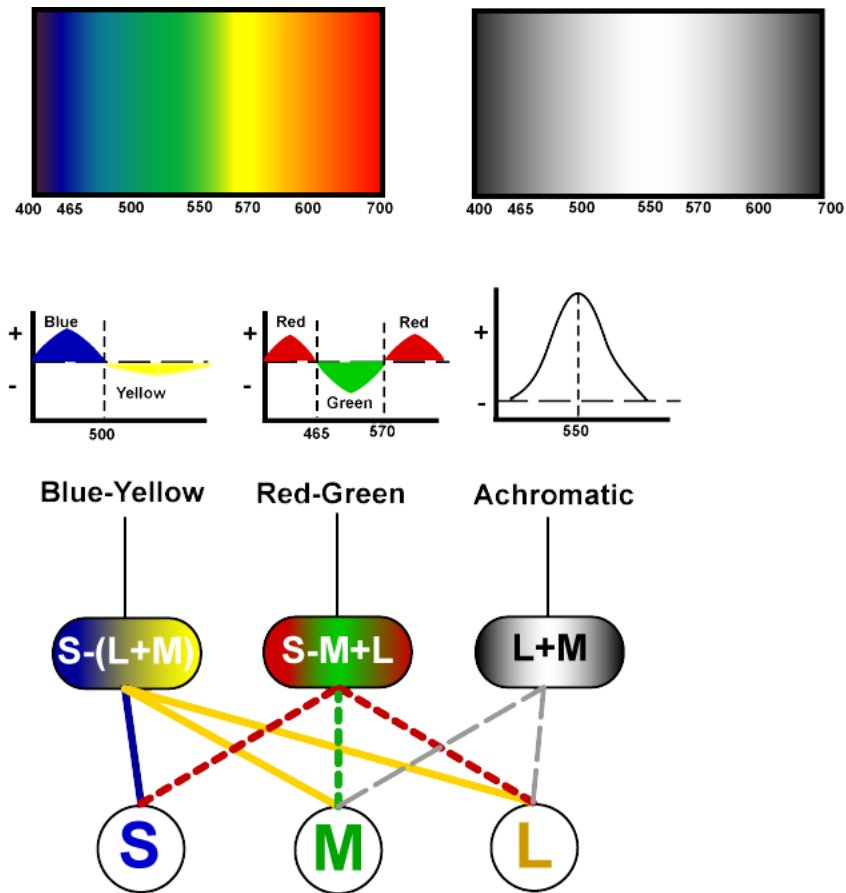


Figure 1.1. A model of an opponent colours theory. The circles represent the cones, the first phase of colour perception. The second level consists of the post-receptor channels that subtract and add the various cone inputs to code for either red or green, blue or yellow, and black or white. Modified from (Civil Aviation Medicine, 2005).

The first phase of the model consists of the cones, and there are three types of cones in humans with normal colour vision (trichromatic): short-wavelength sensitive cones (S-cones), medium-wavelength sensitive cones (M-cones), and long-wavelength sensitive cones (L-cones). The relative sensitivity of each cone is determined by its characteristic photopigments in the outer segment (Pokorny et al., 1979). Figure 1.2 shows the relative spectral quanta absorption of the different cone types. There is actually a range of wavelengths in which each cone type functions, and these are considered to be representative (International Commission on Illumination, 2005). The curves show the probabilities that a particular wavelength of light is absorbed, and the cone response is proportional to the amount of light (quanta) absorbed. The M- and L-cones are activated across all wavelengths of light, whereas S-cones are only activated for wavelengths below ~535nm for most viewing conditions. An individual cone response

can be manipulated by changing the wavelength, altering the number of quanta emitted by a source, or both (Civil Aviation Medicine, 2005).

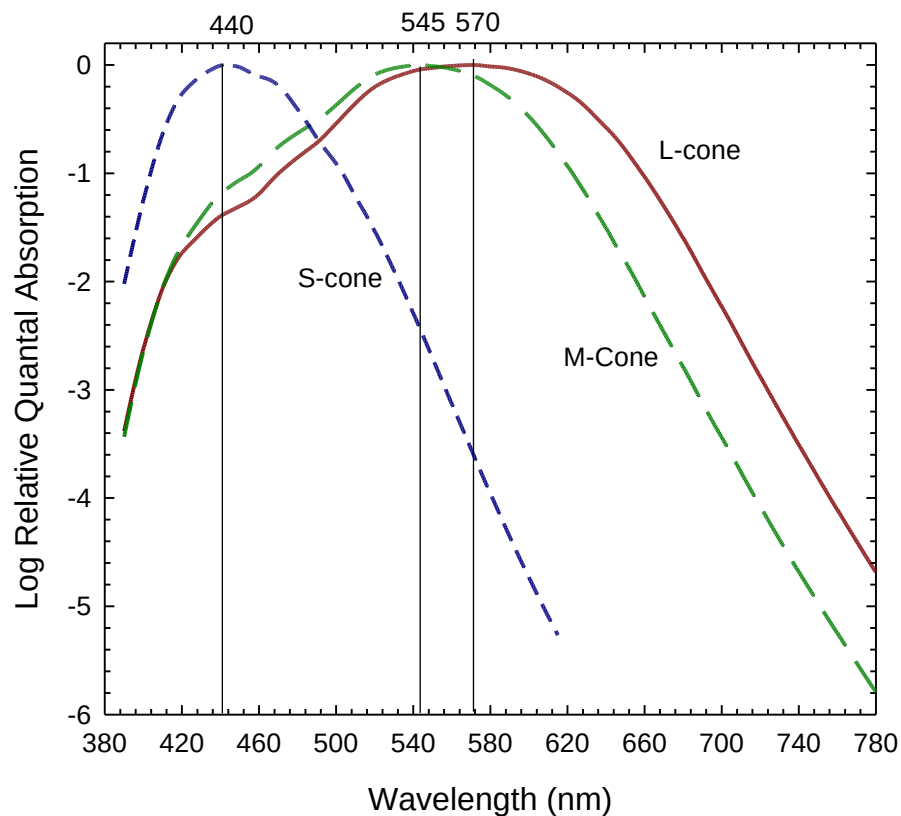


Figure 1.2. The relative absorption curves of S-, M-, and L-cones show the probability that these cones will absorb a particular wavelength of light. Each value represents their peak sensitivity which is the wavelength of light to which the cones are most sensitive (International Commission on Illumination, 2005).

The next stage of the model is at the opponent level which consists of post-receptor channels. There may be more than one opponent stage (Judd, 1949; Guth, 1991; De Valois & De Valois, 1993), but the simplest model was proposed by Hurvich and Jameson, which consists of two chromatic channels (red-green and blue-yellow) and one achromatic channel (black-white) (Hurvich & Jameson, 1957). The two chromatic channels are responsible for coding hue (colour) based on the differences in the signs of the output of each channel, along with the ratio of the responses between the channels (Civil Aviation Medicine, 2005). The achromatic channel is responsible for coding luminance/brightness based on the sum of the L- and M-cone inputs (Civil Aviation Medicine, 2005). For example, blue-green is perceived when there is a response of green from the red-green channel and blue from the blue-yellow channel. This

happens when the input from the S-cones into the blue-yellow channel is greater than the inputs from the M- and L-cones, and the M-cone input is larger than the input of the S- and L-cones into the red-green channel.

1.2 Abnormal Colour Vision

Abnormal colour vision occurs when an individual has colour matches outside of the normal range, when they cannot discriminate between certain types of colours, or both. Abnormal colour vision is also commonly referred to as a colour vision deficiency (CVD)/dyschromatopsia/colourblindness (Bailey, 2010). CVD can either be inherited through genetics (congenital) or through ocular or neurological diseases or disorders (acquired) (Pokorney et al., 1979; Bailey, 2010). Congenital red-green CVD is the most common type, accounting for 99% of all CVDs (Pokorney et al., 1979). The prevalence of red-green CVD varies depending on race, ethnicity and geographical location; but it is most prevalent among individuals of European descent. Generally, ~8% of European men and ~0.4% of European women are affected (Birch, 2012). The reduced prevalence of CVD among women is a result of the X-linked recessive inheritance of the condition (Deeb, 2005). The prevalences of CVD among other racial groups are: 4-6.5% of Asian males, 0.4-1.7% of Chinese females, 6-7.2% of African-American males, and 2-4% of African and Central American males (Birch, 2012).

1.2.1 Classification of Colour Vision Deficiencies

Figure 1.3 shows the classification of congenital and acquired colour vision deficiencies (CVD). They can be classified based on the affected cones and post-chromatic channels. Congenital CVDs are categorized based on the colours that are typically confused, the number of primaries used for colour matching, or the altered cone pigments (Pokorney et al., 1979).

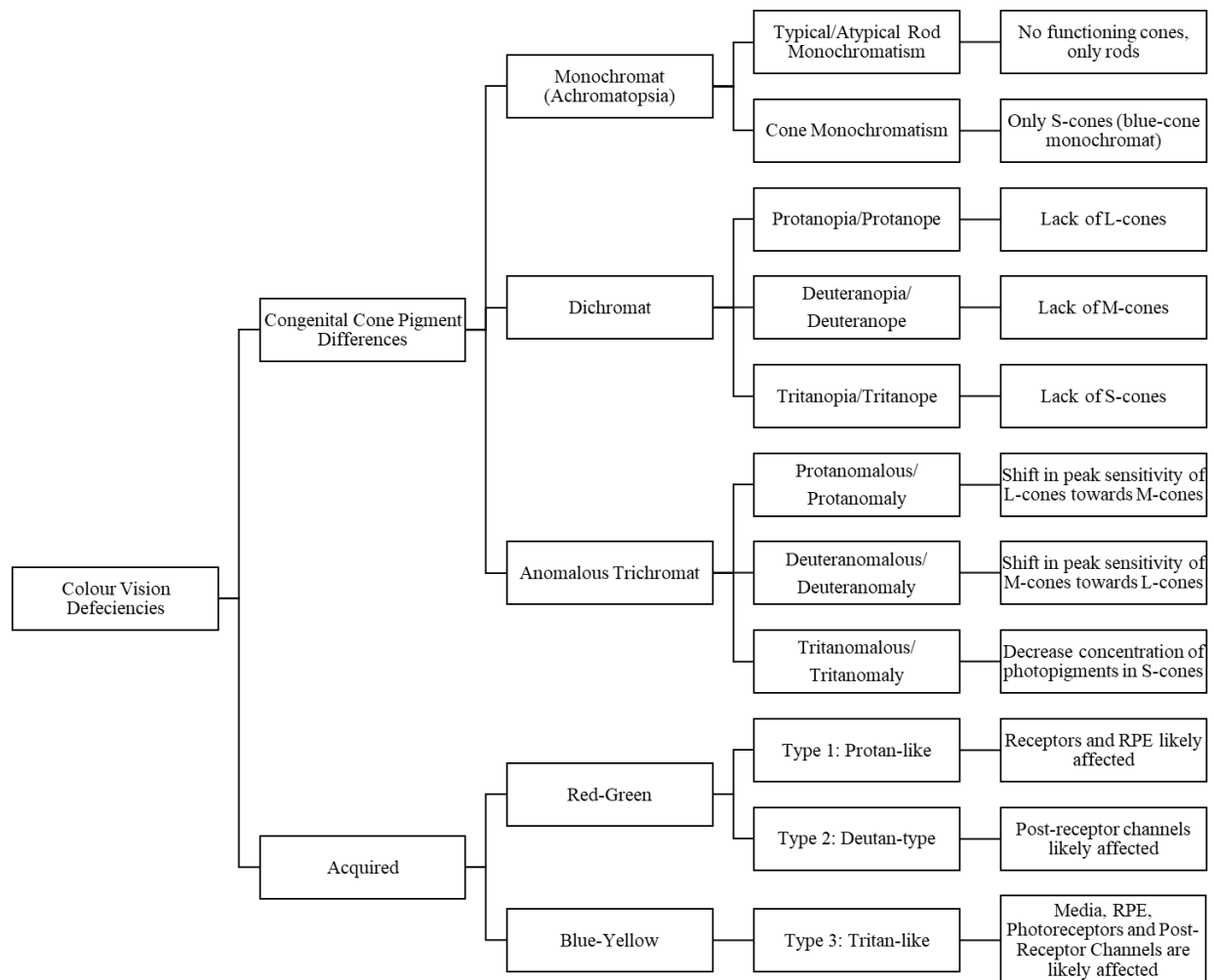


Figure 1.3. This diagram shows the classification of the different types of congenital and acquired colour vision deficiencies (CVD) (Hurvich & Jameson, 1957; Futagbi et al., 2011). The first two columns describe the types of CVD based on how the condition was obtained; the third column highlights the subcategories; and the last column summarizes the mechanisms underlying the defect.

1.2.1.1 Number of Primaries Needed for Colour Matching

1.2.1.1.1 Monochromats

Colour matching occurs when the mixture of the primary lights appears identical to the test light. This happens when the responses of the three cone types are identical for the two stimuli. Individuals with differences in the cone photopigments will require a different number of primaries, a different quantity of primaries, or differences in both to make a match. A monochromat (i.e. achromatopsia) requires only one

primary to match all colours. This indicates that the person has only one functioning class of photoreceptors. There are three types of monochromats:

- i) typical rod monochromatism: behaves as if there are no functioning cones and vision is only mediated by rods;
- ii) atypical rod monochromatism: behaves as if there are no functioning cones during their daily lives, but specialized testing reveals some cone function; and
- iii) cone monochromatism: both rods and S-cones are present, but they only require one primary to make a colour match at scotopic and photopic light levels and two primaries for mesopic light levels.

Colour discrimination and visual acuity are significantly impaired in these individuals.

1.2.1.1.2 Dichromats

Dichromats require only two primaries to make colour matches, which indicates that they may have only two functioning cones mediating photopic vision and rods mediating scotopic vision. There are three subcategories which are:

- i) protanopia/protanope: individuals that lack L-cones;
- ii) deutanopia/deutanope: lack M-cones; and
- iii) tritanopia/tritanope: lack S-cones.

Figure 1.4 shows the relative absorption curves of (A) colour normals in comparison to the three types of dichromats. Each diagram reflects the absence of the curve that corresponds to the cones that they are lacking for (B) protanopes, (C) deutanopes (Deeb, 2005), and (D) tritanopes. In addition to differences in photoreceptors, the dichromats have only one chromatic channel and the achromatic channel. The remaining chromatic channel for the red-green dichromats is the blue-yellow channel based on the response of the S-cones and remaining L-cones for the deutanopes, or S-cones and remaining M-cones for the protanopes. Whereas for blue-yellow dichromats (tritanopes), the remaining chromatic channel is the red-green channel, which is based on the difference in responses of the L- and M-cones.

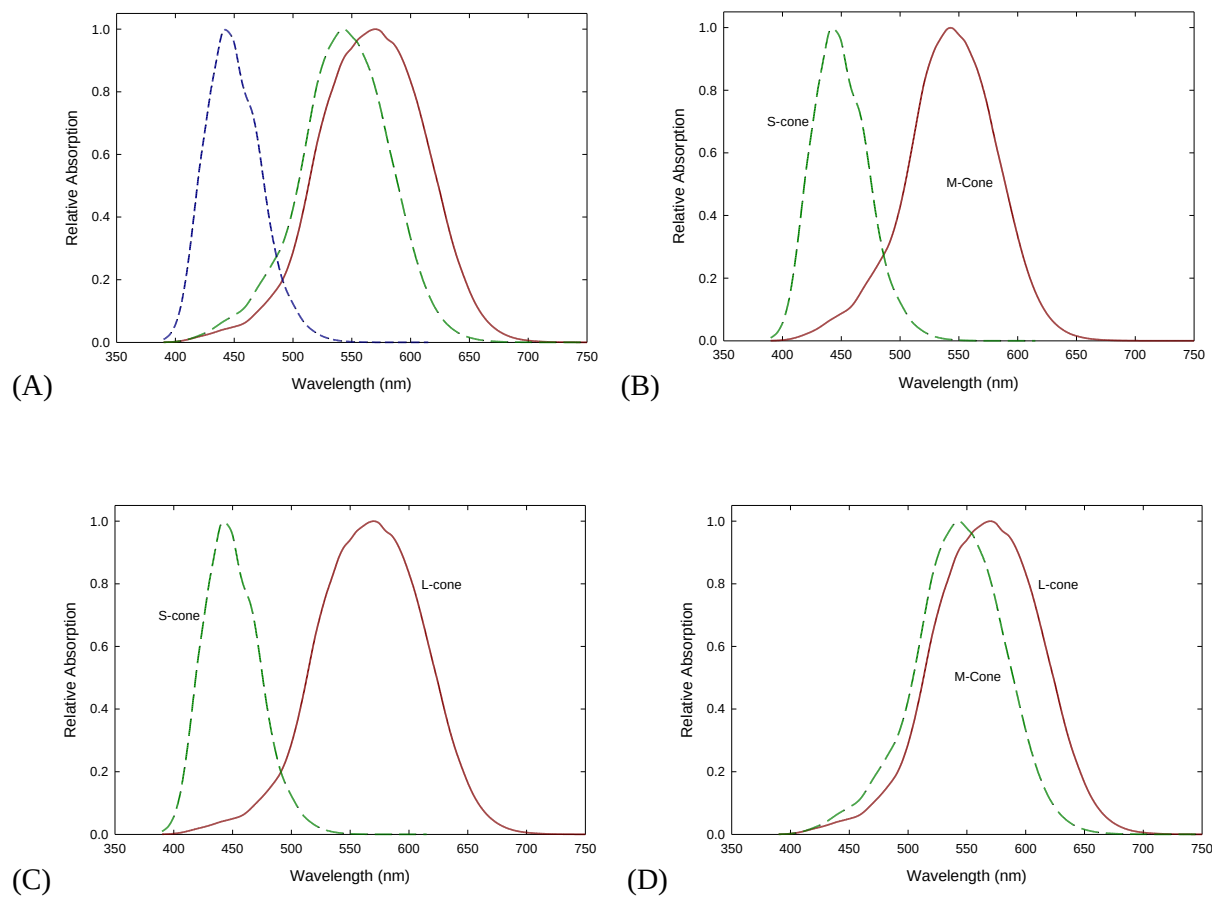


Figure 1.4. The relative absorption graphs of dichromats (two types of cones) of (A) colour normals, (B) protanope, (C) deuteranope, and (D) tritanope.

1.2.1.1.3 Anomalous Trichromats

These individuals are characterized by requiring three primaries to perform colour matching; however, the relative amounts of the primaries are different from colour normals. There are also three subcategories of anomalous trichromats which include:

- i) protanomalous/protanomaly has a shift in the peak sensitivity of the L-cones towards the M-cones;
- ii) deuteranomalous/deuteranomaly has a shift in the peak sensitivity of the M-cones towards the L-cones; and

iii) tritanomalous/tritanomaly has a decrease in the concentration of photopigments in the S-cones or a decrease in the number of S-cones.

The absorption curves for the different types of anomalous trichromats compared to (A) colour normals are shown in Figure 1.5. Each diagram depicts the distinctive feature of (B) protanomalous, (C) deuteranomalous (DeMarco & et al., 1992; Deeb, 2005), and (D) tritanomalous. The colour perception of anomalous trichromats is based on the outputs of both chromatic channels and the achromatic channel, along with their cone analog substitution with the appropriate cones based on Hurvich and Jameson's model.

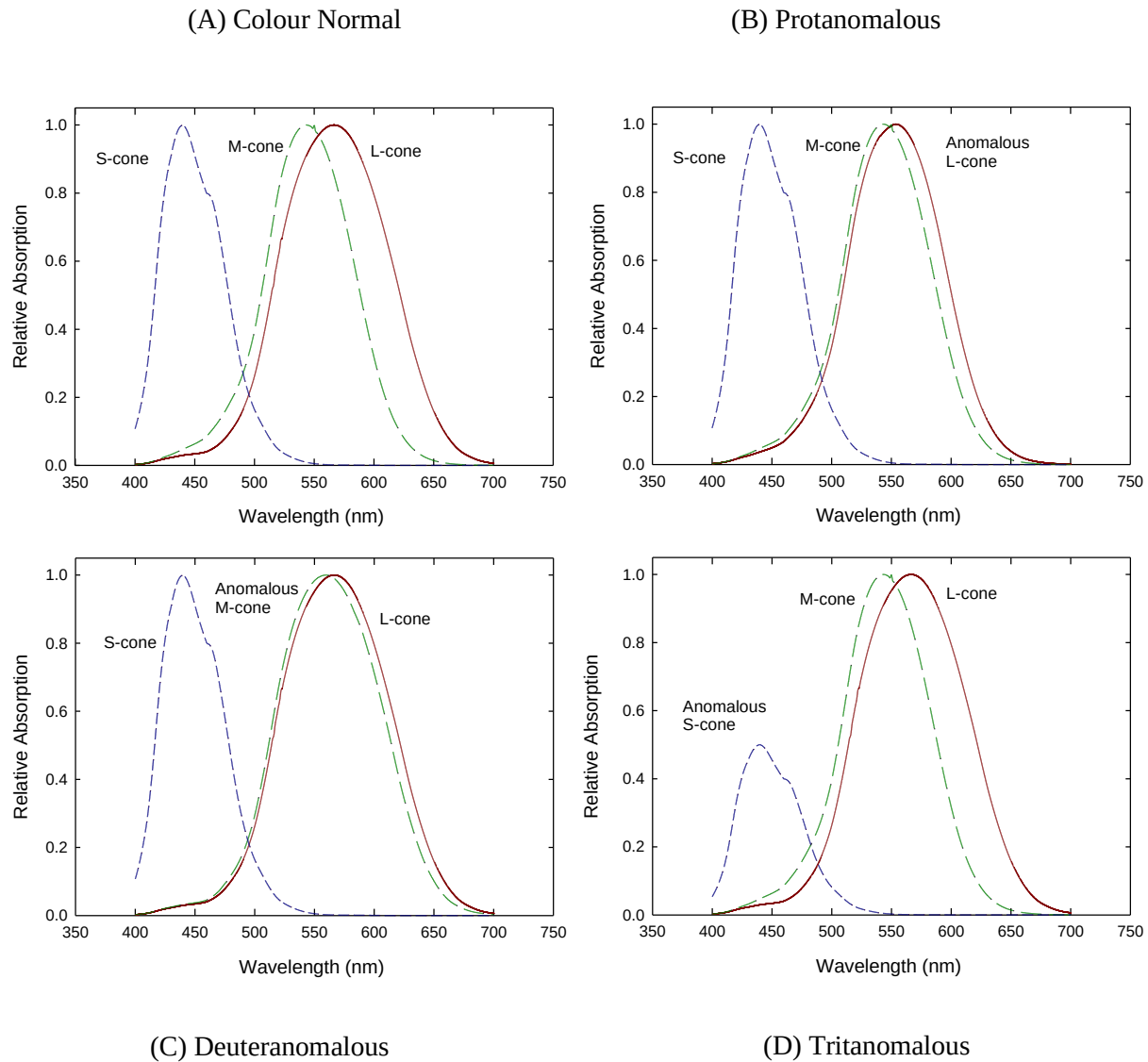


Figure 1.5. The spectral sensitivity graphs of anomalous trichromats (three types of cones) of (A) colour normals, (B) protanomalous, (C) deuteranomalous, and (D) tritanomalous.

1.2.1.2 Acquired Colour Vision Deficiencies

Acquired CVDs are associated with a disorder or disease that has impacted some other aspects of the visual system, which is one major difference between acquired and congenital CVDs, such as visual acuity or visual field (Pokorny et al., 1979). If there is a visual problem in congenital cases, then it is generally independent of the condition. Often acquired colour vision defects also exhibit a generalized loss of colour discrimination, which can be classified by a greater loss along either the blue-yellow or red-green axis (Pokorny et al., 1979).

1.2.1.2.1 Colour Discrimination Loss in Red-Green Axis

There are two types of red-green acquired CVDs. Type 1 red-green exhibits protan-like characteristics and Type 2 red-green exhibits deutan-like characteristics. If an individual has a disease or disorder that affects the receptors and retinal pigment epithelium (RPE), they are likely to have a Type 1 red-green defect. Meanwhile, disorders or diseases that affect the post-receptor structures, particularly the optic nerve, are more likely to exhibit a Type 2 red-green defect. Stargardt macular dystrophy is one condition that causes a Type 1 defect, whereas multiple sclerosis is an example of a condition that can result in a Type 2 red-green defect.

1.2.1.2.2 Colour Discrimination Loss in Blue-Yellow Axis

Blue-yellow acquired defects exhibit tritan-type (type 3) discrimination losses due to its effect on the S-cones. This defect is the most common type of acquired CVD (Pokorny et al., 1979). It can arise from diseases and disorders of the ocular media, RPE, photoreceptors and post-receptor channels. Some common examples of these diseases/disorders are cataracts, age-related macular degeneration, and diabetes.

1.3 Colour Vision and Digital Displays

Coloured digital displays have become an integral part of ordinary daily life. Some commonly used displays are: desktops/laptops, tablets, cell phones, touch screen digital whiteboards, whiteboard computers, and immersive systems. Given the pervasiveness of these devices, it is crucial to determine whether individuals with CVD encounter daily challenges when using these devices and to understand the nature of any problems so that aids can be developed to help them interact with these displays. Most digital displays are comprised of a 3-dimensional RGB colour space, which is similar to the three primaries used for colour matching experiments. The displays are composed of small pixels that serve as small light sources, and each pixel is composed of subpixels consisting of red, green, and blue primaries (Figure 1.6) (Chem Purdue Education, n.d.). The subpixels are too small to resolve at normal viewing distances, so the colour from a pixel is a mixture of the three subpixels. Colours are produced based on the different intensities and combinations of the subpixels (Chem Purdue Education, n.d.).

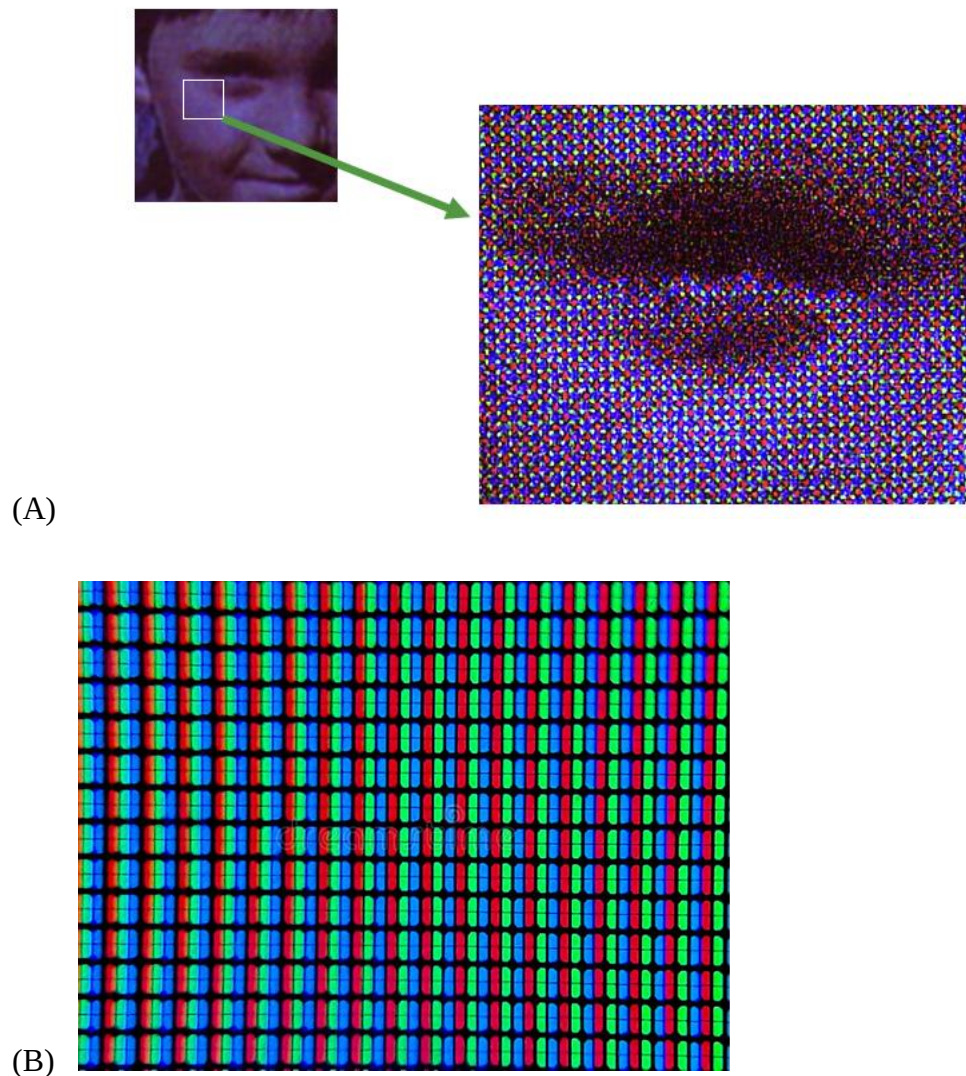


Figure 1.6. An example of (A) a snapshot of the boy's face shows its composition consisting of several red, green, and blue pixels and subpixels. (B) The different combinations and intensities of the pixels/subpixels are used to create the image.

1.4 Daily Challenges for Individuals with Colour Vision Deficiencies

Due to their condition, people with CVD experience difficulties perceiving colours. Since monochromats are rare and they also experience reduced visual acuity in addition to their colour vision defect, this section will primarily highlight the challenges experienced by dichromats and anomalous trichromats. Anomalous trichromats tend to experience fewer problems than their corresponding dichromats because

their hue discrimination is usually better. Regardless of the level of challenges, both dichromats and anomalous trichromats experience colour-related challenges in their daily lives (Steward & Cole, 1989).

1.4.1 Daily Challenges Encountered by People with CVD

Steward and Cole (1989) reported that 75% of those with CVD experienced colour-related challenges with ~90% of dichromats and ~67% of anomalous trichromats reporting some level of difficulty when performing various colour-related tasks. Some examples of the tasks include: selecting clothes, preparing food, and identifying traffic lights (Steward & Cole, 1989). A defect could also impact the lives of these individuals as early as in school. A child's inability to make hue discriminations could potentially affect their quality of life and their performance in certain school subjects, such as science, geography, art, and math (Mashige, 2019). People with CVD not only experience challenges in the performance of tasks, but also in their personal and emotional development. Stoianov et al. (2019) performed an integrative review where several studies suggested that CVD impacts the development of personality and self-esteem.

Colour is also commonly used in conveying information using various colour codes in textbooks, maps, diagrams, graphs, spreadsheets, and photos, where the impairments of colour vision are not usually considered. Studies have explored the experiences of people with CVD when reading and interpreting colour-coded maps in various settings. Olson and Brewer (1997) assessed the performance of 64 respondents (32 red-green CVD) on their ability to read seven pairs of maps using two different renditions ("confusing" and "accommodating"). The "confusing" rendition included colours that are commonly confused by those with red-green CVD (e.g. magenta and green-blue, orange-red and green, and orange and yellow-green), while the "accommodating" avoided these colours (e.g. neutrals, grays and white) (Olson & Brewer, 1997). A majority of those with CVD preferred the "accommodating" rendition as it was easier to use (Olson & Brewer, 1997). Although their speed in obtaining information from the "accommodating" maps improved, they were still relatively slower than those with normal colour vision (Olson & Brewer, 1997). Possible reasons for the longer times could be their lack of trust in their initial impression of colours as expressed by one respondent, or their reduced exposure to coloured maps for which they have likely developed a distaste (Olson & Brewer, 1997). Similar challenges were also found in another study by Long and Junghans (2008), which analyzed the use of coloured maps for orienteering. Orienteering is an individual sport where maps guide participants in selecting the best route to several checkpoints (Long & Junghans, 2008). These maps use colour schemes outlined by the International Orienteering Foundation (IOF) to limit the confusion of checkpoints by those with CVD (Long & Junghans, 2008). Nevertheless, those with CVD still may struggle to read these maps, especially those with more severe defects (Long & Junghans, 2008). Both of these studies highlight that those with CVD

still experience challenges when interacting with colour-coded content, such as maps, even after implementing "accommodations."

1.4.2 Difficulties of Digital Tasks by People with CVD

Despite the daily problems that CVD individuals experience, little work has been done to understand their challenges with discriminating colours on digital displays. The studies that have been done do report that they have difficulty interpreting colour-coded information from electronic flight instrument systems found on aircrafts (Cole & Macdonald, 1988), working on computers (Mashige, 2019), browsing the internet (Futagbi et al., 2011), and distinguishing colours in computer games (Tillem & Gün, 2023). A study by Mashige (2019) reported that CVD schoolchildren in South Africa were more likely to report difficulties when using the computer. Sixty-three percent of the students who reported difficulties with this task had CVD as compared to 37% who had normal colour vision (Mashige, 2019). Similar results were found by Futagbi et al. (2011) who reported that 64.3% of people with CVD studying high school and university sciences experienced difficulty identifying colour-coded instructions outlined by pop-up menus and 28.6% with distinguishing colour-coded buttons and words that outlined similar items or different functions when browsing the internet (Futagbi et al., 2011). These two studies show that some CVDs encounter problems using digital displays, but it is difficult to gauge how extensive the problem is because the number of CVDs in those two studies was limited to less than 20.

1.5 Types of Assistive Technologies for Digital Displays

There are currently no treatments available that can cure CVD, but there have been several advancements in assistive technologies over the last decade (Bardeci & Lagori, 2021; Melillo et al., 2017). Some of these aids include: grayscale images for the colour perception of dichromats, mobile applications that can assist in the detection of traffic lights, and the development of colour-assistance systems. These modifications can be classified into two categories: active and passive solutions. Active solutions consist of electronic aids that actively alter or amplify the perception of colours. These include computer software that can modify itself at any time, such as adjusting the settings on the displays or using algorithms that can enhance the contrast of colours in real-time or with limited delay (e.g. smart glasses) (Martínez-Domingo et al., 2019). Currently, there are three general software solutions that are used. These are: recolouring, edge enhancement, and pattern superposition (Figure 1.7). Recolouring adjusts colours within an image so they are more distinguishable, edge enhancement produces luminous borders of adjacent colours to outline the differences, and pattern superposition applies additional data (e.g. certain coloured regions) so that the coloured object is more recognizable (Hung et al., 2020; Xu et al., 2022).

Most of these techniques were primarily designed for dichromats (Xu et al., 2022) and they include some drawbacks, such as not taking into consideration the experiences of users (Lin et al., 2019), accessibility, social scrutiny (Popleteev et al., 2015), and lack of ability to respond in circumstances that are spontaneous or unaltered (Sutton et al., 2022). There has been an increase in the popularity of optical see-through head-mounted displays and Computational Glasses, which have been used to improve the experience augmentation and enhancements (Sutton et al., 2022) using less invasive strategies (Popleteev et al., 2015).

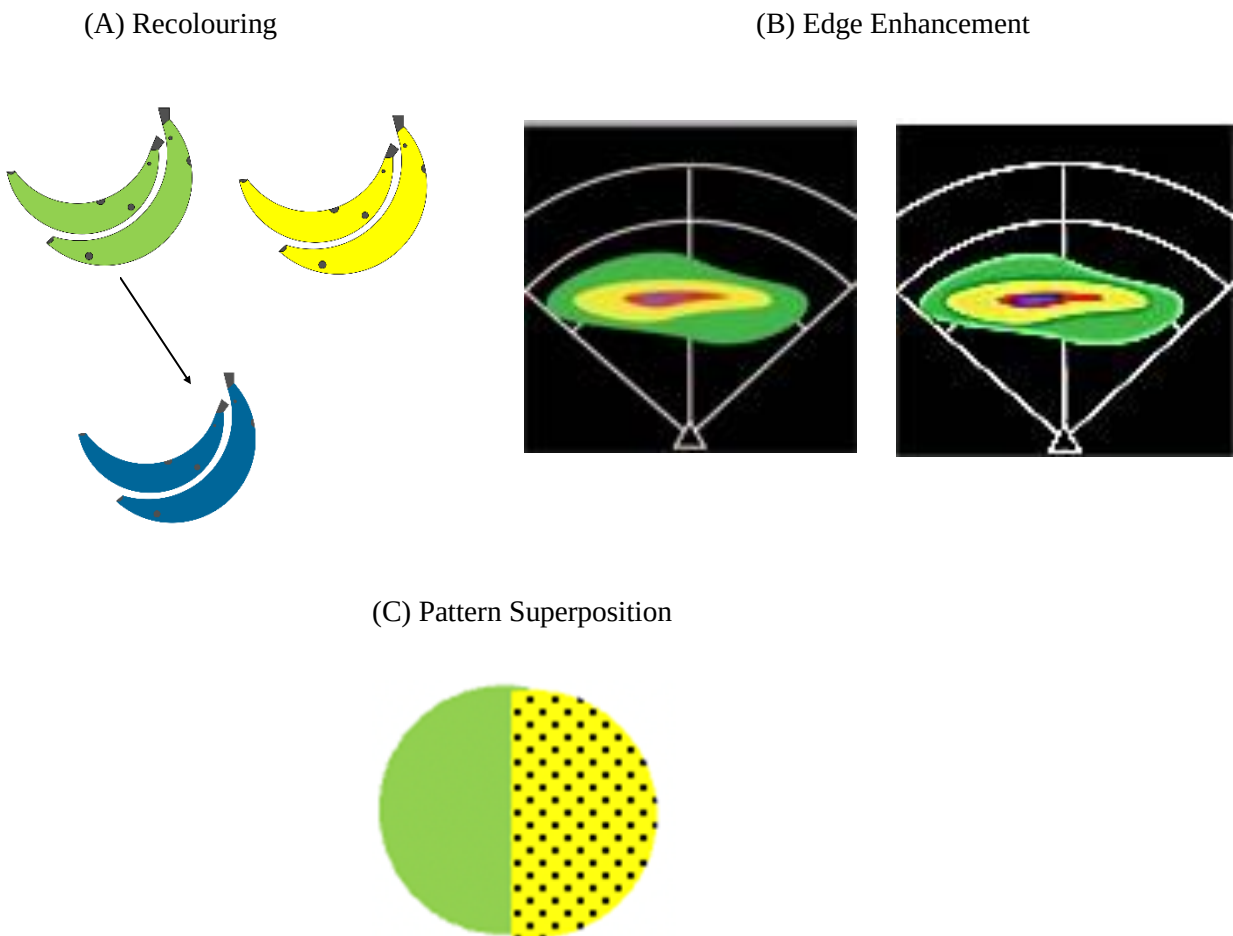


Figure 1.7. These are the three types of active solutions that can be implemented onto digital displays: (A) recolouring, (B) edge enhancement, and (C) pattern superposition.

The second type of assistive technologies are passive solutions which include aids that do not require the expenditure of energy as only one solution is implemented throughout the use of the display. Coloured filters, tinted spectacles and contact lenses are examples (Martínez-Domingo et al., 2019). One

example of tinted glasses in today's market is EnChroma lenses (Salih et al., 2020). These glasses were developed based on Seebeck's theory which uses the alterations in the relative brightness of reds and greens when viewing through different coloured filters (Schmidt, 1976). These lenses use multi-notch filters to create differences in brightness to enhance colour discrimination (Salih et al., 2020). Male et al. (2022) reviewed electronic or optical devices developed between 1976 and June 2022 to assess whether they improve colour vision. This review concluded that current devices, such as "EnChroma Glasses, Chromagen filters, and EnChroma Cx-14" showed no clinical significance in enhancing the perception of colours, and they believe that the recommendation of these aids may be more counterproductive as they do not display results as advertised (Male et al., 2022). Other studies have also shown that these solutions were not effective in enhancing their overall colour vision (de Fez et al., 2002; Gómez-Robledo et al., 2018; Martínez-Domingo et al., 2019; Bastien et al., 2020; Pattie et al., 2022) and they could actually reduce the colour perception of colours that wearers were generally able to distinguish (Popleteev et al., 2015). However, some studies suggest some advantages of using coloured filters (Salih et al., 2020; Bardeci & Lagori, 2021; Alkhudairy & Al Shalman, 2022). One example is Salih et al. (2020) who assessed the effectiveness of tinted contact lenses, X-Chrom and ChromaGen, in comparison to tinted glasses (Salih et al., 2020). X-Chrom and ChromaGen lenses employ a red filter in one eye to enhance colour contrast, making them more distinguishable for individuals with CVD (Salih et al., 2020). Both aids showed improvements in the observation and judgment of colours under certain conditions, but these improvements did increase the performance to the level of individuals with normal colour vision (Salih et al., 2020). Since more of these aids are becoming readily available, their effectiveness must be further explored, specifically passive solutions, to determine whether they truly enhance colour vision. This study will examine their effectiveness when implemented onto various digital displays based on the perspective of people with CVD.

1.6 Chapter Conclusion

There is a gap in research that explores the direct effect of CVD on their interaction with digital displays. Previous studies have highlighted the challenges that people with CVD experience in their daily lives, such as choosing clothes, preparing food, identifying traffic lights (Steward & Cole, 1989), their academic performance in certain school subjects (Mashige, 2019), their development of self-esteem (Stoianov et al., 2019), and their ability to read colour-coded maps (Olson & Brewer, 1997; Long & Junghans, 2008). But only a few studies have focused on their differences in performing digital tasks, such as using computers (Mashige, 2019), browsing the internet (Futagbi et al., 2011), and computer gaming (Tillem & Gün, 2023). As these devices become more prevalent in daily life, there is an increased interest in exploring the

relationship between CVD and digital displays. Tilem and Gün's study (2023) concluded that technology can enhance the experience of gamers with CVD, which can help make games more accessible and inclusive. Technology does not only have the potential to make games more accessible, but it could also do the same in other areas of life. However, the technology has to address the person's problems in an effective manner.

Chapter 2

Purpose

The purpose of this study was to determine the challenges encountered by individuals with congenital red-green colour vision defects (CVDs) when using different digital displays in their daily lives, using an online survey conducted in Canada and the United States of America (USA).

The study's first objective was to determine the prevalence of difficulties that CVD individuals experience when performing colour-related tasks on digital displays. Some examples of tasks include: interpreting colour-coded mathematical or chemical equations in school, editing photos at work, identifying warning and caution icons on digital displays in motorized vehicles, and reading advertisements on social media platforms. These prevalences were examined across several demographic factors, such as age group and sex.

The second objective was to determine the extent of difficulty that these individuals experience when making colour-related judgements on displays. In the survey, the respondents were asked to rank the difficulty of any colour-related task that they encountered in their daily lives.

The third objective was to determine which digital devices were most commonly used when they were experiencing these challenges. This information could be useful in determining which devices to target for any possible soft- or hardware solutions to help in their colour discrimination when using digital displays.

The final objective was to determine what aids, if any, were currently being implemented to help them perform the colour-related tasks and their effectiveness.

Assuming that the problems individuals with CVD encounter when using digital displays are prevalent and more than trivial, the results would help provide a better understanding of the challenges that they face when carrying out various colour-related tasks on digital displays and provide guidance for possible assistive devices.

Chapter 3

Materials and Method

3.1 Survey Description

The survey was designed to determine whether people with CVD encountered problems in carrying out colour-related tasks on digital displays in their daily lives and to estimate the degree of the problem. The Survey Research Centre (SRC) at the University of Waterloo helped design the questions, format the survey, recruit the participants, and provide an overall summary of the findings. This online survey was only administered in English. It consisted of a total of 25 questions focusing specifically on CVD and digital displays. The complete version of the survey is in Appendix A. Below is a general overview.

- Demographic screening (mandatory)
 - e.g. country of residence, age, and sex
- Vision screening test - Abbreviated Waggoner Colour Vision Test (mandatory)
- Questions about the nature of the CVD
 - When did you become aware of the defect?
 - Did a healthcare professional diagnose the defect?
 - The time between awareness and diagnosis
 - The severity of the defect which was estimated from the frequency of encountering problems in their daily lives. The reason for using this indirect approach was that our previous experience indicated that many individuals with CVD say that their colour vision problem is mild regardless of the severity measured on clinical tests.
- Ranking the level of difficulty when using different background brightness on digital displays.
- The experiences of colour defectives when performing a number of colour-related tasks on digital displays in various areas of daily life.
- An open-ended question regarding the most difficult colour-related tasks when using digital displays.
- Ranking the effectiveness of different aids or modifications implemented on digital displays in helping with their colour judgments.
- Additional comments on experiences with digital displays and modifications (open-ended question).

3.2 Daily Aspects Covered in the Survey

The following is the list of the areas of daily life that were surveyed:

- School
- Work/Volunteering
- Recreation/Hobbies
- Social Media
- Gaming and eSports
- Online Shopping or Banking
- In-Person Shopping or Banking
- Driving/Motorized Vehicles
- Travelling

These questions were developed with the help of three individuals with CVD.

3.3 Screening for Colour Vision Deficiencies

An abbreviated Waggoner Colour Vision Test was used to screen for congenital red-green defects. This test consisted of 5 vanishing pseudoisochromatic plates. The plates were selected by Waggoner Diagnostics (Rogers, AR) from their screening series because their in-house research showed that the individual plate's screening efficiency was high. An example of one of the plates is shown in Figure 3.1. Respondents who failed the test were allowed to continue with the survey. Failure was two or more errors. One error was permitted in case there was a data entry error. This screening test did not classify the severity of the defect as the test stopped once two plates were failed. A small pilot study with two colour normals and three subjects with CVD indicated that the test would identify CVD subjects. To reduce the possible number of confounding factors, the following instructions were also included:

1. Remove any glasses with coloured lenses.
2. Sit about 20in (50cm) from the computer monitor.
3. Reset the colour management back to the original settings.

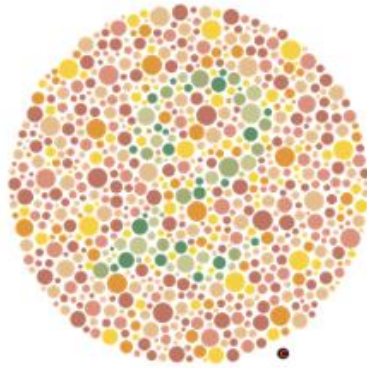


Figure 3.1. An example of a pseudoisochromatic plate from the Abbreviated Waggoner Colour Vision Test used in the survey.

3.4 Recruitment Strategy

3.4.1 Survey Platform

Subjects were recruited using two platforms: Leger recruitment company (closed survey) and through social media, specifically Facebook and Twitter (open survey). Leger recruited participants from the ages of 10 years old and above, while the social media recruitment was limited to individuals from 18 years old and older. Facebook advertisements directed towards specific demographics (e.g., location and age) were used to recruit for the open survey.

The target number of respondents for the closed survey was 275 (~175 respondents from Canada and ~100 respondents from the USA) with at least 125 respondents under 18 years old (Table 3.1). The higher number of Canadians was a reflection of Leger's reduced ability to recruit participants from the USA. For the open survey, the target size was about 100 adults, and there was no quota for Canada or the USA. This total sample size was based on cost considerations and a previous study by Steward and Cole (1989) who administered their survey to 102 colour defectives. Their study and ours were both directed towards first-world countries (Australia vs Canada and USA), and the types of survey questions were relatively similar (e.g. awareness of CVD and challenges in daily life, such as work and driving). Based on this information, it was deemed that approximately 100 adult respondents from each survey platform and 100 respondents under 18 years old would provide an adequate representative sample.

Table 3.1. The respondent quota is based on the location and age group of the panel firm (closed survey).

Demographic	Quota
Canadian Youth	75
American Youth	50
Canadian Adult	100
American Adult	50
TOTAL	275

The average time length to complete the survey was 15 minutes. It was available from July 19, 2022 until September 1, 2022. During the six weeks of data collection, a total of 19,032 survey invitations were sent out to panel firm members, and 13,931 email reminders were later sent. A clean-up of the data was done after meeting all the quotas, and 14 respondents from the closed survey and two respondents from the open survey were removed because their responses were faster than the expected completion of the survey and/or provided questionable answers.

3.4.2 Sex

There were no exclusions based on sex, but because there is a lower prevalence of congenital red-green CVD in females than males, it was anticipated that only a few female respondents would complete the survey.

3.5 Description of Survey Platforms

With the exception of the parental consent in the closed survey, the surveys administered to them were identical. The participants who completed the closed survey received both LEO points and "chances" toward a monthly draw through Leger. Participants who were screened out or withdrew before completing the survey received a portion of the total LEO points towards their account along with one "chance" towards their monthly draw. No reimbursement was provided for the individuals who completed the open survey. This study was reviewed and received ethics clearance through the University of Waterloo Research Ethics Board (REB #43990).

3.6 Statistical Analysis

The data in this study was either nominal or ordinal so non-parametric statistical procedures were used. The statistical software that was used to perform most of the non-parametric tests was IBM SPSS Statistics Version 29.0.0.0 (241), except for the Pearson's chi-square test results for chapters 6-8 of the

Results. This was performed using GraphPad Prism 10 version 10.1.2 (324) since it was simpler to use this software based on how the raw data was organized.

The chi-square test of independence (χ^2) was used to determine whether there were significant associations between demographic factors (chapter 4) and demographic factors and questions about CVD (chapter 5). It was also used in subsequent chapters (chapters 6-8) to determine if there were significant associations between tasks, modifications, and types of digital displays selected based on either sex or age group. For chapters 6-8, the Mann-Whitney U test was also performed to determine whether there were significant differences in the rankings of tasks or modifications based on sex and age group. The Kruskal-Wallis H test was performed on the rankings to examine whether severity caused significant differences. If the main effect of severity on the rankings was significant, then the Dunn post-hoc test with the Bonferroni correction (adjusted p-value) was used to determine which pairwise comparisons reached statistical significance. The Mann-Whitney and Kruskal-Wallis tests are both non-parametric tests that compare the differences in the rankings between two (Mann-Whitney test) or more (Kruskal-Wallis test) groups based on a particular demographic factor (sex, age group, and severity). The Friedman K test was used to determine whether there were significant differences between the difficulty rankings across the three background brightness by the same respondents since no data was missing (chapter 6). The Wilcoxon signed-rank test with the Bonferroni correction was used as the post-hoc test to determine which pairwise comparisons were significantly different if there was a significant main effect. The significance level for most analyses was $p \leq 0.05$, except for the p-values obtained from the Mann-Whitney, Kruskal-Wallis and Friedman tests, which were based on the adjusted p-value for significance to account for the multiple comparisons using the Bonferroni correction ($\frac{\alpha}{\# \text{ tasks}}$).

Chapter 4

Results - Demographic Factors

The results section will be divided into chapters focusing on the different areas covered in the survey and their own discussion at the end. This chapter will discuss the demographic results (survey platform, location, age, age group, and sex). Age refers to the age bracket that the respondent fits into (e.g., 10-13 years old), and age group refers to youth (10-17yo) and adults (≥ 18 yo).

4.1. Distribution of Respondents from the Closed and Open Surveys

The following information was provided in a report from the Survey Research Centre at the University of Waterloo that summarized our data collection. Of the 19,032 individuals who the Leger recruitment company invited to complete the survey, 13,425 did not log into the survey, 5,301 respondents were not eligible, and 23 respondents left the survey at some point with insufficient data. The remaining 283 respondents (78 Canadian youth, 51 USA youth, 104 Canadian adults, and 50 USA adults) completed the closed survey. That is, 5% of the respondents who logged into the survey, completed it. For the open survey, a total of 1231 logged into the survey. Of these individuals, 801 individuals dropped out of the survey, 330 individuals were ineligible, and 100 completed the survey. After reviewing the data for invalid responses, the final count for the open survey was 98 respondents (42 Canadian adults and 56 USA adults). This results in a completion rate for the open survey of 8%. In total, 381 respondents completed the survey across both platforms. With this number of respondents, all quotas were either met or exceeded.

The distribution of the respondents is shown in Table 4.1 and Table 4.2 summarizes the Pearson's chi-square test (chi-square test; χ^2). For one pair of demographic factors, age and survey platform, the chi-square test was only performed on adults because there were no youth in the open survey. In other cases, the data was pooled into the youth and adult age groups because some youth age categories had zero frequencies.

Table 4.1. The demographics of respondents based on the survey platform, location, age group, age, and sex. The percentages are based on the total number of respondents who completed the survey (N=381).

Demographic Factors	Sex			
	Male (N=280)		Female (N=101)	
Survey Platform	Closed	Open	Closed	Open
	50.9%	22.6%	23.4%	3.1%
	(194)	(86)	(89)	(12)
Location	Canada	USA	Canada	USA
	40.9%	32.5%	17.8%	8.7%
	(156)	(124)	(68)	(33)
Age Group	Youth	Adult	Youth	Adult
	22.6%	50.9%	11.3%	15.2%
	(86)	(194)	(43)	(58)
Age Category	10-13yo: 8.1% (31)		10-13yo: 6.0% (23)	
	14-17yo: 14.4% (55)		14-17yo: 5.2% (20)	
	18-22yo: 3.9% (15)		18-22yo: 2.4% (9)	
	23-29yo: 10.2% (39)		23-29yo: 2.9% (11)	
	30-39yo: 10.5% (40)		30-39yo: 5.0% (19)	
	40-49yo: 11.0% (42)		40-49yo: 1.6% (6)	
	50-59yo: 7.6% (29)		50-59yo: 2.4% (9)	
	60+yo: 7.6% (29)		60+yo: 1.0% (4)	

Table 4.2. The demographic parameters that showed significant dependencies with each other. The p-values in parentheses represent significant associations.

Demographic Factors		Pearson's chi-square test (χ^2)		
		χ^2 Value	Degrees of Freedom (df)	Asymptotic Significance (p-value)
Age (Adult)	Survey Platform	30.5	5	(< 0.001)
Location	Survey Platform	13.8	1	(< 0.001)
Survey Platform	Sex	13.8	1	(< 0.001)
Age Category	Sex	18.7	7	(0.009)
Age Group	Sex	4.7	1	(0.031)
Location	Sex	4.1	1	(0.042)
Location	Age	9.7	7	0.21
Location	Age Group	0.2	1	0.64

The majority of respondents (74.3%) came from the closed survey. More Canadians (58.8%) than Americans (41.2%) completed the survey, as it was easier to recruit Canadians for the closed survey. However, it was interesting to note that more Americans did complete the online survey (US: 57.1%; Canada: 42.9%). These differences were statistically significant ($p < 0.001$). The frequency of adults (66.1%) was significantly higher than youth (33.9%), which was expected since no youth respondents were recruited through social media. Nevertheless, this result was also the case in the closed survey, but the difference was not as large. Youth made up 45.6% of the closed survey respondents and 54.4% were adults. Within the adults, there were more young adults (23-39yo) recruited in the open survey and more older adults (≥ 40 yo) in the closed survey. These differences were also statistically significant ($p < 0.001$).

A total of 280 males and 101 females completed the survey, meaning that 26.5% of the participants were female. There was a higher-than-expected participation rate by females, which raised concerns of validity, which will be discussed later. Although there were more males than females in both surveys, females made up a higher proportion in the closed survey (closed: 31.4%; open: 12.2%). These differences were statistically significant ($p < 0.001$). Females were predominately composed of adults, similar to males, but the proportions of youth (43) and adults (58) within females were relatively similar. This was also reflected in the age category where females were primarily comprised of the younger adults (10-17yo and 23-39yo), whereas a higher proportion of the older adults (23+yo) within the males. These differences were statistically significant for both age group ($p = 0.031$) and age category ($p = 0.009$).

4.2 Chapter Discussion

4.2.1 Findings in the Distribution of Respondents in Closed and Open Surveys – Prevalence of Female Participation Rate

A total of 381 respondents (280 males) from Canada and the USA completed the survey. The participation of females in the survey was higher than expected (overall: 26.5%), which initially raised concerns about the validity of the survey given its low prevalence in the female population. The female prevalence was compared in both countries and based on the proportions of the females (101) who completed the survey, 67.3% (68) of them were Canadians and 32.7% (33) were Americans. If the proportion of females is expressed relative to the total number from each country who completed the survey, the proportion of females from each country is similar (30.4% Canadian females; 21.0% American females).

The proportions of female participants were also compared based on survey platforms, where the closed survey consisted of 31.4% females and 12.2% females in the open survey. According to the report from the Survey Research Centre at the University of Waterloo, a total of 19,032 invitations were sent out to panel firm members, where 89 females completed the closed survey, corresponding to a participation rate of 0.47%. This rate is comparable to rates found in Birch's literature review (2012), where she reported an average prevalence rate of 0.43% (range from 0.36% to 0.50% for European Caucasian females). We cannot conduct a similar analysis for the open survey because we do not know how many people read the social media advertisements. Nevertheless, the female participation rate of 12.2% for the open survey was comparable to the participation rates found in two studies that were conducted in Waterloo, Canada which used social media, posters around the university, and advertisements in newspapers to recruit subjects (Almustanyir & Hovis, 2015; Almustanyir et al., 2020). One study had a female participation rate of 6% (Almustanyir & Hovis, 2015), and the second study had a female participation rate of 10% (Almustanyir et al., 2020). Although these rates are slightly lower than the open survey value, they are comparable given the low prevalence of CVD in the female population. Overall, 79.2% of the females reported having their CVD diagnosed by a healthcare professional (80). There were 80.9% in the closed survey (72) and 66.7% in the open survey (8).

When taking into account the number of invitations that were sent out and similar female prevalence rates, as shown in Birch's study (2012) for the closed survey, the response rates of females between the open survey and the two Waterloo studies that used similar recruitment methods, and the

high percentage of females self-reporting being professionally diagnosed, the concerns of validity were subsided.

4.2.2 Significant Associations Between Demographic Factors

Sex was the only demographic factor that showed consistently different distributions across demographic parameters (survey platform, location, age, and age group). This was expected as there is variation in the prevalence of congenital red-green CVD between males and females, where ~8% of European men and ~0.4% of European women are affected due to its X-linked recessive inheritance (Birch, 2012). The differences in the survey platforms resulted from more Canadians completing the closed survey as compared to more Americans completing the online one. As expected, there were more adults in the closed survey since there were no youth recruited through social media. However, more older adults completed the closed survey than the open survey, which consisted of younger adults. The larger overall percentage of Canadians was due to them being more easily recruited in the closed survey than Americans.

Chapter 5

Results – Questions About Their Colour Vision Deficiency

This chapter will examine responses to questions about their colour vision deficiency (CVD) regarding when they became aware of their CVD, whether a healthcare professional has diagnosed them, the time between awareness and diagnosis of their condition, and the severity level.

5.1 Awareness of Colour Vision Deficiency

Figure 5.1 shows the (A) overall distribution of when respondents became aware of their CVD. Out of the 381 respondents who completed the survey, the largest group but not a majority of respondents (40.2%; 153) became aware of their condition in elementary school. Some also became aware of their defect after high school (31.2%; 119), and others were unaware until they took the survey (3.2%; 12). There was insufficient statistical evidence to conclude whether there was any dependency between when the adult respondents became aware of their defect and the demographic factors of location, survey platform and sex ($p \geq 0.11$) (Table 5.1). Youth were excluded from the analysis because none were recruited through the open survey. Nevertheless, both surveys had a significant dependency between the time of awareness and age group ($\chi^2 = 43.5$, $df = 5$, $p < 0.001$). Figures (B) and (C) show the distribution of awareness of the adult and youth respondents, respectively. The higher frequency of youth becoming aware of their condition before high school was expected since the age range in the youth group is restricted to 18 years old and younger. Regardless, the majority of individuals in both age groups became aware of their defect in elementary school.

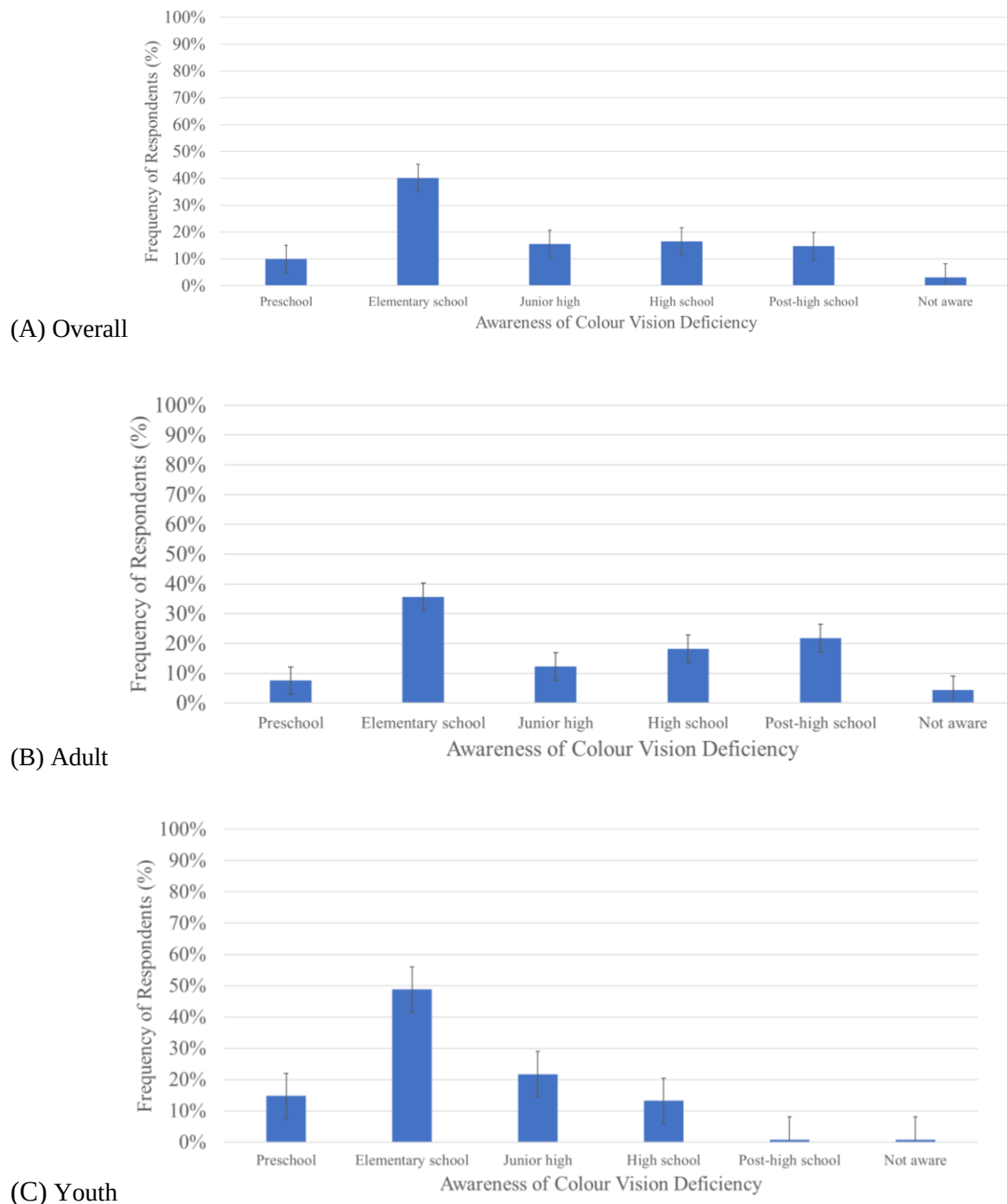


Figure 5.1. The overall distribution of (A) overall respondents (N=381), (B) adults (N=252), and (C) youth respondents (N=129) based on when they became aware of their colour vision deficiency (Q1). The error bars represent the standard error.

Table 5.1. The dependencies of the demographic parameters with awareness. The p-values in parentheses show statistical significance.

Demographic Factors	Pearson's chi-square test (χ^2)		
	χ^2 Value	Degrees of Freedom (df)	Asymptotic Significance (p-value)
Age Group	43.5	5	(< 0.001)
Survey Platform	9.1	5	0.11
Age (Adult)	33.5	25	0.12
Sex	4.1	5	0.54
Location	1.9	5	0.86

5.1.1. Effect of Severity on Awareness

Another factor that was analyzed was the effect of severity on the awareness of CVD. Figure 5.2 (A) shows the distribution of awareness based on severity for all respondents and (B) for only adults. The overall respondents were primarily composed of adults as they are the only age group expected to be present after high school. Both figures displayed similar trends where people with CVD who encountered difficulties more frequently reported becoming aware of their condition earlier, which would be expected. However, a few respondents became aware of their defect after high school, regardless of their severity. Figure (C) shows the distribution of the youth respondents. This included one individual who became aware of their condition after high school and labelled their severity as encountering problems "more than once a week," and another who was unaware of their defect until they took the survey and labelled their severity as encountering problems "at least once a week." A similar trend between awareness and severity was present among youth (more severe defects became aware of their condition earlier). Regardless of the variations in the distributions, there was no significant dependency between awareness and severity on the overall respondents ($\chi^2 = 25.0$, $df = 16$, $p = 0.069$). The "not aware" category was removed from the analysis as there were no respondents who were unaware of their defect and reported encountering problems "at least once a month." The chi-square test could not be performed on youth and adults, individually, because it did not meet the inclusion criteria that the expected value must be greater than 1 or more than 20% of expected values must be greater than 5, even after combining categories.

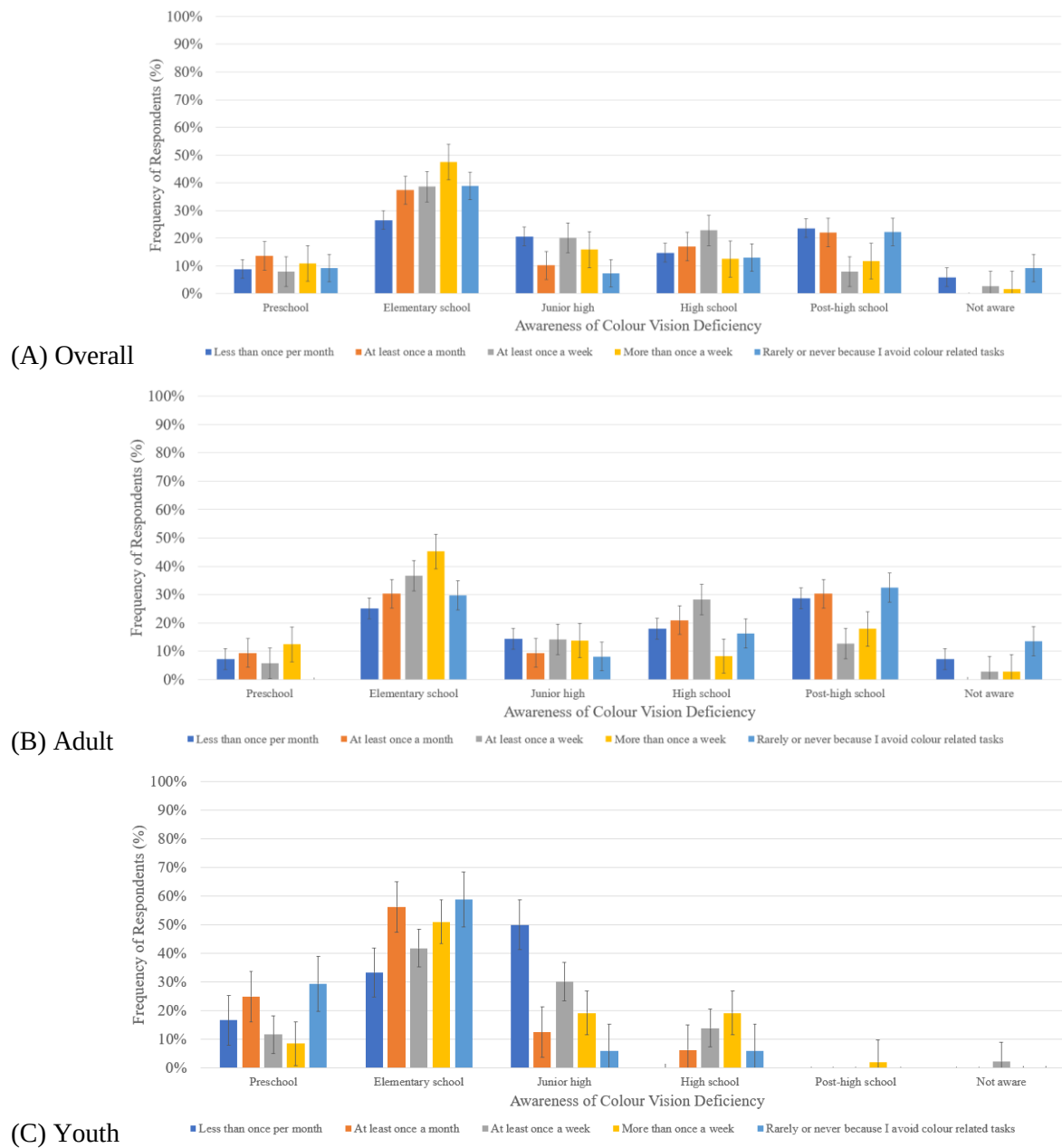


Figure 5.2. The distribution of awareness of colour vision deficiency based on severity for (A) overall (N=381), (B) adults (N=252), and (C) youth respondents (N=129). The error bars represent standard error.

5.2 Professional Diagnosis of Colour Vision Deficiency

Figure 5.3 shows the distribution of whether respondents were ever professionally diagnosed with CVD. From the 381 respondents who completed the survey, 77.2% (294) were diagnosed, 17.3% (66) were not, 2.4% (9) preferred not to answer, and 3.1% (12) did not respond to the question.

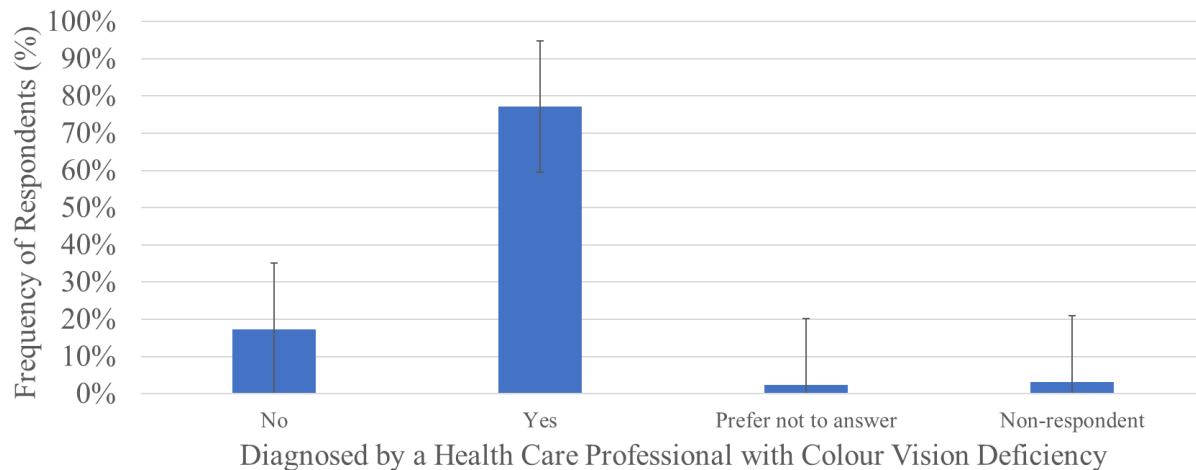


Figure 5.3. The overall distribution of respondents based on whether respondents were ever diagnosed by a healthcare professional (Q2A) (N=381). The error bars represent standard error.

Since the majority (77.2%) of respondents who completed the survey responded with "yes," its distribution was plotted based on the five demographic factors to analyze whether they were different. The chi-square test could not be performed since the responses are not mutually exclusive. Figure 5.4 shows the distributions for (A) survey platform, (B) location, (C) age, (D) age group, and (E) sex. Based on the figures, there were relatively similar distributions in the "yes" response across all categories of each demographic factor, where ~70% of respondents were professionally diagnosed. However, there were some variations in age and age group where slightly more youth (~86%) reported being professionally diagnosed than adults (~73%).

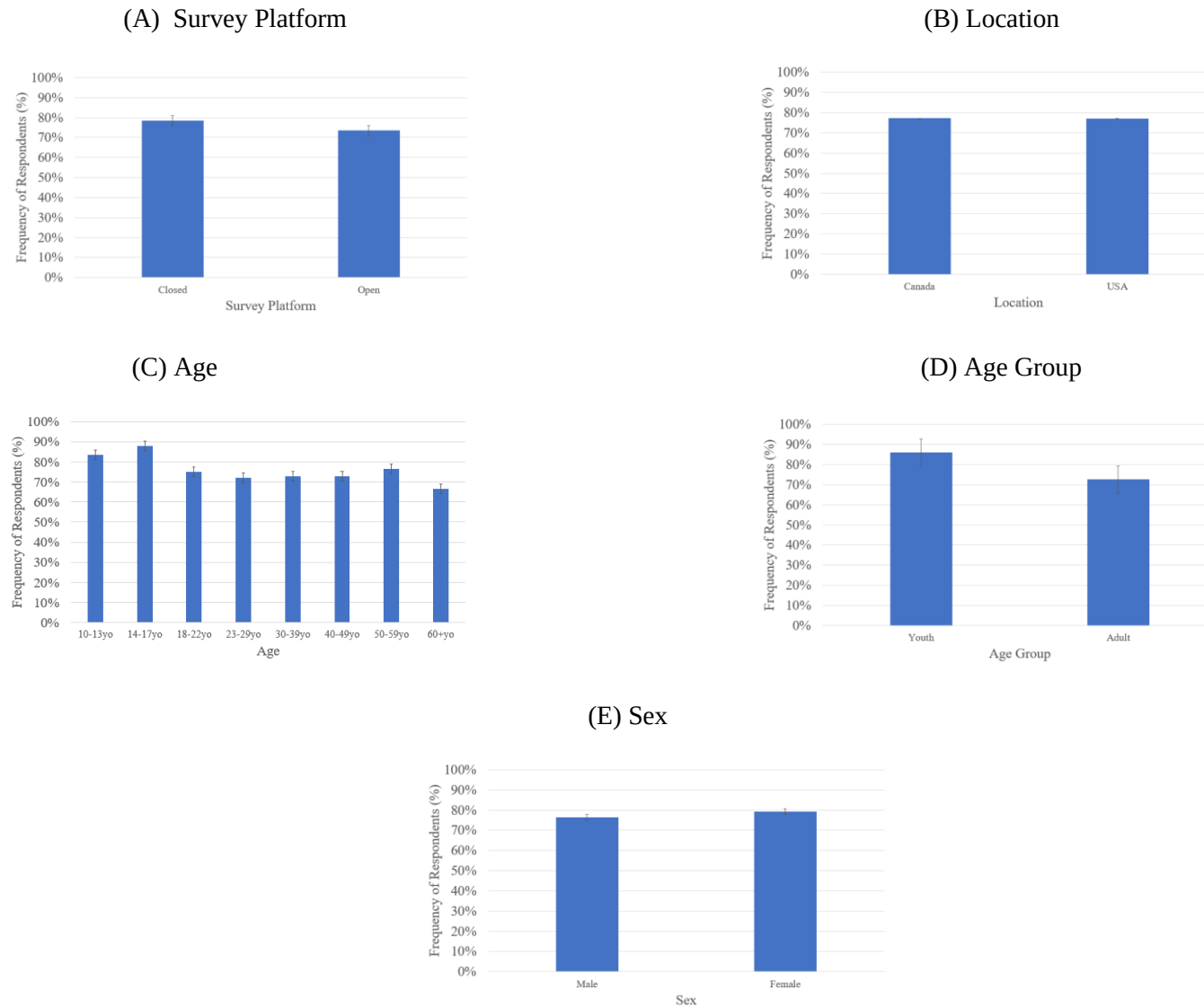


Figure 5.4. The distribution of respondents on whether they were diagnosed by a healthcare professional (Q2A) for “yes” (N=294) based on (A) survey platform, (B) location, (C) age, (D) age group, and (E) sex. The error bars represent standard error.

The data was also initially examined to determine whether there are any dependencies between diagnosed versus undiagnosed participants regarding their condition based on demographic factors (e.g. age, age group and sex) and the other questions about CVD. However, this approach was shortly rejected as there were similar distributions between diagnosis and awareness ($p = 0.32$), and diagnosis and severity ($p = 0.61$).

5.3 Time Between Awareness and Diagnosis of Colour Vision Deficiency

Figure 5.5 shows the distribution of respondents for the time between awareness and diagnosis for those who reported being professionally diagnosed. Many individuals (22.8%; 87) did not respond to this question or were unsure about the time (18.9%; 72). However, for those who could remember and responded, the majority indicated that it was more than 5 years (16.3%; 62) from when they were aware of their defect to be diagnosed, but the frequencies for the other time intervals were only slightly less. Based on the chi-square test, there were no significant dependencies on the frequencies with age category within the adult group, survey platform within adults, location and sex (χ^2 , $p \geq 0.068$). However, there were significant dependencies with survey platform, age, and age group as shown in Table 5.2. The "non-respondents" were included in the analysis to provide a better representation of the distribution across all responses by the respondents, and to understand the dependency of demographic factors on time between awareness and diagnosis.

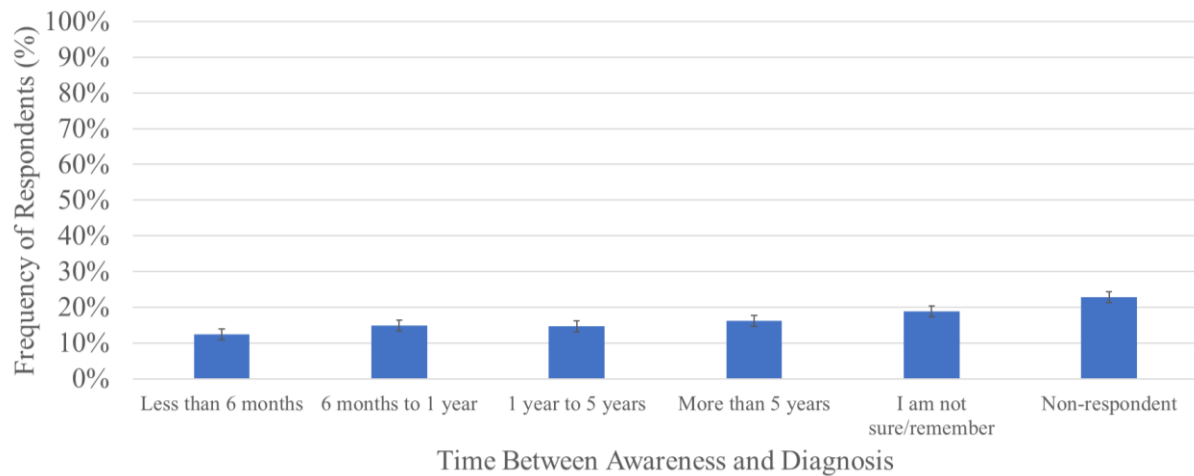


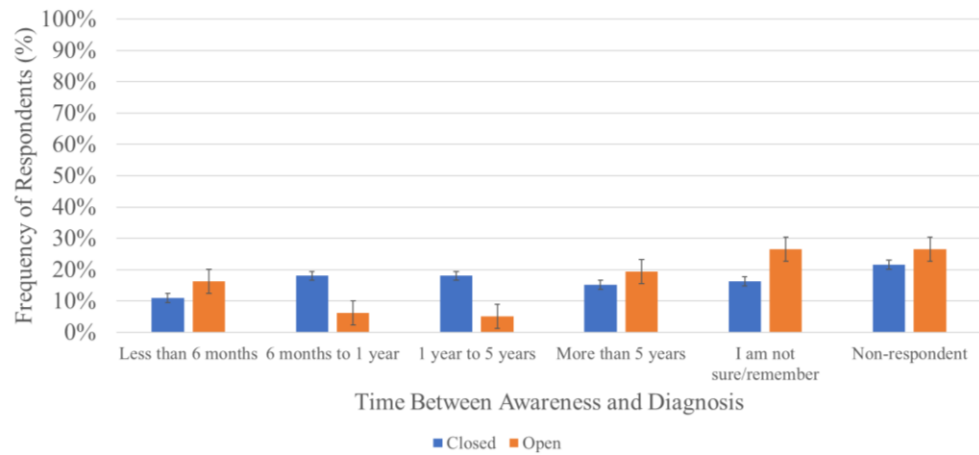
Figure 5.5. The overall distribution of respondents based on the time between awareness of colour vision deficiency and being professionally diagnosed by a healthcare professional (Q2B) (N=381). The error bars represent standard error.

Table 5.2. The dependencies of the demographic parameters with time between awareness and diagnosis. The p-values in parentheses show statistical significance.

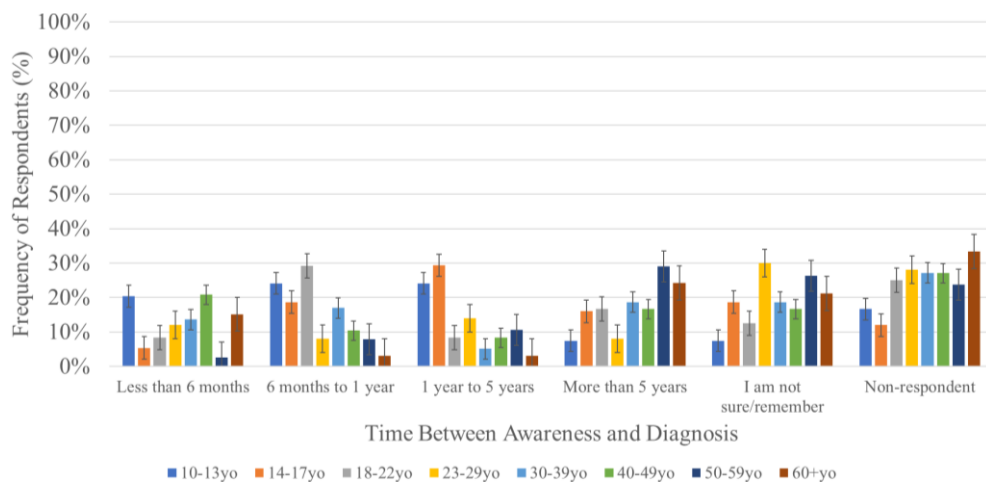
Demographic Factors	Pearson's chi-square test (χ^2)		
	χ^2 Value	Degrees of Freedom (df)	Asymptotic Significance (p-value)
Survey Platform	22.5	5	(< 0.001)
Age	76.0	35	(< 0.001)
Age Group	36.3	5	(< 0.001)
Survey Platform (Adult)	10.3	6	0.068
Age (Adult)	31.2	25	0.18
Location	6.1	5	0.30
Sex	0.6	5	0.99

Figure 5.6 shows the distributions of (A) survey platform, (B) age, and (C) age group. Age includes specific age ranges (e.g. 10-13yo and 14-17yo), whereas age groups compared distributions between youth and adults. As expected, the younger respondents were more likely to have less time between their awareness and diagnosis given their restricted age range. These demographic factors showed significant dependencies ($p < 0.001$). For those 18 years old and older, the number of non-responses or do not remember increased along with an increase in the longest interval between awareness and diagnosis response for the two oldest age groups. There was no need to perform a post-hoc test on the age category as this similar trend was also reflected in the age group distribution, where youth were more likely to have a shorter time interval between awareness and diagnosis. For the survey platforms, the open

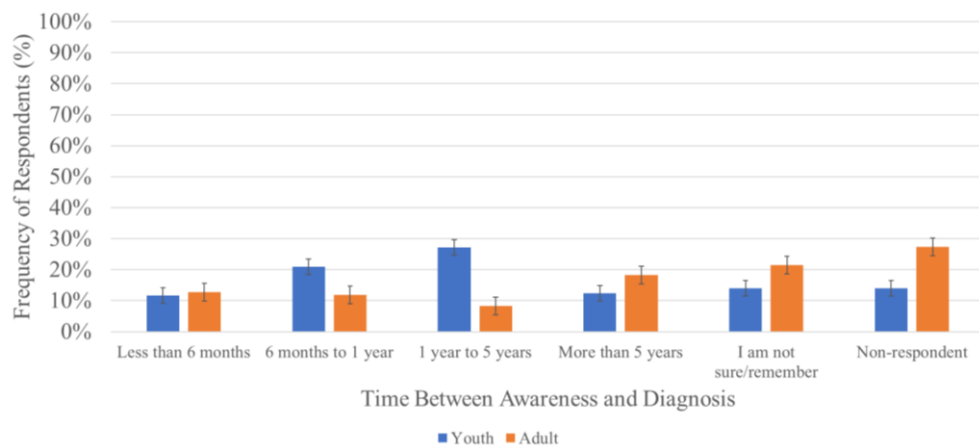
survey consists of only adults who were less likely to respond to the 6 months to 1 year, and 1 year to 5 years categories. We decided to combine respondents into age groups to equal out any differences in age distributions across both survey platforms. When the youth are excluded, there is no significant difference between survey platforms ($p = 0.068$).



(A) Survey Platform



(B) Age



(C) Age Group

Figure 5.6. The distribution of respondents based on the time between awareness of colour vision deficiency and being professionally diagnosed by a healthcare professional (Q2B) (N=381) based on (A) survey platform, (B) age, and (C) age group. The error bars represent standard error.

5.3.1 Effect of Severity on Time Between Awareness and Diagnosis

Severity was also examined to determine whether it affects the time between awareness and diagnosis of CVD. Figure 5.7 (A) shows the distribution for all respondents, (B) for only adults, and (C) for only youth. There was a similar trend between overall and adults where there was generally no relationship between severity and time between awareness and diagnosis. However for youth, individuals with more severe defects had shorter durations (≤ 5 years). There was a significant dependency for the time of awareness and diagnosis with severity on all respondents ($\chi^2 = 48.5$, $df = 20$, $p < 0.001$). The chi-square test could not be performed on youth and adults, individually, because it did not meet the inclusion criteria that the expected value must be greater than 1 or more than 20% of expected values must be greater than 5, even after combining categories.

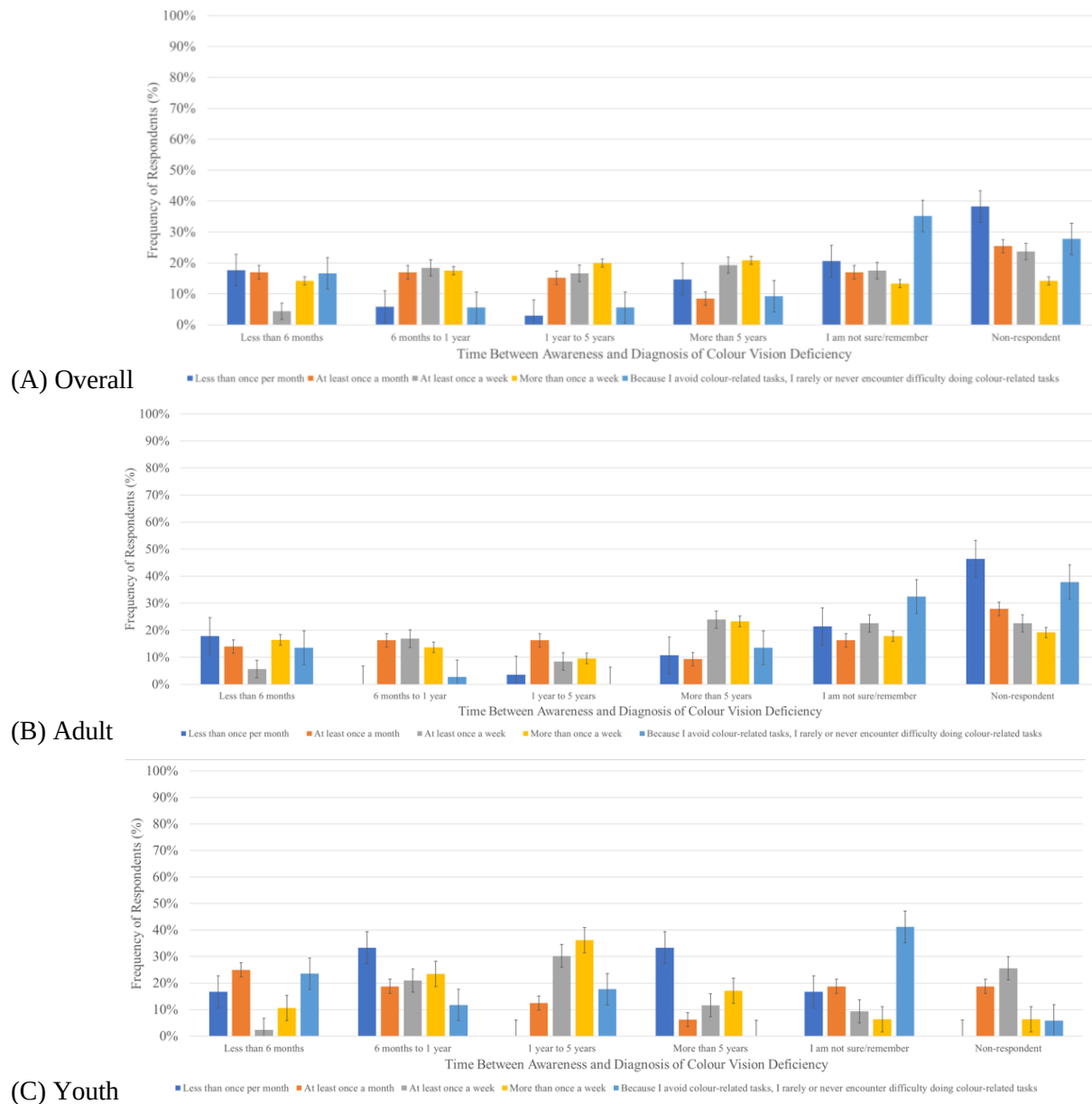


Figure 5.7. The distribution of time between awareness and diagnosis of colour vision deficiency based on severity for the (A) overall (N=381), (B) adults (N=252), and (C) youth respondents (N=129). The error bars represent standard error.

5.4 Severity of Colour Vision Deficiency

Figure 5.8 shows the overall distribution of respondents for the different severity levels. Severity was used as a surrogate to measure the frequency of encountering problems, as described in the Methods chapter. The breakdown of the sample based on severity was 24.4% (93) were categorized with "mild"

defects ("less than once per month" and "at least once a month"), 61.4% (234) "severe" ("at least once a week" and "more than once a week"), and 14.2% (54) were avoidant ("rarely or never encountered difficulty because they avoid colour-related tasks"). There were no significant dependencies between severity and any of the demographic factors (age adult, location, age group, survey platform and sex) (χ^2 ; $p \geq 0.11$) (Table 5.3).

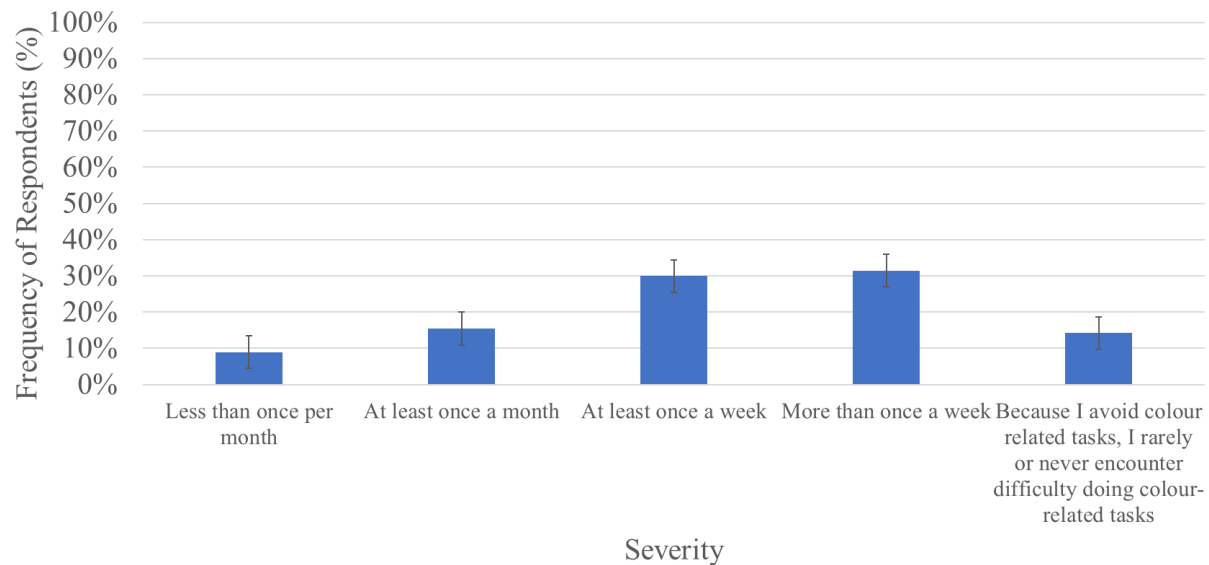


Figure 5.8. The overall distribution of respondents based on the severity of colour vision deficiency (Q3) (N=381). The error bars represent standard error.

Table 5.3. The dependencies of the demographic parameters with severity. The p-values in parentheses show statistical significance.

Demographic Factors	Pearson's chi-square test (χ^2)		
	χ^2 Value	Degrees of Freedom (df)	Asymptotic Significance (p-value)
Age Group	7.6	4	0.11
Location	6.7	4	0.15
Age (Adult)	26.0	20	0.17
Survey Platform	6.4	4	0.17
Sex	6.1	4	0.19

Figure 5.9 shows the distribution of (A) sex and (B) age group based on severity. Although there were no significant differences between either sex or age group, the figures are included to show how severity varies among these two demographic factors since their relationship to other factors will be examined in later sections. The trend in these figures reflects the trend in the overall distribution.

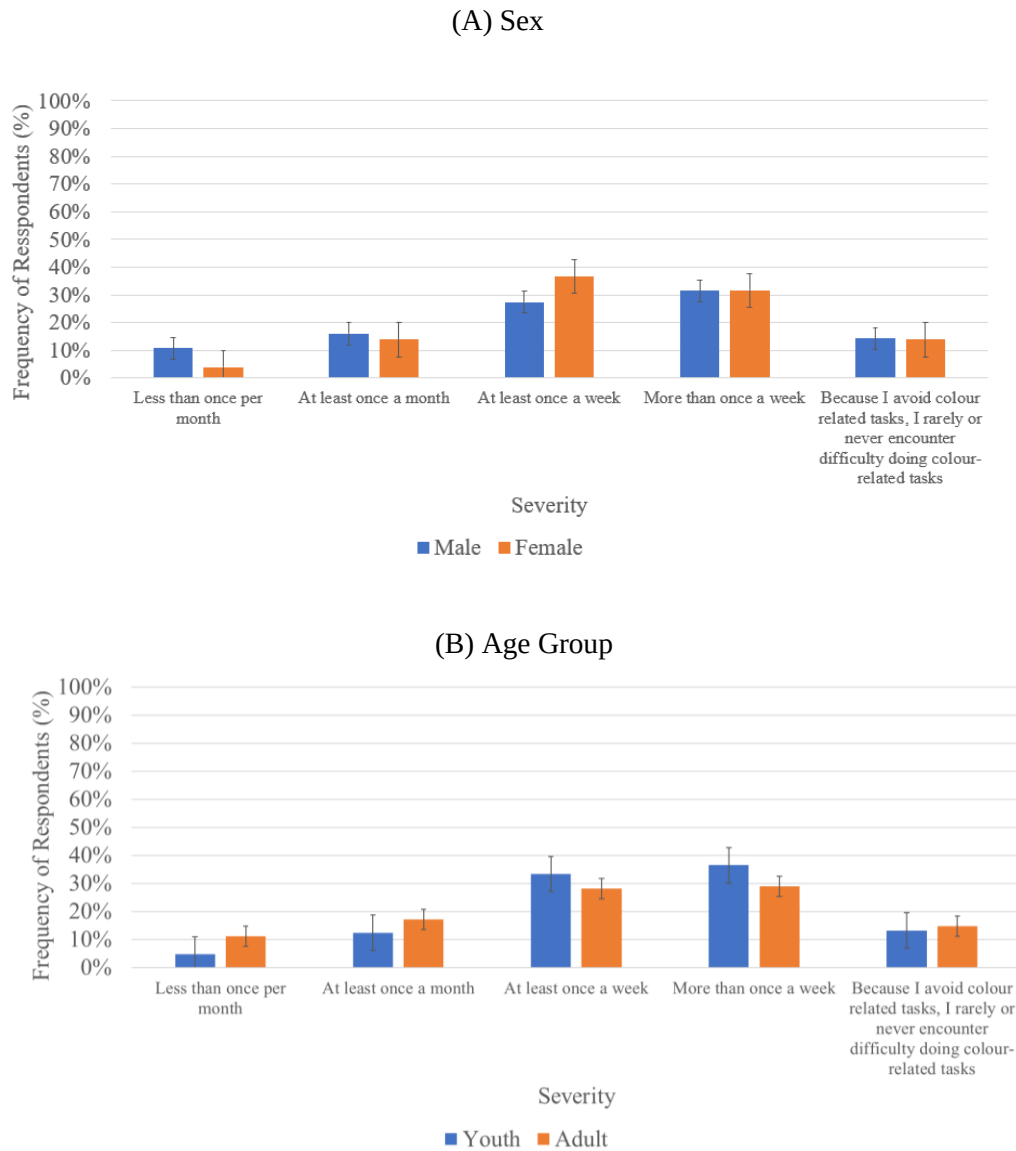


Figure 5.9. The distribution of severity reported by respondents (N=381) based on (A) sex and (B) age group. The error bars represent standard error.

5.5 Chapter Discussion

5.5.1 Awareness of CVD

The purpose of determining when the respondents became aware of their CVD was to provide a better understanding of CVD experiences in coping with their defect. The information could also be helpful in developing vision screening protocols and practice standards regarding CVD. The result that the majority became aware of their defect during elementary school is not unexpected. By the time many children reach elementary school, teachers are likely using colours to teach more complex topics or trying to create

more engaging environments. This would likely be the time when children with CVD notice their challenges since they tend to perform worse on assignments and tests that rely heavily on coloured content (Jadhav et al., 2017), which can result in the child developing a faulty foundation for learning and low self-confidence (Cole, 2004; Albany-Ward, 2011). Even though the degree to which colour is used to convey information may vary across ages, colour likely continues to play a vital role in children's education. In Steward and Cole's study (1989), 23.3% of the respondents (49% of dichromats and 8% of anomalous trichromats) became aware of their CVD in primary school. Another 25.6 % (22% of dichromats and 28% of anomalous trichromats) became aware before graduating high school. The remaining became aware later on in life or were unaware until taking part in the survey (Steward & Cole, 1989).

Respondents in this study, however, were more likely to be aware of their CVD at an earlier age, with 50.1% of the respondents being aware of the defect by elementary school and an additional 35.2% by the end of high school. There were 14.7% who became aware of their CVD after high school. In this study, only 3.2% were unaware of their CVD until they took the survey compared with the 17.6% in Steward and Cole's survey. There are several possible reasons for the differences in the results. One could be the difference in the use of colour in the two educational systems. In North America, colour may be used more extensively than in Australia at the time. It could also be the case that with the advent of coloured digital devices in everyone's daily life, a person with a CVD would become aware of the colour vision problems at an earlier age. An increased emphasis on providing vision care to children currently in North America could also contribute to the differences in the survey results. However, we believe that the primary reason is the different recruitment processes. Steward and Cole's subjects were consecutive patients of a single practice, and some respondents came to the practice because the first indication that they had a CVD was that they failed a trade colour vision test. Most of these latter individuals had milder defects. Our process likely recruited more individuals with moderate-to-severe CVD, who were well aware of their defect because of a recent diagnosis or a reminder of their previously diagnosed CVD as a result of a recent eye examination or interactions with family or friends. Regardless, it is unlikely that our recruitment process would encourage individuals with mild defects to participate; thus, fewer people in the sample became aware of their defect after high school. Of course, any combination of these factors could contribute to the difference between the two surveys.

Indirect support for the idea that the survey recruited individuals with more severe defects was the result that CVDs who experience difficulties more frequently were more likely to become aware of their condition earlier in life. Interestingly this trend was present in both youth and adults. One might

expect that the majority of youth respondents would become aware of their defect at an earlier age, but this was somewhat the case for adults. Most of the adults became aware of their CVD after elementary school, which was still early on but not as early as youth.

5.5.2 Diagnosis of CVD

Diagnosis was another aspect of the condition that we were interested in exploring because it could provide an indication of the standard of care that CVD individuals receive in Canada and the USA. Our study showed that 77.2% of the respondents reported having their CVD diagnosed by a healthcare professional. This percentage is slightly higher than the 73.5% having a prior CVD diagnosis in the Steward and Cole's (1989) survey. Given the difference in recruitment between both studies, there is a surprising agreement between current diagnostic practices with ones performed 30 years ago in another Western country. The company sent invitations to adults, so it is more likely that their knowledge of the child's CVD was a result of a diagnosis by a healthcare professional. It is also possible that the child's colour vision was assessed prior to the survey because there was a family history of colour vision problems.

5.5.3 Time Between Awareness and Diagnosis

The purpose of exploring the time between awareness and diagnosis was to determine the duration between experiencing challenges imposed by the colour defect and assessment by a healthcare professional. This is of interest because it could be another reflection of the standard of vision care. For example, a long duration between awareness and diagnosis could reflect the lack of colour vision testing at routine visual assessments or the lack of any vision assessment. The duration could also reflect how the CVD is perceived or impacted by the individual or family members. That is, a long duration could result from CVD having minimal impact on the person's daily life. In this study, the findings do not show a clear trend, except for the youth, where individuals with more severe defects tend to have a shorter duration between awareness and diagnosis (≤ 5 years). Most respondents (41.7%) did not respond or were not sure/did not remember the time between awareness and diagnosis. This suggests that they were either unaware of the defect until the survey or the diagnosis was not memorable. However, given that only 3.2% were unaware of their defect until the survey, it appears that the majority of the non-respondent individuals simply could not remember when the diagnosis was made or when they became aware of difficulties.

The general trend for the rest of the subjects was that frequencies for the other intervals for males and females were similar. As expected, the youth group was more likely to remember the interval and

have a shorter duration between awareness and diagnosis, given that they were younger and the recruitment process.

5.5.4 Severity of Condition

Severity is another important aspect of the condition as it gives us an idea of the difficulty level that people with CVD experience. In our clinical experience, some discrepancy often exists in the severity obtained from professional testing and people with CVD's experience, so the frequency of encountering problems was used as a surrogate of severity. Helfand (1999) also reported similar results where six of the eight respondents who had more severe CVDs felt that their defects were minor, and two other respondents with mild defect did not view themselves as being disabled. There were seven respondents who preferred to remain among the "norm" by having their condition hidden (Helfand, 1999).

For this section, there were no demographic factors that showed significant dependency with severity, which suggests that there was no bias within the age group, sex, and survey platform. The higher percentage of respondents experiencing challenges at least once a week (61.4%) was likely due to self-selection. Individuals having more frequent problems with colour-related tasks are more likely to have a diagnosis and become aware of their defect, where they may have been more willing to participate in the survey.

5.6 Approach for Analysis

After reviewing all the results from the chi-square test for the demographic factors and the screening questions, we decided to pool the data based on location and survey platform because that helps even out the distribution based on severity. Also, the distribution of data based on survey platforms showed that the open survey had a greater number of respondents within young adults (20-29 years old and 30-39 years old), and the closed survey had more respondents in the younger and the older demographics. By pooling the data across platforms, it helped balance the age distribution of respondents. For the remainder of this thesis, the data will be analyzed based on sex, age group and severity. Analyzing the data based on sex examines possible differences in the experiences between males and females. Since there was a higher-than-expected prevalence of females who completed the survey, we wanted to explore whether there were any differences in the experiences between males and females. To our knowledge, there are no other surveys that specifically examined the experiences of females with CVD. Because there were empty cells in some of the youth age categories, similar proportions in the two age groups based on location, and similar average proportions based on location (chapter 4), we decided to pool the ages into youth and

adult to determine if adults and youth have different issues with displays that could be related to how they incorporate them into their daily lives. There are some variations in the distribution of location across the different adult ages, but they are not significantly different. Because the distributions of severities were not significantly different between sex or age group, the analysis across severities will be for the entire number of respondents for the questions.

Chapter 6

Results – Background Brightness

This chapter explores the difficulty in reading coloured letters, numbers or icons when using different background brightness on digital displays (white, medium bright, and dark). The medium bright background refers to backgrounds that incorporate colours with similar intensities to grey or light blue.

6.1 Comparisons of Difficulty Rankings of Different Background Brightness

Figure 6.1 shows the distribution of the 381 respondents who ranked the difficulty level of the three backgrounds. There were relatively similar distributions in the rankings where most respondents reported encountering either "a little difficulty" (white: 37.5%, 143; medium: 39.9%, 152; dark: 34.1%, 130) or "some difficulty" (white: 32.8%, 125; medium: 39.1%, 149; dark: 33.3%, 127) across the backgrounds. The Friedman K test showed that there were significant differences in the mean rankings ($\chi^2 = 15.5$, $df = 2$, $p < 0.001$; adjusted p-value for significance = 0.017), specifically for the rankings between the "white background" and "medium bright background" (adj. $p = 0.013$) (Table 6.1).

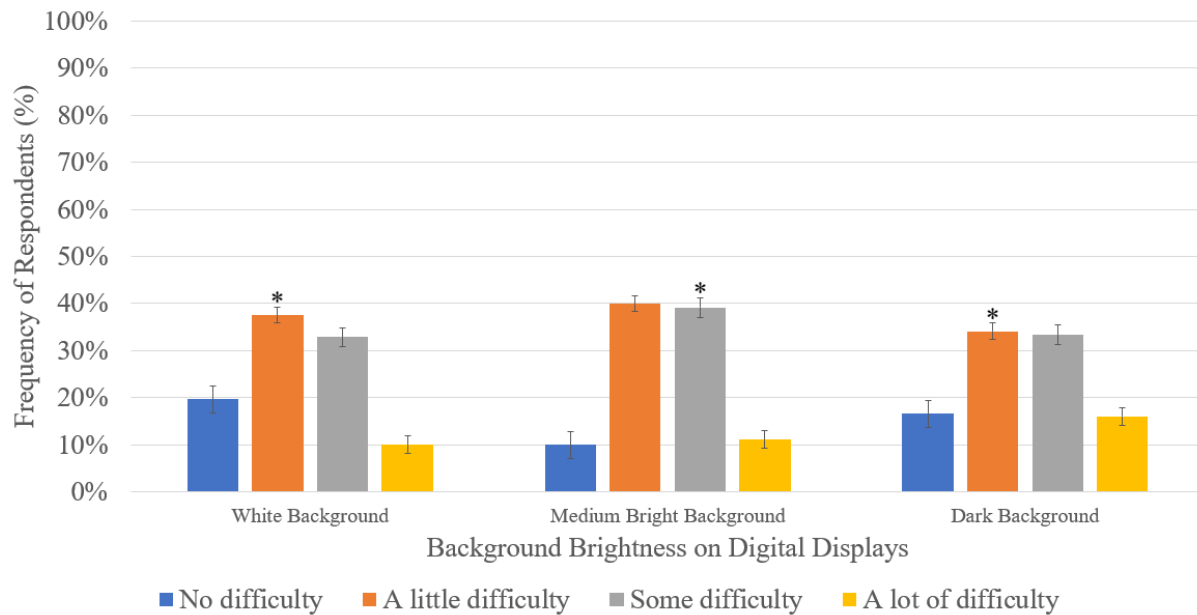


Figure 6.1. The frequency of respondents who ranked the difficulty for the background brightness (N=381). The asterisks (*) identify the median ranking for each background. The error bars represent standard error.

Table 6.1. The results of the Friedman K test compare the difficulty rankings across the three background brightness. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.017$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Variable	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Wilcoxon signed-rank test with Bonferroni correction)		
					Background Brightness Pair		Adjusted Significance
Background Brightness	381	15.5	2	(< 0.001)	"white background"	"medium bright background"	(0.013)
					"white background"	"dark background"	0.093
					"medium bright background"	"dark background"	1.00

6.2 Difficulty Rankings of Background Brightness: Differences in Sex

There were 369 respondents ranked at least a little difficulty with one of the backgrounds. This consisted of 72.6% (268; 95.7% of males who ranked the difficulty of the background brightness reported at least a little difficulty) males and 27.4% (101; 100.0%) females. Figure 6.2 shows the distribution of males and females who ranked at least a little difficulty. The background that both sexes most frequently

encountered challenges with was the "medium bright background" (male: 91.8%, 246; female: 96.0%, 97), and the distributions were similar. There was no significant association between the backgrounds and sex ($\chi^2 = 0.05$, $df = 2$, $p = 0.98$).

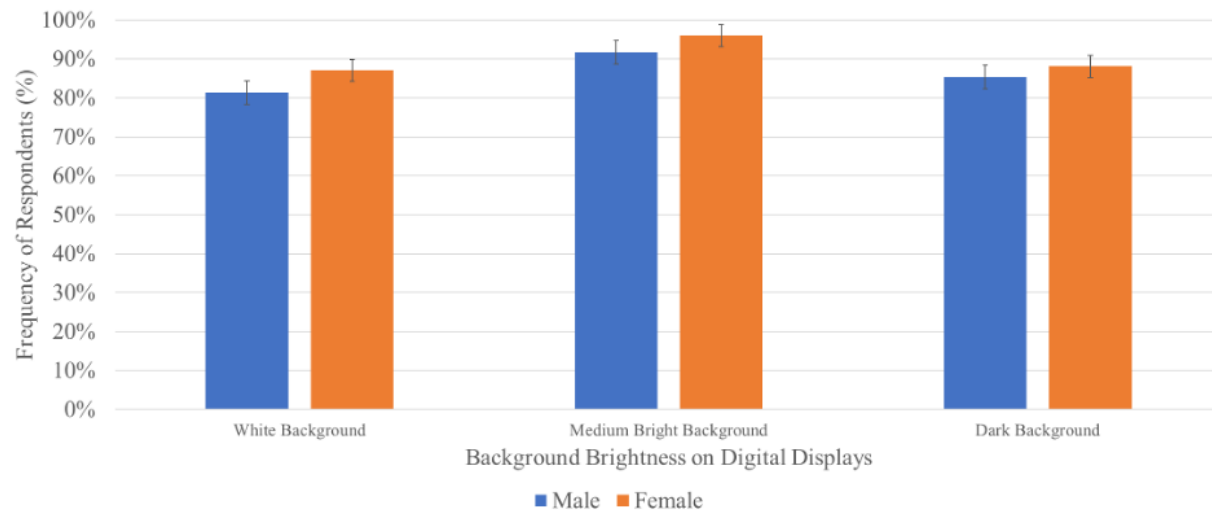
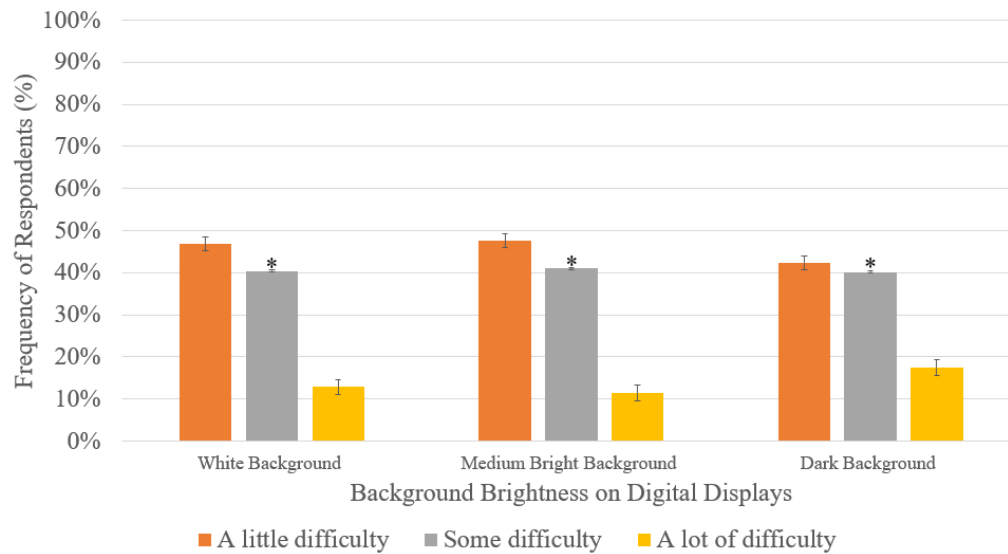
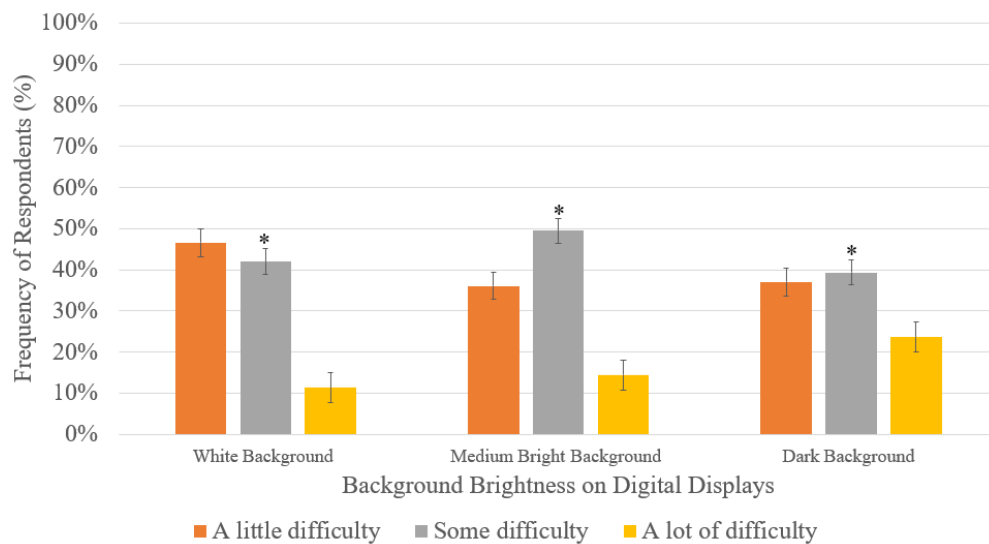


Figure 6.2. The frequency of male and female respondents who ranked at least a little difficulty with the background brightness (N=369). The error bars represent standard error.

Figure 6.3 shows the distribution of the difficulty ranking by (A) males and (B) females. The median ranking for both sexes was "some difficulty" across all backgrounds. Although there were some variations in the difficulty rankings across the different backgrounds, there were no significant differences in the rankings ($p \geq 0.062$; adjusted p-value for significance = 0.017).



(A) Male



(B) Female

Figure 6.3. The distribution of ranked difficulty by (A) male (N=268) and (B) female (N=101) respondents when reading coloured letters, numbers or icons on digital displays using a white, medium bright and dark backgrounds. The percentages are based on respondents who ranked the difficulty of each particular background brightness. The asterisks (*) identify the median ranking for each background. The error bars represent standard error.

6.3 Difficulty Rankings of Background Brightness: Differences in Age Group

Out of the 369 respondents who ranked the difficulty of the backgrounds, there were 34.7% (128; 99.2%) youth and 65.3% (241; 95.6%) adults. Figure 6.4 shows the distribution of both age groups. The "medium

bright background" (youth: 99.2%, 127; adult: 89.6%, 216) was the background that both age groups frequently encountered difficulties. Even though there were similar distributions between age groups, there were slightly more youth than adults who ranked at least "a little difficulty." There was no significant association between the three backgrounds and age group ($\chi^2 = 0.1$, $df = 2$, $p = 0.95$).

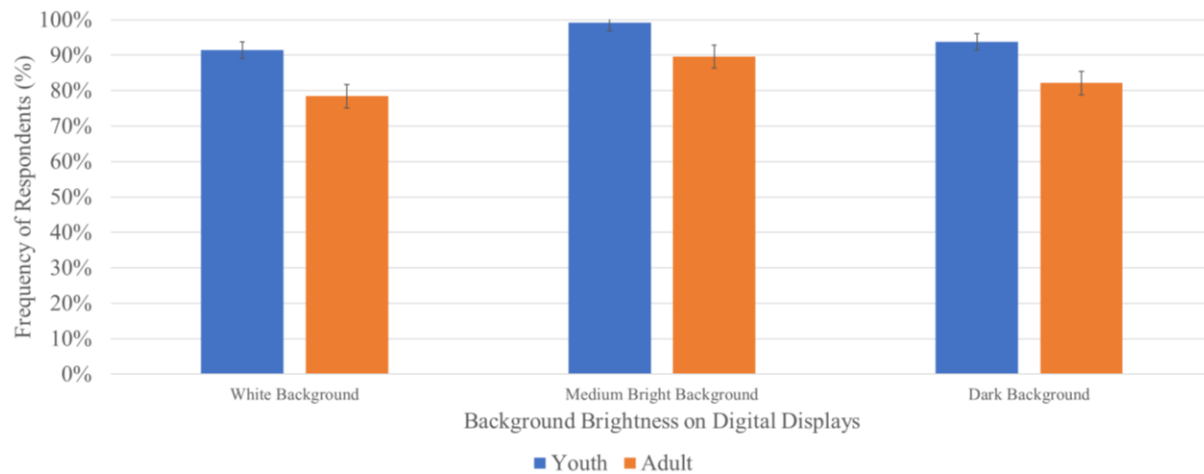
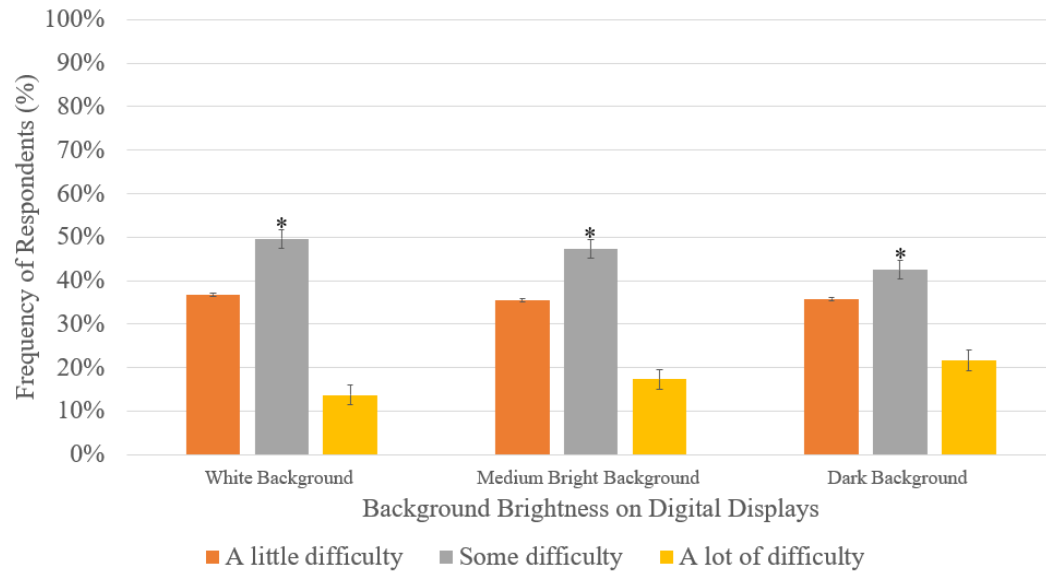
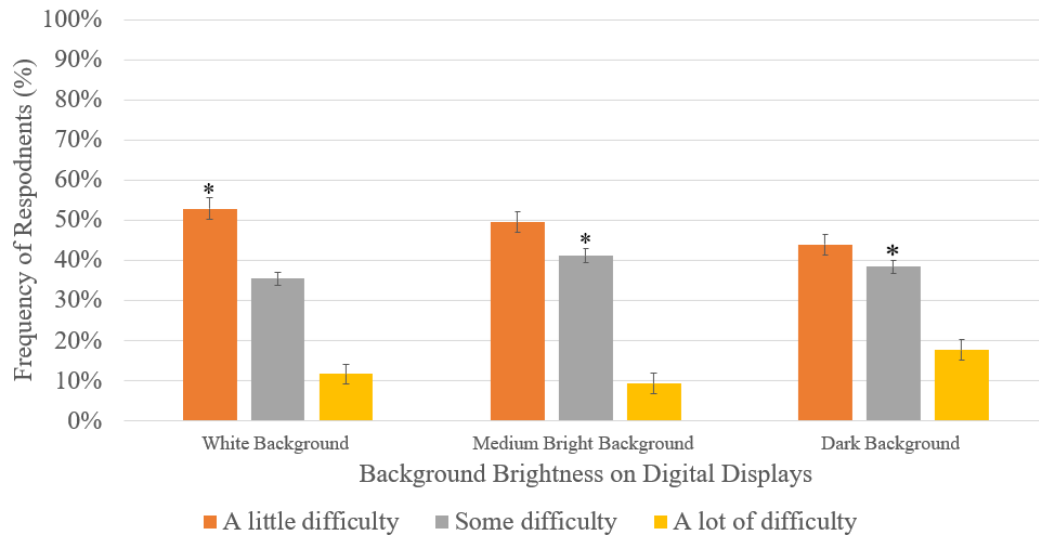


Figure 6.4. The frequency of youth and adult respondents who ranked at least a little for the background brightness (N=369). The error bars represent standard error.

Figure 6.5 shows the ranking distribution for (A) youth and (B) adults. The median ranking across all backgrounds was "some difficulty" for youth. For adults, the median ranking was similar to that of youth ("some difficulty") except for "white background," which had a median ranking of "a little difficulty." Based on the Mann-Whitney test, the rankings within each background for both age groups were significantly different for the "white background" ($p = 0.014$) and "medium bright background" ($p = 0.004$), but not for the "dark background" ($p = 0.15$; adjusted p -value for significance = 0.017).



(A) Youth



(B) Adult

Figure 6.5. The distribution of ranked difficulty by (A) youth (N=128) and (B) adult (N=241) respondents when reading coloured letters, numbers or icons on digital displays using a white, medium bright and dark backgrounds. The percentages are based on respondents who ranked the difficulty of each particular background brightness. The asterisks (*) identify the median ranking for each background. The error bars represent standard error.

6.4 Difficulty Rankings of Background Brightness: Differences in Severity

Figure 6.6 shows the distribution of rankings as a function of severity for the different backgrounds of (A) white, (B) medium bright, and (C) dark. The median ranking for most severity levels was similar across

all backgrounds in that there is a shift in the distributions towards increased difficulty as the severity increases. The exception was the dark background, where the median ranking for "less than once a month" was higher than "at least once a month."

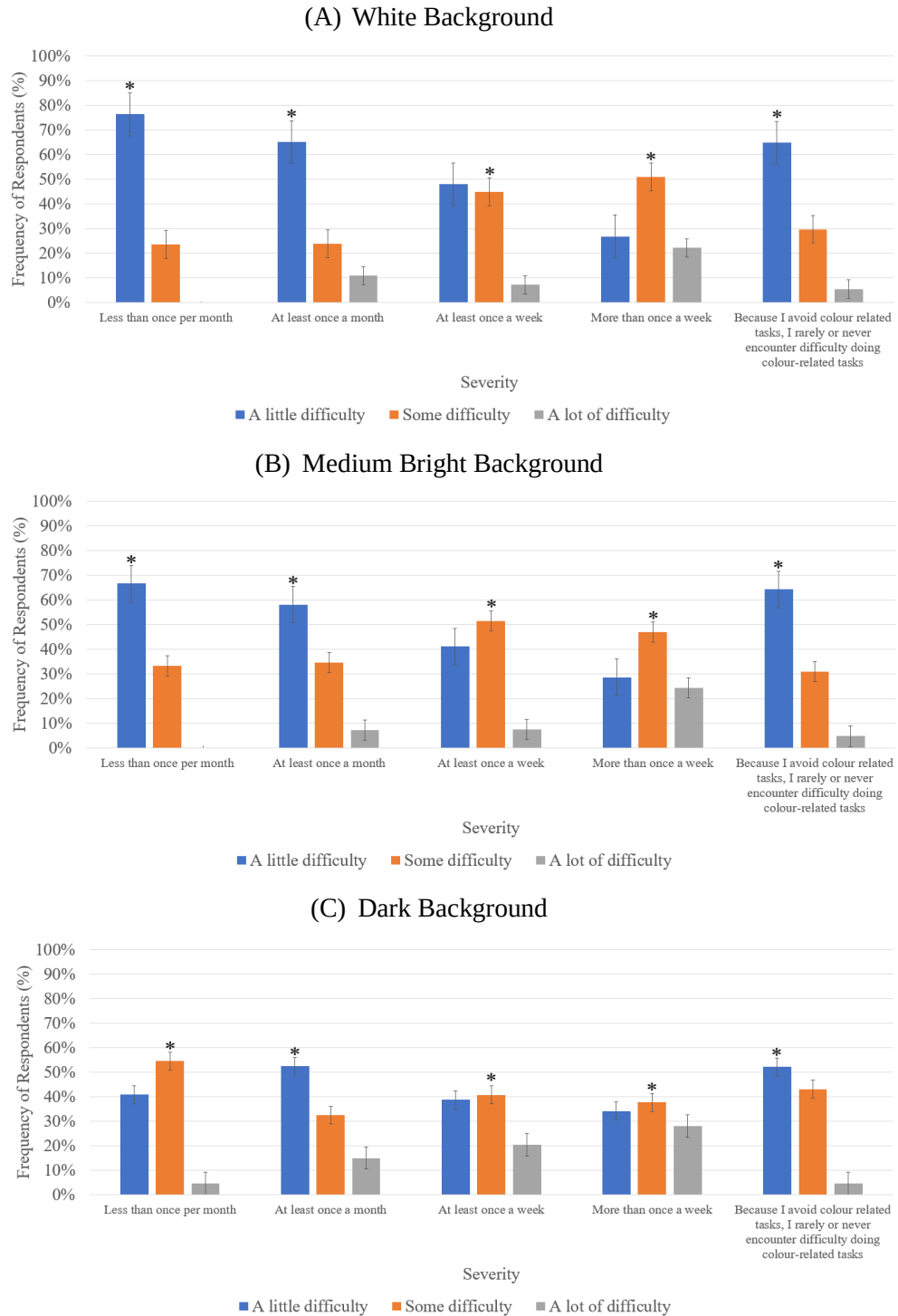


Figure 6.6. The distribution of ranked difficulty by all respondents with (A) white, (B) medium bright, and (C) dark backgrounds. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

Table 6.2 shows the severity results from the Kruskal-Wallis test. The shift in the rankings shown in the figure was significant for all three backgrounds. More specifically, the pairwise comparisons revealed a significant difference between "more than once a week" and "because I avoid colour-related tasks, I rarely or never encounter difficulty doing colour-related tasks" for all three backgrounds. For the white and medium bright background, the pairwise comparisons also showed significant differences for "less than once per month" and "more than once a week," "at least once a month" and "more than once a week," and "at least once a week" and "more than once a week."

Table 6.2. The results of the Kruskal-Wallis H test of the difficulty rankings for the three background brightness based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.017$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Background Brightness	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair	Adjusted Significance	
White Background	306	37.0	4	(< 0.001)	"at least once a month"	"more than once a week"	(0.00)
					"more than once a week"	"because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks"	(0.00)
					"less than once per month"	"more than once a week"	(0.001)
					"at least once a week"	"more than once a week"	(0.003)
Medium Bright Background	343	35.0	4	(< 0.001)	"at least once a month"	"more than once a week"	(0.00)
					"more than once a week"	"because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks"	(0.00)
					"less than once per month"	"more than once a week"	(0.001)
					"at least once a week"	"more than once a week"	(0.041)
Dark Background	318	12.1	4	(0.017)	"more than once a week"	"because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks"	(0.028)

6.5 Chapter Discussion

The background brightness did have an effect on the level of difficulty experienced by the respondents as a group. As expected, the background that potentially results in the lowest luminance contrast, the medium-bright background, also resulted in a higher median difficulty rating than the white and dark backgrounds (Figure 6.1). The difference between the white and medium-bright backgrounds reaching statistical significance. The one unusual finding was that the frequency of "a lot of difficulty" for the dark background was higher relative to the white background, even though the median rankings were similar. This trend is also present for each sex and age group. We would have expected these frequencies to be the same or to have a lower frequency for "a lot of difficulty" for the dark background given the higher luminance contrast. The more frequent responses for the dark background may result from lower luminance contrast sensitivity, so the respondents could not distinguish the difference in the brightness of the coloured letters, which could be used as a secondary clue to the letter's colour. There might be differences in the difficulty for the dark background between protans and deutans, but since we did not ask about the nature of their defect, we could not address this issue.

Although there were no differences between sexes, the youth did find more difficulty than adults in reading coloured letters on a white and medium-bright background. It is uncertain whether this is due to a practice effect, different displays, or adults having adjusted their colour calibration settings to improve letter visibility and the youth not having done so. Verriest et al. (1985) performed a study on 72 colour normals, 30 red-green anomalous trichromats and 31 dichromats who were administered a series of colour-related tests on a multi-coloured visible display unit (VDU). One of the tests was the readability of coloured text. Unfortunately, the description of the study and results is only a summary of a company report, so it is difficult to determine if their results were similar to the survey results. Nevertheless, the subjects with CVD had more difficulty identifying colours.

Not directly related to the survey question, Hathibelagal (2023) reported that CVD search performance for natural objects displayed on a computer monitor was worse relative to colour normals. Increasing the saturation, which would also increase the brightness contrast, did improve the performance of the protan subjects (not to colour-normal levels) more than the deutan subjects (Hathibelagal, 2023). These results support our finding that identifying coloured objects for CVD is better when the object has a higher luminance contrast with its background, but the improvement may not be large (Figure 6.7).



Figure 6.7. An example of coloured text on a (A) white background, (B) medium bright background, and (C) dark background to display the variations in contrast between the different background brightness.

The change in the rankings as the severity of the CVD becomes more severe is expected. The increase in the median difficulty ranking occurs at the level of severity corresponding to "at least once a week" for all three backgrounds, indicating that individuals with the more severe defects are going to struggle more in reading, and changing the background may not help in general, which is consistent with Hathibelagal's (2023) findings. If they have a lot of difficulty reading coloured characters on a dark background, increasing the background light level to a medium or brighter light level may not help. The unexpected result was that individuals who avoid colour-related had a low median ranking for the difficulty level. One would assume that individuals who avoid colour-related tasks would have a fairly severe defect. The data suggests that this group includes a mixture of all severity levels, which means that their avoidance is used more as an effective way to cope with their defect and its impact on them using digital displays.

Chapter 7

Results – Areas of Life

This chapter describes the challenges individuals with CVD encounter when performing colour-related tasks using digital displays in several areas of life, including:

- School
- Work/Volunteering
- Recreation/Hobbies
- Social Media
- Gaming & eSports
- Online Shopping or Banking
- In-Person Shopping or Banking
- Driving/Motorized Vehicles
- Travelling

There is information on the prevalence of these problems, the extent of their difficulty, and the types of displays they encounter these challenges. Since there were generally little to no respondents who reported “no difficulty, the analysis only focused on those who ranked at least “a little difficulty” with a task as it was assumed that the exclusion of a small number of respondents should not influence any conclusions.

7.1 School

The first area of life explored was at school. Out of the 381 respondents who completed the survey, 151 respondents (39.6%) reported being enrolled in an educational program, 225 respondents (59.1%) were not enrolled in any educational program, and 5 respondents (1.3%) preferred not to answer. Of the 151 respondents enrolled in school, 51.0% were male youth (77), 16.6% male adults (25), 22.5% female youth (34), and 9.9% female adults (15). This means that 89.5% of male youth, 12.9% of male adults, 79.1% of female youth, and 25.9% of female adults who completed the survey were enrolled in school. Figure 7.1 shows the distribution of students enrolled in the various educational programs. The majority (41.1%; 62) of the respondents were enrolled in high school (45 males and 17 females).

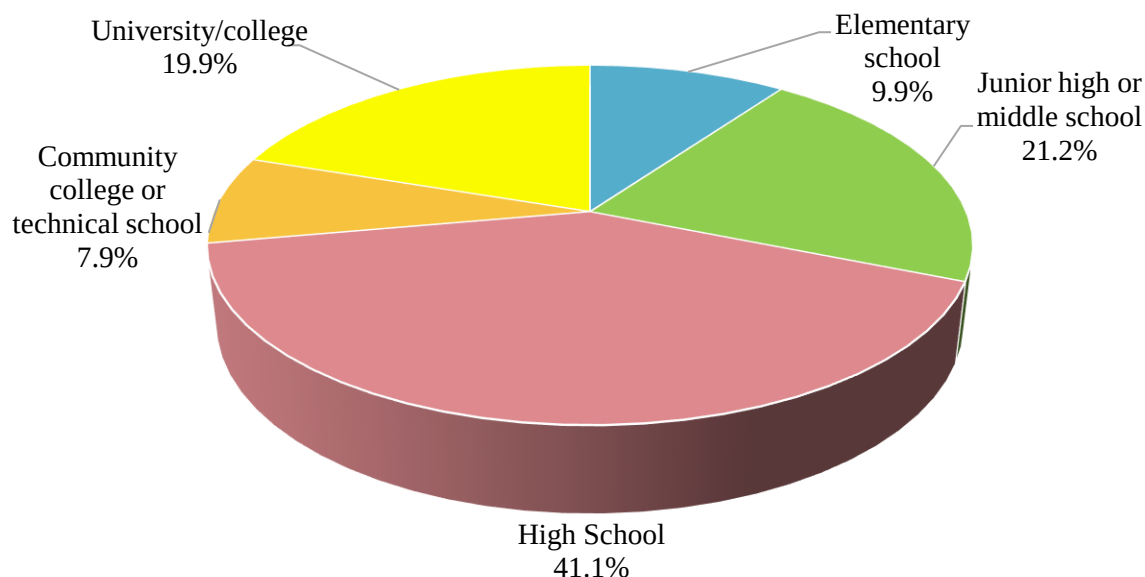


Figure 7.1. The overall distribution of respondents based on the level of educational program (N=151).

7.1.1 Difficulty Rankings of Colour-Related Tasks at School: Sex Differences

Students were asked about the types of coloured tasks that they experienced difficulties (e.g. reading, interpreting, reviewing, creating or editing) when using digital displays at school. A total of 148 students selected at least one task, with 145 reporting at least a little difficulty with one of the tasks. This means that 96.0% of the students enrolled in an education program reported difficulty with at least one of the tasks. The latter group consisted of 66.9% males (97) and 33.1 % females (48) females enrolled in an educational program. There were 95.1% of males and 98.0% of females enrolled in school who ranked at least a little with a task.

Figure 7.2 shows the distribution of the male and female students who ranked at least a little difficulty across the different tasks. The tasks that the male students most frequently encountered difficulties with were: “colour-coded diagrams” (61.7%; 60), “colour-coded instructions” (57.7%; 56), and “graphs” (56.7%; 55). For females, the three tasks that caused the most frequent challenges were: “colour-coded diagrams” (81.3%; 39), “maps” (52.1%; 25), and “colour-coded instructions”/“colour-coded mathematical or chemical equations”/“editing photos or other coloured images” (50.0%; 24). Although there were some variations in the distribution, there was no significant association across the eight tasks based on sex ($\chi^2 = 5.2$, $df = 7$, $p = 0.64$). The “other” category was removed from the further

analyses because only one female selected this category, so the assumption that expected values have to be greater than 1 was not met with its inclusion.

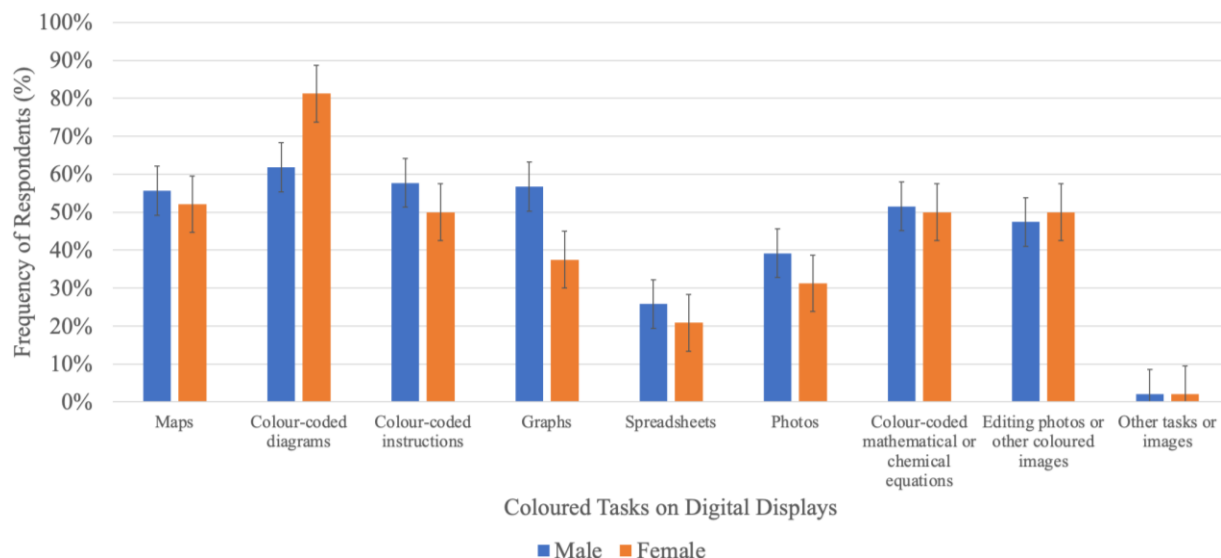
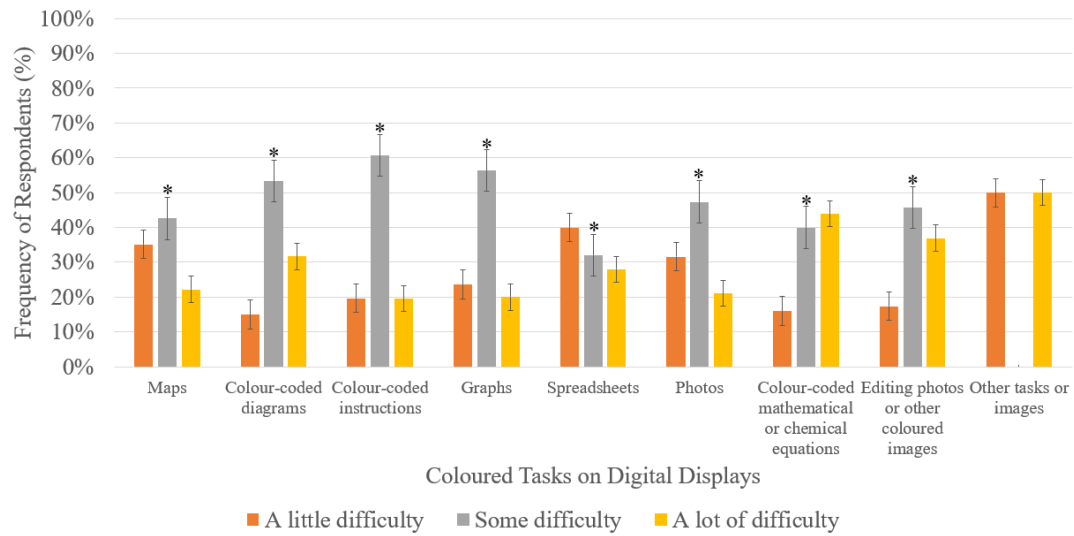
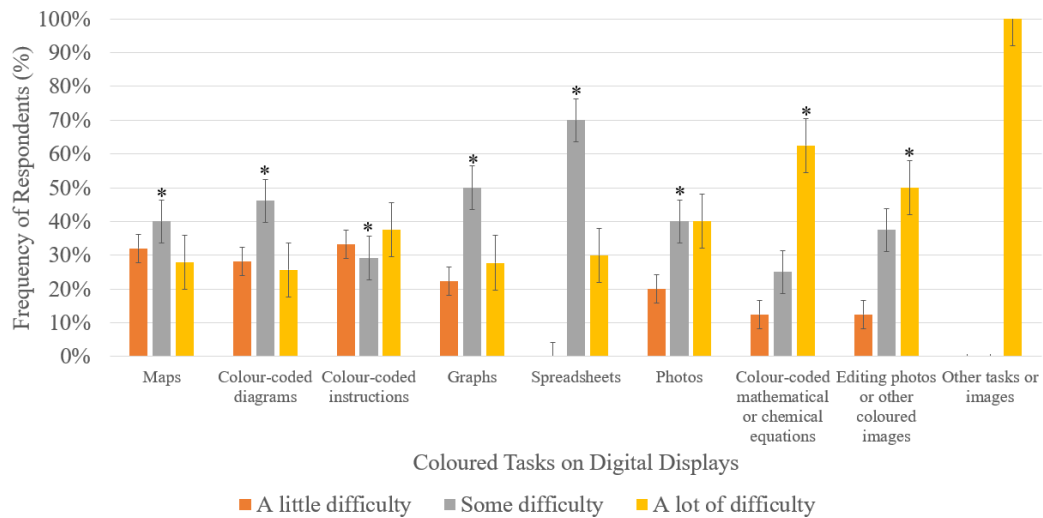


Figure 7.2. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks at school (N=145). The “other tasks” include the responses of 2 males and one female. The error bars represent standard error.

Figure 7.3 shows the distribution of the (A) males and (B) females’ rankings. The median rankings for the males were similar across all coloured tasks which was “some difficulty.” There was no median ranking for the “other tasks” since there were only 2 males and 1 female. The “other” tasks included “art (creating a colour wheel and general recolouring)” reported by a male student in elementary school who experienced “a lot of difficulty,” and “graphic design/videography” reported by another male university/college student who experienced “a little difficulty.” For females, there was also a similar distribution (“some difficulty”) for most tasks, except “equations” and “editing” which had median rankings of “a lot of difficulty.” One female university/college student experienced “a lot of difficulty” with identifying “solution colours in chemistry labs” so a median ranking could not be indicated. These differences were not significant across the eight tasks based on the Mann-Whitney test for each task ($p \geq 0.17$; adjusted p-value for significance = 0.0063).



(A) Male



(B) Female

Figure 7.3. The distribution of ranked difficulty by (A) males (N=97) and (B) female (N=48) respondents when reading, interpreting, reviewing, creating or editing coloured images and other content on digital displays at school. The percentages are based on respondents who ranked the difficulty of each particular task. Two male students reported difficulties with “other tasks” which each account for 50%, as well as one female student which accounts for the 100% difficulty ranking. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.1.2 Difficulty Rankings of Colour-Related Tasks at School: Age-Group Differences

Of the 145 respondents who ranked these educational tasks, 74.5% were youth (108) and 25.5% were adults (37). This means that 97.3% of youth and 92.5% of adults enrolled in school ranked at least a little with a task. Figure 7.4 shows the distribution of the youth and adult students who ranked at least a little difficulty across the different tasks. The three tasks which caused the most frequent problems were “colour-coded diagrams” (youth: 67.6%, 73; adult: 70.3%; 26), “colour-coded instructions” (youth: 54.6%, 59; adult: 56.8%; 21), and “maps” (youth: 54.6%; 59; adult: 54.1%; 20). Both age groups displayed relatively similar distributions. There was no significant association between the eight tasks and age groups ($\chi^2 = 3.4$, $df = 7$, $p = 0.84$). The “other” category included the responses of one youth and two adults, who were removed from this analysis for reasons similar to those mentioned for sex.

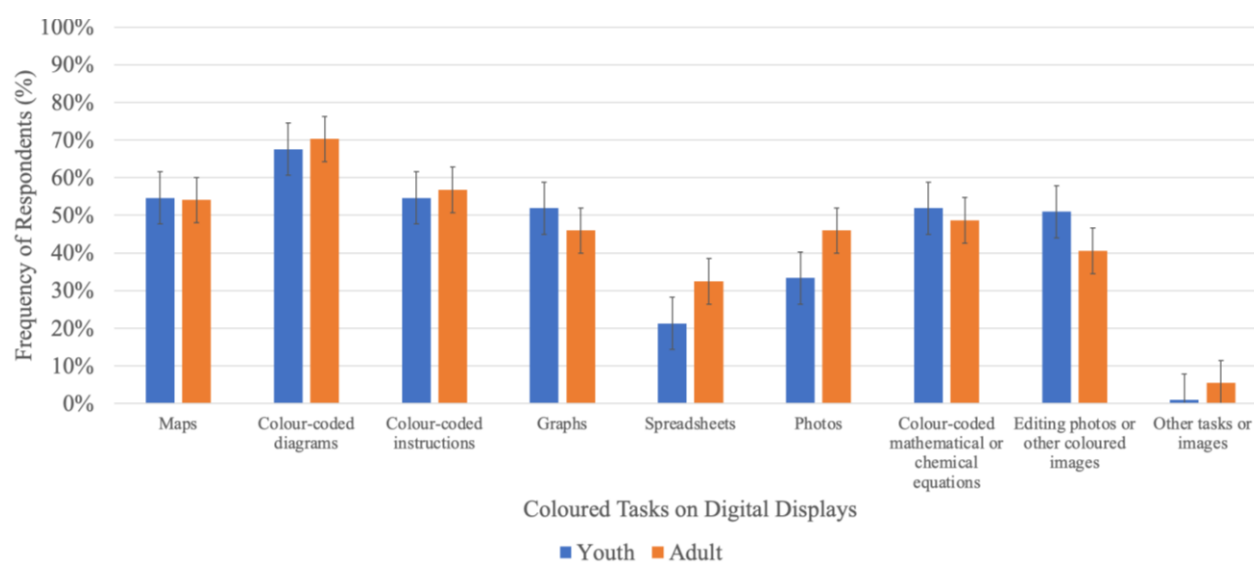
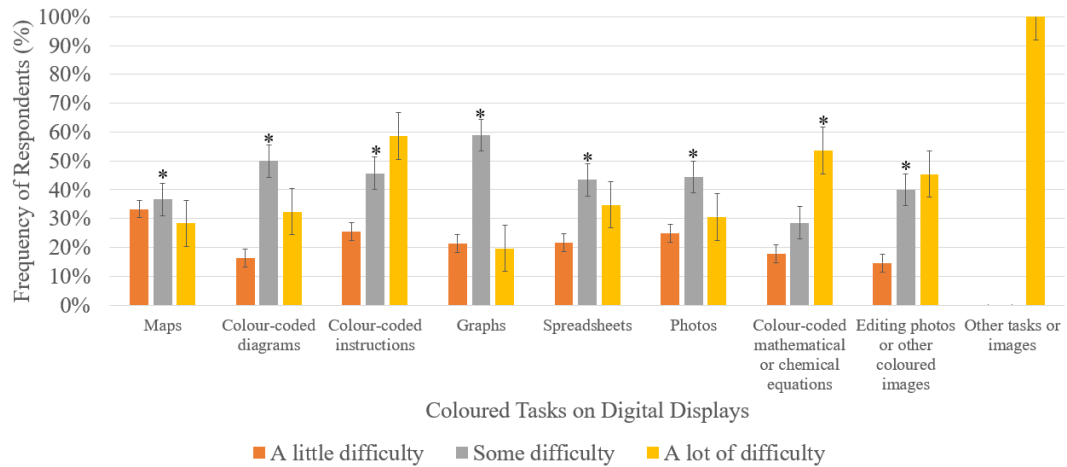
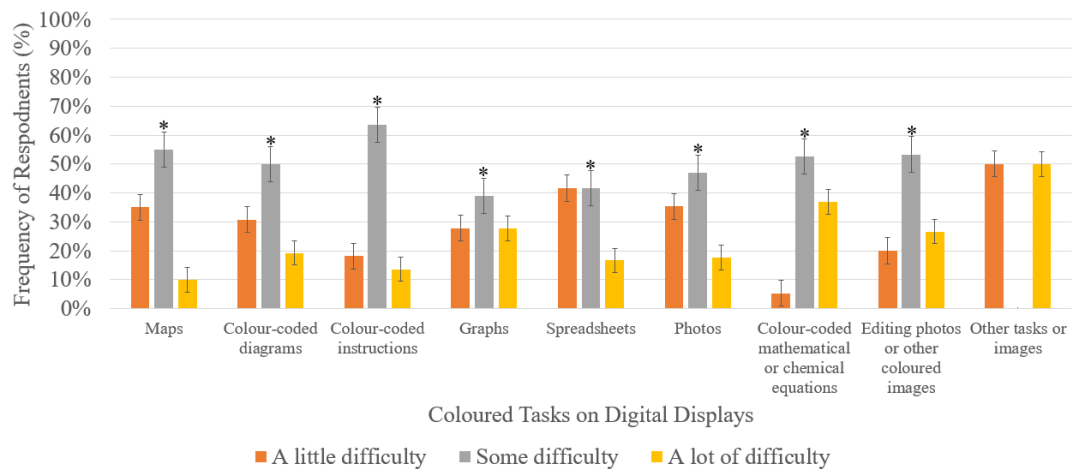


Figure 7.4. The frequency of youth and adult respondents who ranked at least a little for the coloured tasks at school (N=145). The “other tasks” include the responses of one youth and 2 adults. The error bars represent standard error.

Figure 7.5 shows the distribution of the ranking for youth and adults, respectively. Both age groups were similar in that the median ranking for most tasks was “some difficulty.” The exceptions were “colour-coded mathematical or chemical equations” in the youth group which had a median ranking of “a lot of difficulty.” There was only 1 youth and 2 adult respondents who reported challenges with “other tasks” so median rankings were not indicated, and this category was excluded from further analyses. The rankings within a task for two age groups across the other eight tasks were not significantly different according to the Mann-Whitney test ($p \geq 0.083$; adjusted p-value for significance = 0.0063).



(A) Youth



(B) Adult

Figure 7.5. The distribution of ranked difficulty by (A) youth (N=108) and (B) adult (N=37) respondents when reading, interpreting, reviewing, creating or editing coloured images and other content on digital displays at school. The percentages are based on respondents who ranked the difficulty of each particular task. One youth student accounted for the 100% difficulty ranking, and two adult students accounted for the 50% ranking in the “other” category. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.1.3 Difficulty Rankings of Colour-Related Tasks at School: Severity Differences

The respondents were pooled together to explore the effect of severity on the difficulty rankings. Table 7.1 shows the results from the Kruskal-Wallis test for the rankings of the eight tasks based on severity. The tasks that showed significant differences were “colour-coded diagrams” ($H = 18.1$, $df = 4$, $p = 0.001$) and “editing photos or other coloured images” ($H = 16.0$, $df = 4$, $p = 0.003$; adjusted p-value for

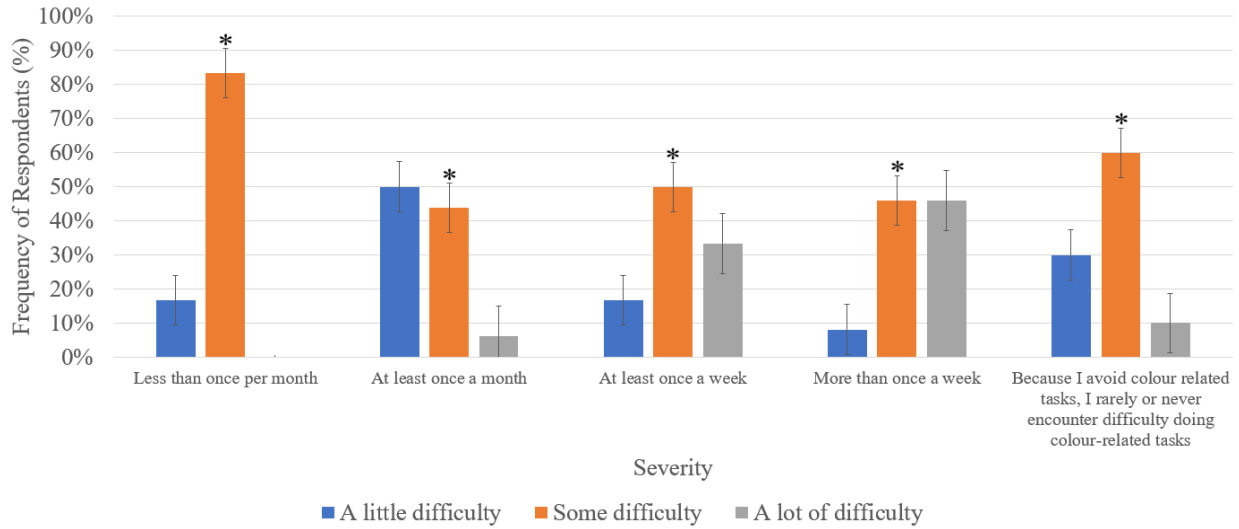
significance = 0.0063). The pairwise comparisons revealed a significant difference between “at least once a month” and “more than once a week” for both tasks (diagrams: adj. $p = 0.001$; editing: adj. $p = 0.002$). The “other” category was excluded from this analysis since it was omitted in the Mann-Whitney analyses for sex and age group.

Table 7.1. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed at school based on severity. The values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0063$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Colour-coded diagrams	99	18.1	4	(0.001)	“at least once a month”	“more than once a week”	(0.001)
Editing photos or other coloured images	70	16.0	4	(0.003)	“at least once a month”	“more than once a week”	(0.002)
Photos	53	10.1	4	0.039	N/A		
Maps	79	9.8	4	0.044	N/A		
Colour-coded instructions	80	7.2	4	0.13	N/A		
Spreadsheets	35	6.7	4	0.15	N/A		
Colour-coded mathematical or chemical equations	74	4.6	3	0.21	N/A		
Graphs	73	5.3	4	0.26	N/A		

Figure 7.6 shows the distribution of rankings as a function of severity for the significantly different task of (A) colour-coded diagrams ($p = 0.001$) and a task where the differences were not significant (B) “colour-coded instructions” ($p = 0.13$). Although the median rankings across all severity levels were “some difficulty” across all severity levels, the distribution is shifting towards a lot of difficulty as the severity increases. The pairwise comparisons show this shift reaches statistical significance for the mild (“at least once a month”) and severe (“more than once a week”) individuals.

(A) Colour-coded diagrams ($p = 0.001$)



(B) Colour-coded instructions ($p = 0.13$)

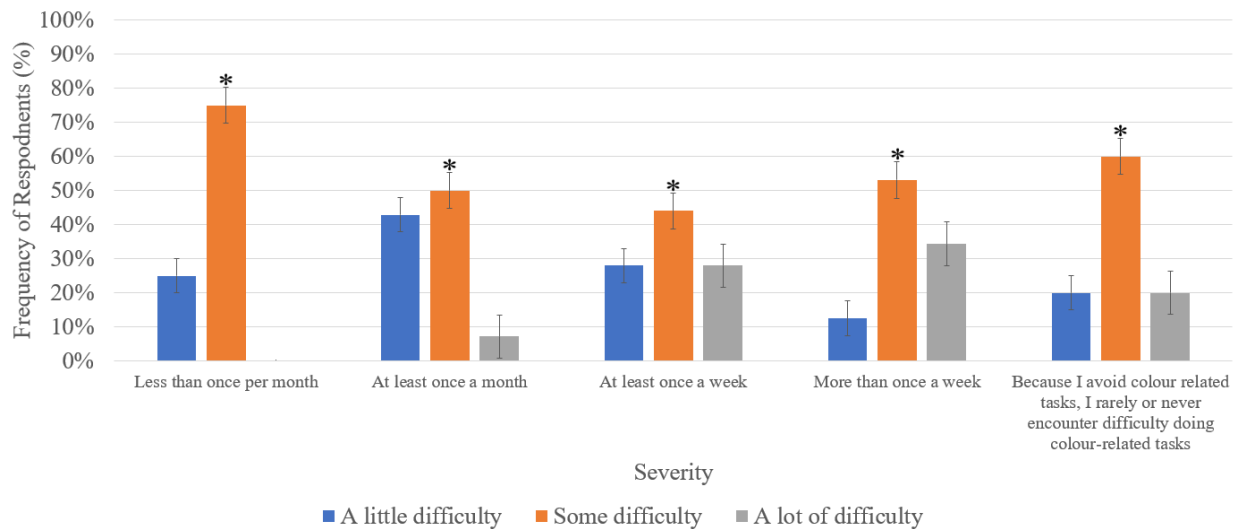


Figure 7.6. The distribution of ranked difficulty by all respondents with (A) colour-coded diagrams and (B) colour-coded instructions. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.1.4 Most Difficult School Subjects

Students were asked which school subjects they had trouble completing colour-related tasks on digital displays. There were 145 students who selected at least one school subject. This group consisted of 67.6% males (98) and 32.4% females (47). The breakdown based on age group was 73.8% youth (107) and 26.2% adults (38). There were 96.1% of males, 95.9% of females, 96.4% of youth, and 95.0% of adults enrolled in school selected a school subject that they had trouble with. Figure 7.7 shows the distribution of the eight school subjects based on (A) sex and (B) age group. The distributions are remarkably similar. Both groups showed that there were at least a few respondents from each sex and age group who experienced some difficulties with the school subjects listed. “Geography,” “Science,” and “Graphic Design/Art” courses were the top three subject areas with challenging colour-related tasks. The “other” subject area consisted of three students who reported having difficulties with “anthropology” by a male high school student, “any subject where the professor uses red and green to convey information” by a male university/college student, and “any class where they must distinguish between with blue or purple” by a male student in community college/technical school. The chi-square test did not reveal any significant association for sex ($\chi^2 = 5.8$, $df = 7$, $p = 0.56$) and age group ($\chi^2 = 3.2$, $df = 7$, $p = 0.86$). The “other” category was excluded from this analysis because it did not meet the assumption that expected values must be greater than 1.

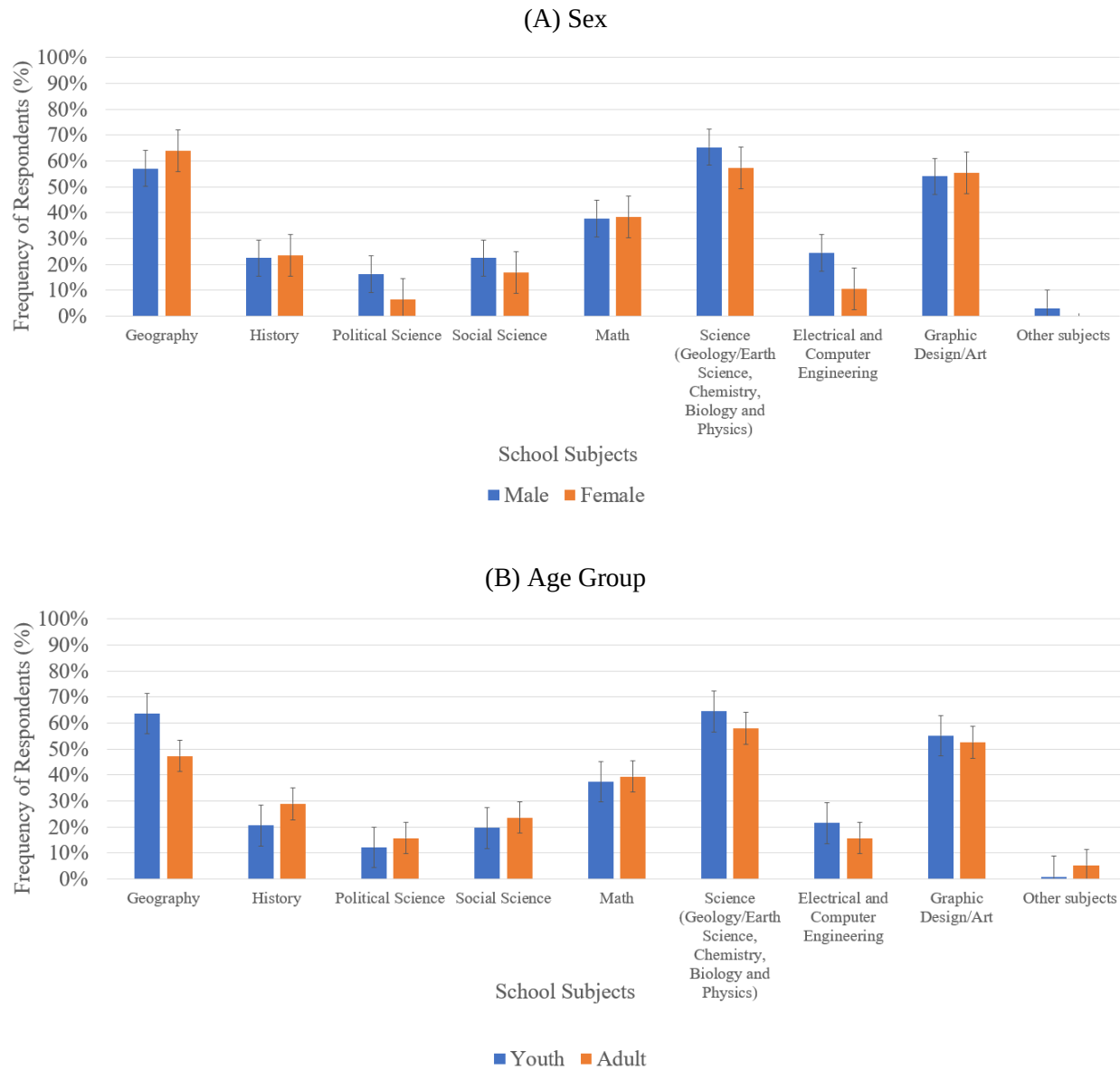


Figure 7.7. The distribution of the school subjects that students encountered difficulties when using displays based on (A) sex and (B) age group (N=145). The “other subjects” include the responses of one male youth and 2 male adults. The error bars represent standard error.

7.1.5 Digital Displays where Difficulties are Encountered

There were 148 students who selected at least one digital display that they encountered problems with. There were 66.9% males (99) and 33.1% females (49). For age group, the breakdown was 73.0% youth (108) and 27.0% adults (40). This means that 98.0% of students enrolled in an educational program selected a display. There were slightly more than 145 students who ranked at least a little difficulty with a

task due to the small number of individuals who did not rank the tasks. There were 97.1% of males, 100.0% of females, 97.3% of youth, and 100.0% of adults enrolled in school who had trouble with a display at school or while doing homework. Figure 7.8 shows the frequencies of individuals reporting colour-related problems with displays based on (A) sex and (B) age group. There were relatively similar distributions in the displays selected by both sexes and age groups. Based on the chi-square test, there was no significant association between the five selected displays and demographic factors of sex ($\chi^2 = 0.1$, $df = 4$, $p = 1.00$) and age group ($\chi^2 = 4.1$, $df = 4$, $p = 0.40$) at school. The “other digital displays” were removed from the analysis as none was reported by any respondent.

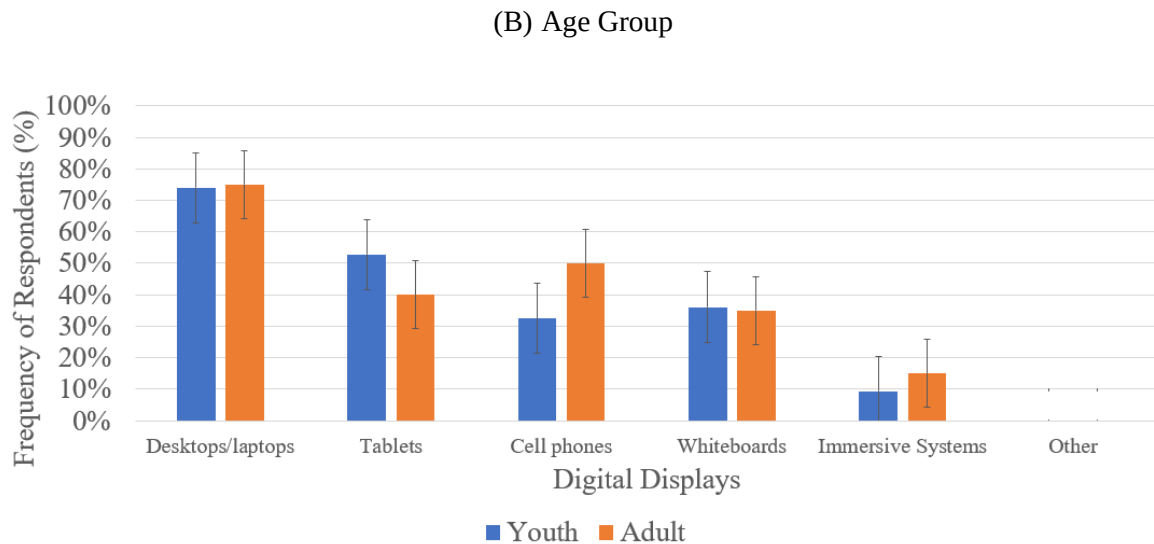
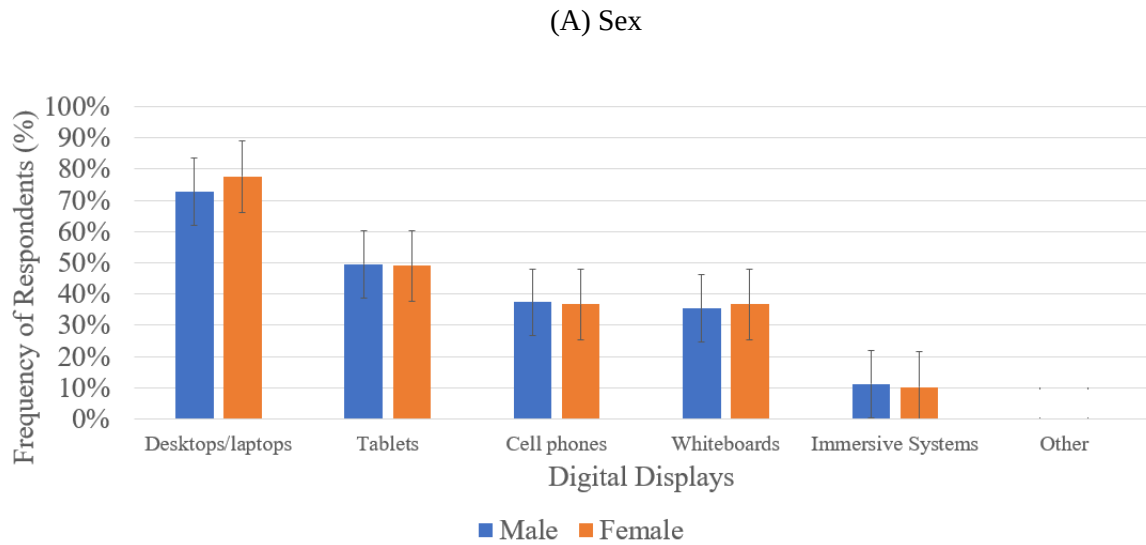


Figure 7.8. The distribution of digital displays that students found challenging when using at school based on (A) sex and (B) age group (N=148). There were no respondents who reported difficulty with “other displays.” The error bars represent standard error.

7.2. Work/Volunteering

This section will discuss the challenges encountered at work/volunteering. Out of the 381 respondents who have completed the survey, 215 respondents (56.4%) reported working/volunteering, 161 respondents (42.3%) were unemployed or not volunteering, and 5 respondents (1.3%) preferred not to answer. The working/volunteering respondents were comprised of 77.2% who worked full-time (166), 17.7% who worked part-time (38), and 5.1% who only volunteered (11). They consisted of 8.4% male

youth (18), 69.3% male adults (149), 3.7% female youth (8), and 18.6% female adults (40). This means that 20.9% of male youth, 76.8% of male adults, 18.6% of female youth, and 69.0% of female adults who completed the survey reported working/volunteering.

7.2.1 Difficulty Rankings of Colour-Related Tasks at Work/Volunteering: Sex Differences

This section of the survey asked about the coloured tasks they experienced difficulty reading, interpreting, reviewing, creating or editing on digital displays at work/volunteering. Of the 215 respondents who reported working or volunteering, 183 respondents selected at least one task where they encountered troubles, but only 166 respondents ranked the level of difficulty. Seventy-seven percent (77.2%) of the respondents experienced trouble with at least one of the tasks. This is comprised of 77.7% males (129) and 22.3% females (37) who work or volunteer ranked at least a little difficulty. There were 77.2% of males and 77.1% of females who worked/volunteered who ranked at least a little difficulty with one of the tasks.

Figure 7.9 shows the distribution of the male and female respondents who ranked at least a little difficulty with the coloured tasks. For the males, the three tasks which caused the most frequent problems were: “colour-coded diagrams” (70.5%; 91), “colour-coded plans/instructions” (58.9%; 76), and “maps” (55.0%; 71). The females also reported difficulties with “colour-coded diagrams” (81.1%; 30) and “colour-coded plans/instructions” (59.5%; 22), but the third most frequent task was “graphs” (43.2%; 16). Although there were some variations in the distribution of the rankings across the tasks, the chi-square test did not reveal any significant association between the seven tasks and sex ($\chi^2 = 6.2$, $df = 6$, $p = 0.40$).

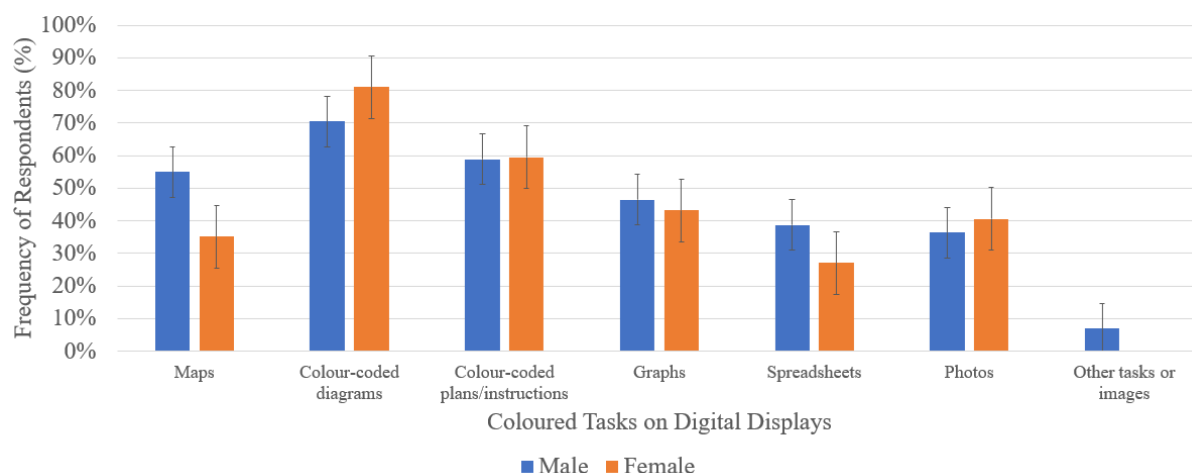


Figure 7.9. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks at work/volunteering (N=166). The “other tasks” include the responses of 9 males and no females. The error bars represent standard error.

Figure 7.10 shows the distribution of the rankings for (A) males and (B) females. The median rankings for the males for all coloured tasks were “some difficulty,” and the median rankings were similar for the females (“some difficulty”). There were 9 male adults who listed challenges with other tasks at work/volunteering, where the majority had difficulty identifying “coloured wires” which was reported by four adults with a median ranking of “a lot of difficulty.” These differences were not significant across the six tasks based on the Mann-Whitney test for each task ($p \geq 0.11$; adjusted p-value for significance = 0.0083). There were no female responses in the “other tasks or images” so this category was removed from this analysis.

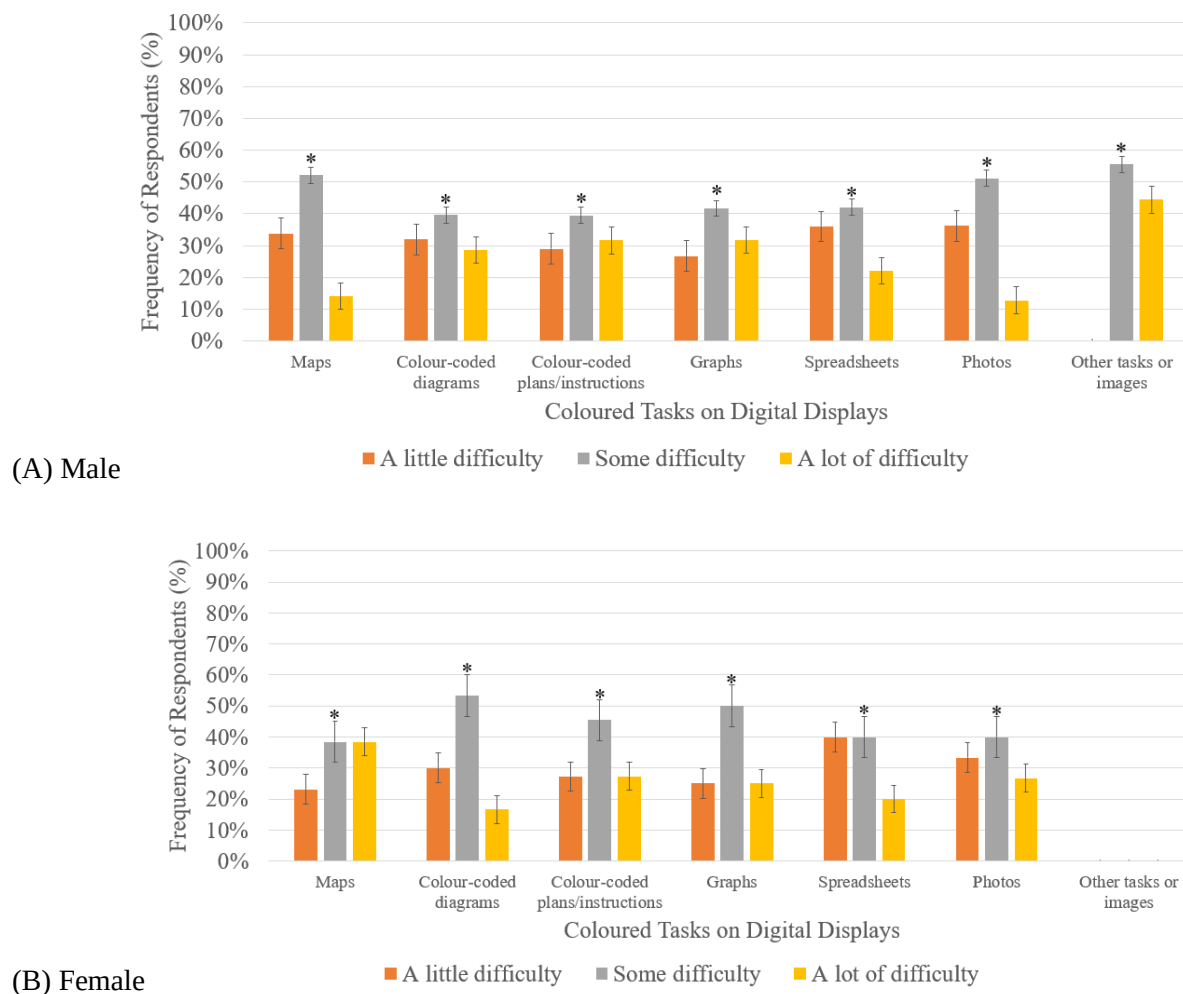


Figure 7.10. The distribution of ranked difficulty by (A) male (N=129) and (B) female (N=37) respondents when reading, interpreting, reviewing, creating or editing coloured images and other content on digital displays at work or volunteering. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.2.2 Difficulty Rankings of Colour-Related Tasks at Work/Volunteering: Age-Group Differences

Out of the respondents who reported working/volunteering, 12.7% were youth (21) and 87.3% were adults (145) ranked at least a little difficulty for one of the tasks. This means that 80.8% of youth and 76.7% of adults who work/volunteer reported difficulty with a task. Figure 7.11 shows the distribution of youth and adult respondents. The tasks that youth most frequently encountered problems with were “maps” (66.7%; 14), “colour-coded diagrams” (42.9%; 9), and “colour-coded plans/instructions” (42.9%; 9). For adults, the tasks that they most frequently encountered difficulties with were “colour-coded diagrams” (77.2%; 112), “colour-coded plans/instructions” (61.4%; 89) and “maps” (48.3%; 70). Although there were some variations, there was no association between the six tasks and age groups ($\chi^2 = 6.0$, $df = 5$, $p = 0.31$). The “other” category was removed from this analysis because it did not meet the assumption that the expected values must be greater than 1 since no youth selected this category.

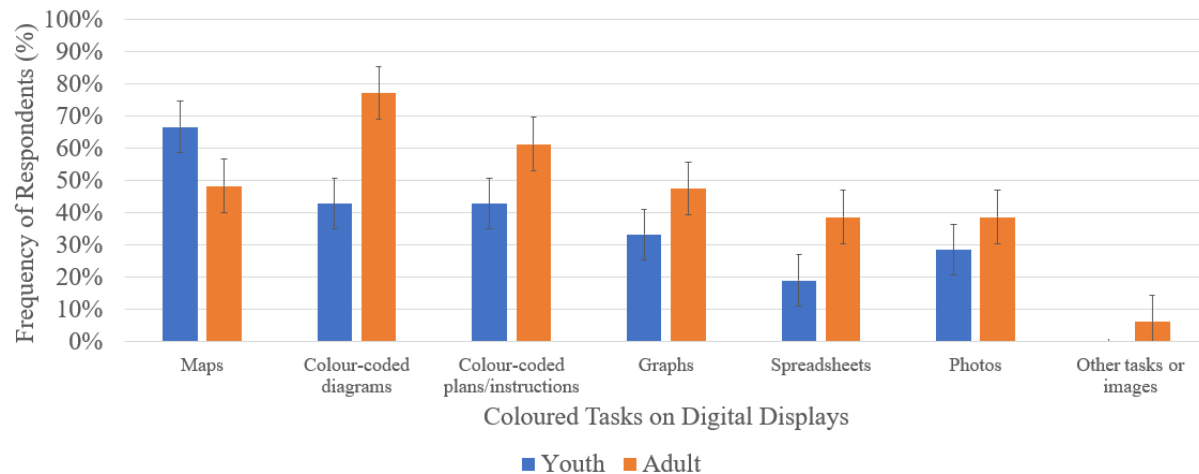
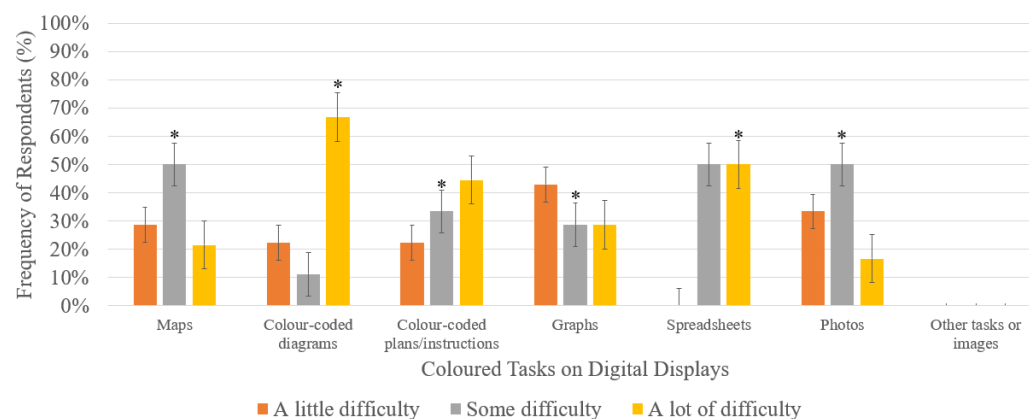
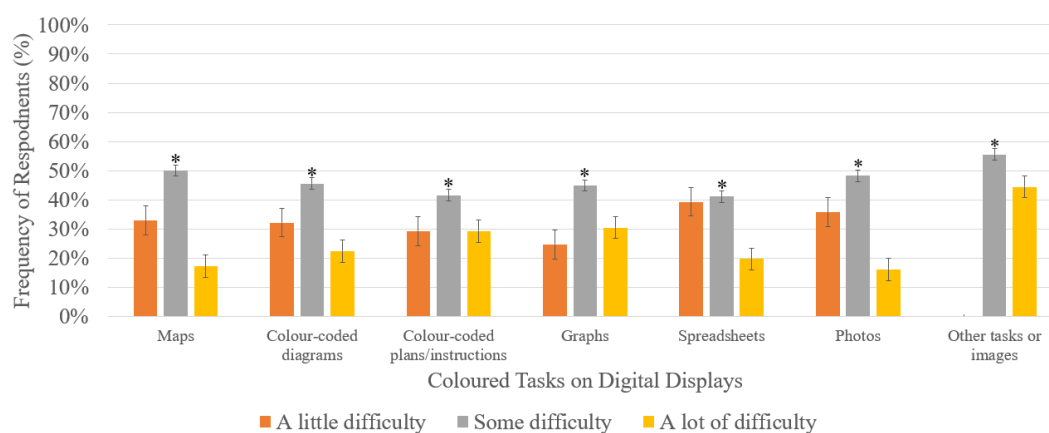


Figure 7.11. The frequency of youth and adult respondents who ranked at least a little difficulty for the coloured tasks at work/volunteering (N=166). The “other tasks” include the responses of no youth and 9 adults. The error bars represent standard error.

Figure 7.12 shows the distribution of the rankings for (A) youth and (B) adults. The median rankings for the youth respondents for most tasks were “some difficulty,” except for “colour-coded diagrams” and “spreadsheets” which had median rankings of “a lot of difficulty.” For the adults, the median rankings were similar to those of the youth (“some difficulty”) for all coloured tasks. The differences within the six tasks between both age groups were not significantly different based on the Mann-Whitney test ($p \geq 0.044$; adjusted p-value = 0.0083). No youth respondents reported difficulties with “other tasks or images,” so this category was removed from this analysis.



(A) Youth



(B) Adult

Figure 7.12. The distribution of ranked difficulty by (A) youth (N=21) and (B) adult (N=145) respondents when reading, interpreting, reviewing, creating or editing coloured images and other content on digital displays at work/volunteering. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.2.3 Difficulty Rankings of Colour-Related Tasks at Work/Volunteering: Severity Differences

The effect of severity on the difficulty rankings was explored on respondents that were pooled together. Table 7.2 shows the results from the Kruskal-Wallis test for the six tasks. “Colour-coded diagrams” was the only task that showed significant differences in the rankings based on severity ($H = 24.3$, $df = 4$, $p < 0.001$; adjusted p-value for significance = 0.0083). The pairwise comparisons showed significant differences between “at least once a month” and “more than once a week” (adj. $p = 0.00$). The “other” category was excluded from this analysis since it was omitted in the Mann-Whitney analyses for sex and age group.

Table 7.2. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed at work/volunteering based on severity. The values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0083$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Colour-coded diagrams	121	24.3	4	(< 0.001)	“at least once a month”	“more than once a week”	(0.00)
Colour-coded plans/instructions	98	11.6	4	0.021	N/A		
Spreadsheets	60	4.7	4	0.32	N/A		
Photos	62	3.1	4	0.55	N/A		
Graphs	76	2.7	4	0.61	N/A		
Maps	84	1.2	4	0.88	N/A		

Figure 7.13 shows the distribution of the difficulty rankings based on severity for the significantly different task of (A) “colour-coded diagrams” ($p < 0.001$) and a task where the differences were not significant for (B) “photos” ($p = 0.55$). The median ranking for most severity levels was “some difficulty,” except for “at least once a month” which had a median ranking of “a little difficulty” for both tasks. There is a general shift towards a lot of difficulty as the defects become more severe. This is shown through the pairwise comparison, which shows a significant difference between mild (“at least once a month”) and severe (“more than once a week”) individuals in “colour-coded diagrams.”

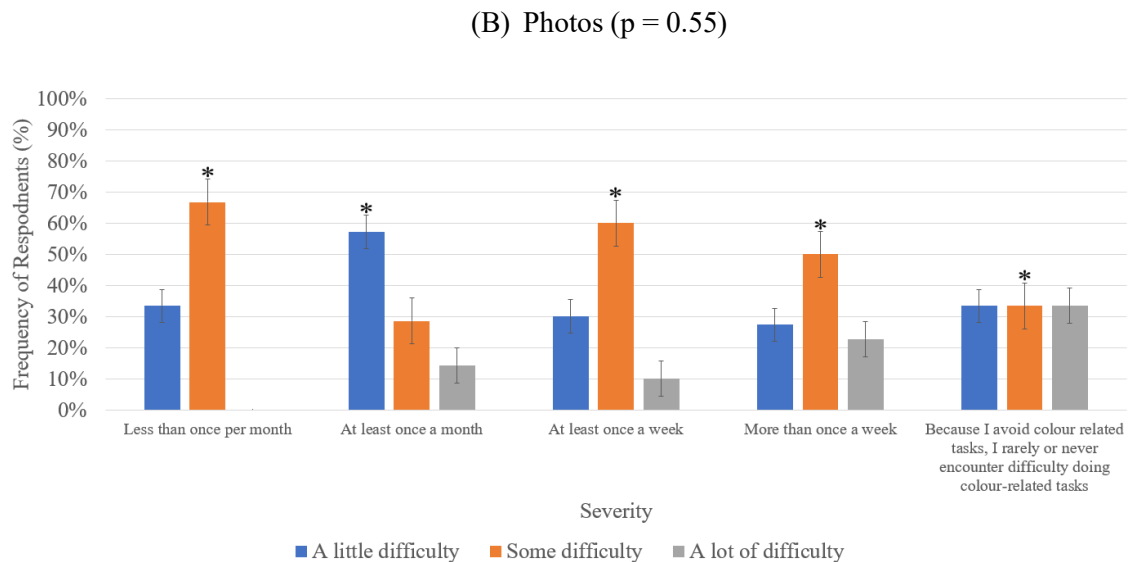
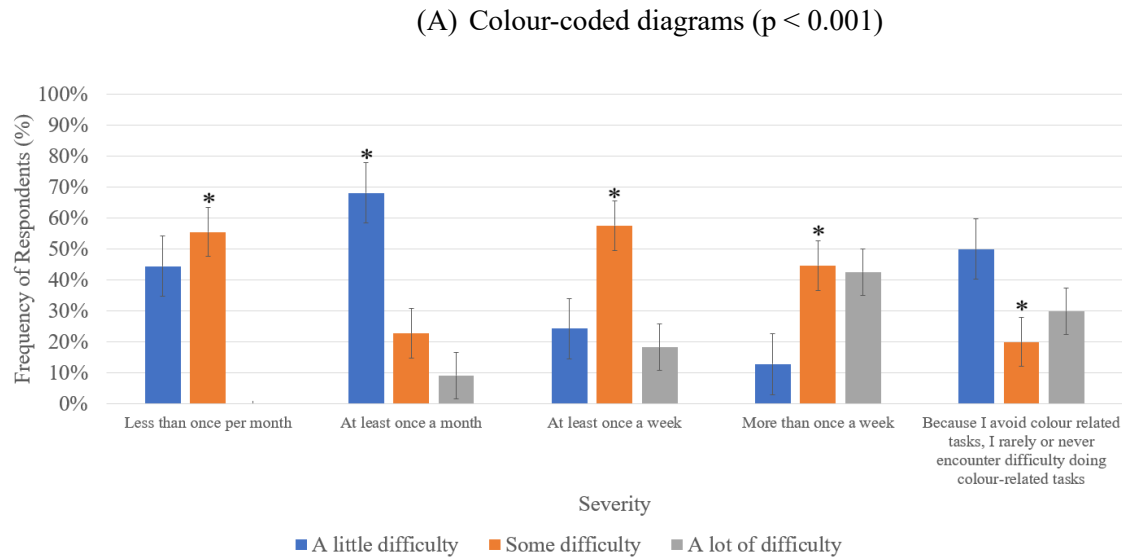


Figure 7.13. The distribution of ranked difficulty by all respondents with (A) colour-coded diagrams and (B) photos. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.2.4 Digital Displays where Difficulties are Encountered

There were 182 respondents who selected at least one display, which means that 84.7% of those who worked/volunteered selected a display. This consists of 75.8% males (138) and 24.2% females (44). Based on age group, there was 12.6% youth (23) and 87.4% adults (159). There were more respondents

who selected a display than 166 respondents who ranked difficulty with a task due to the few respondents who did not rank the tasks. There were 82.6% of males, 91.7% of females, 88.5% of youth, and 84.1% of adults who work/volunteer who experienced difficulty with a display at work or volunteering. Figure 7.14 shows the distribution of the displays selected by respondents based on (A) sex and (B) age group. The other displays listed by two male adults included “broadcast monitors” and “vehicle GPS system.” Both sexes most frequently encountered challenges with desktops/laptops and cell phones. The displays that youth and adults experienced challenges with differed. Youth most frequently experienced difficulties with tablets, desktops/laptops, and whiteboards. Whereas adults most frequently encountered problems with desktops/laptops and cell phones.

For the statistical analyses, the “other digital displays” were removed because they did not meet the assumption that all expected values must be greater than 1. One male youth reported having difficulties with “none” of the displays at work/volunteering in the “other” category, so his response was omitted. “Whiteboards” and “immersive systems” were combined into one category for the analysis by age group to meet all the test assumptions. Although there were some variations, there was a significant association between the selected displays and age group ($\chi^2 = 12.3$, $df = 3$, $p = 0.0065$) but not for sex ($\chi^2 = 0.9$, $df = 4$, $p = 0.93$).

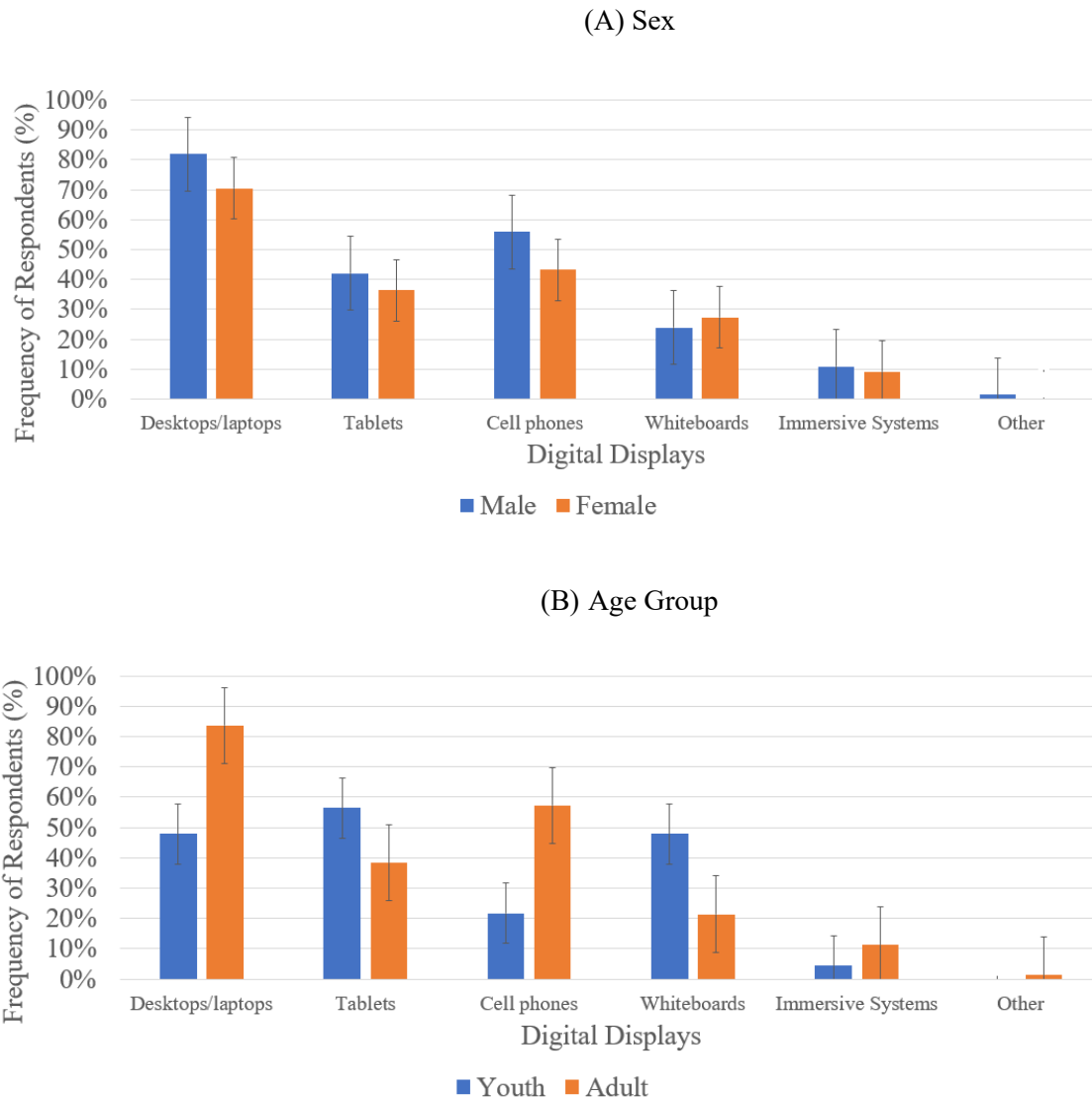


Figure 7.14. The distribution of digital displays that respondents found challenging when using at work/volunteering based on (A) sex and (B) age group (N=182). The “other displays” include the responses of 2 male adults. The error bars represent standard error.

7.3 Recreation/Hobbies

This next area of life explored is hobbies and recreational activities, excluding gaming. Of the total 381 respondents who completed the survey, 208 respondents (54.6%) used digital devices for hobbies or recreational activities, 172 respondents (45.1%) did not, and 1 respondent (0.3%) preferred not to answer. There was one male youth who initially reported participating in recreation/hobbies, but his response was better suited for “gaming/eSports” so his responses were included in that section of the survey. Out of the respondents who do use devices for hobbies or recreational activities, there were 25.0% male youth (52),

49.0% male adults (102), 11.1% female youth (23), and 14.9% female adults (31). There were 60.5% of male youth, 52.6% of male adults, 53.5% of female youth, and 53.4% of female adults who completed the survey use devices for hobbies or recreational activities.

7.3.1 Difficulty Rankings of Colour-Related Tasks in Hobbies or Recreational Activities: Sex Differences

People with CVD were asked which coloured tasks they had difficulty using digital displays. There were 184 respondents who chose tasks they experienced trouble with, and 173 of them ranked at least a little difficulty with one of the coloured tasks. Eighty-three percent (83.2%) of the respondents experienced trouble with at least one of the tasks. Of the respondents who participated in hobbies or recreational activities, 72.8% were males (126), and 27.2% were females (47) ranked the difficulty. This means that 81.8% of males and 87.0% of females who reported using devices for hobbies or recreational activities ranked at least a little difficulty with a task.

Figure 7.15 shows the distribution of the male and female respondents who experienced at least a little difficulty across the different tasks. The tasks that the males most frequently encountered difficulties with were "colour-coded diagrams" (61.9%; 78), "colour-coded plans/instructions" (57.9%; 73), and "maps" (55.6%; 70). For the females, the three tasks which caused the most frequent problems were "colour-coded plans/instructions" (61.7%; 29), "editing coloured images (including photos)" (59.6%; 28), and "colour-coded diagrams" (57.4%; 27). Although there were slight differences in the distribution, they were not significantly different across the seven tasks based on sex ($\chi^2 = 4.4$, $df = 6$, $p = 0.62$).

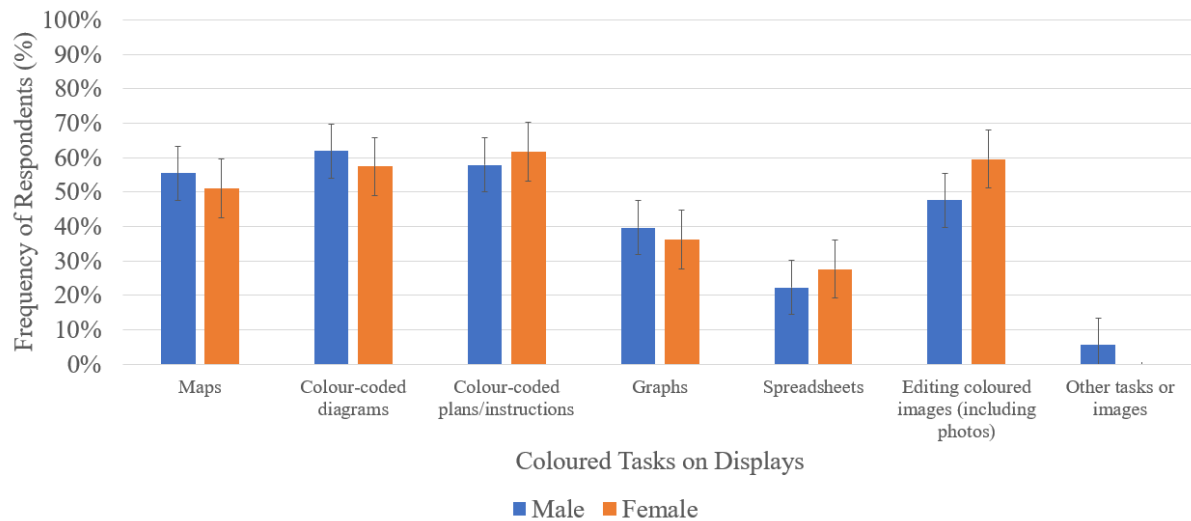
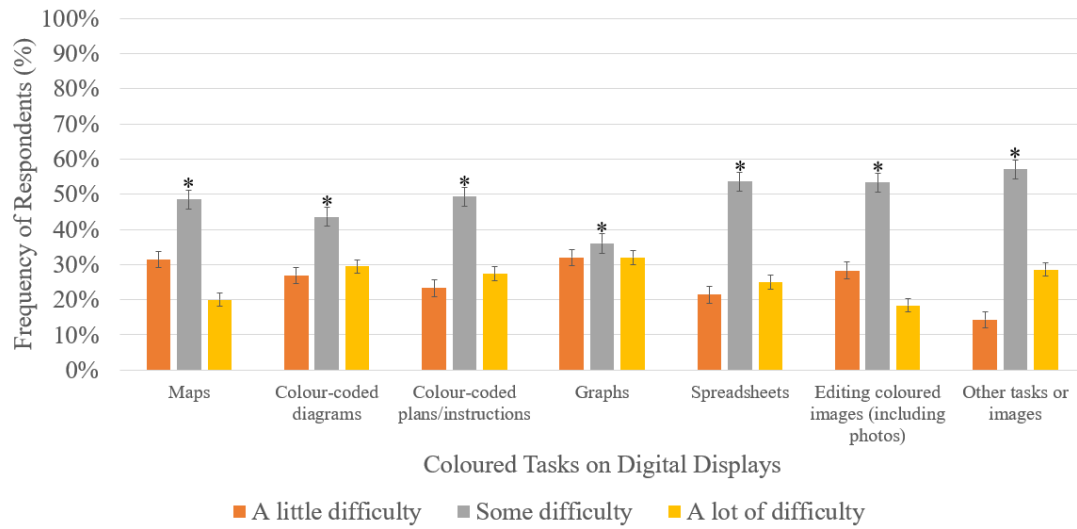
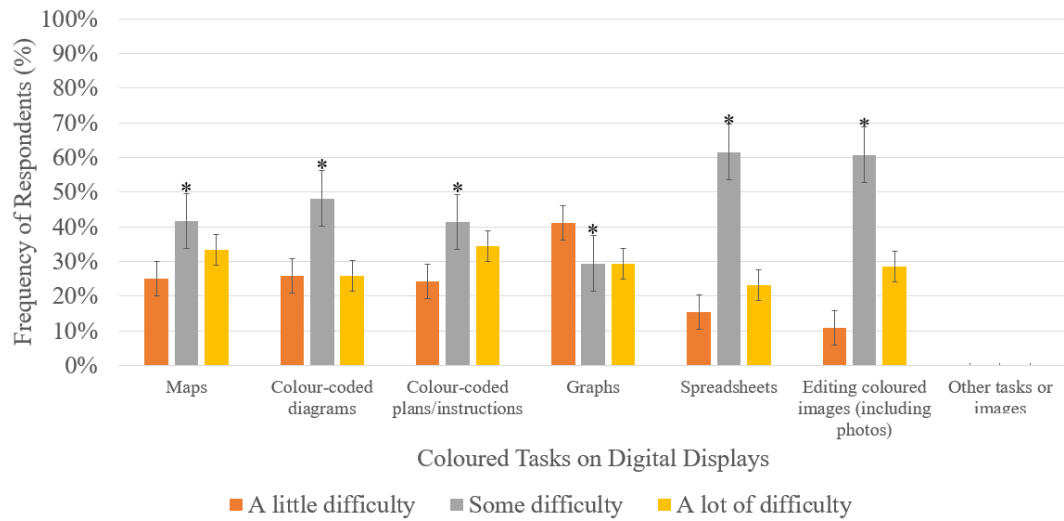


Figure 7.15. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks in hobbies or recreational activities (N=173). The “other tasks” include the responses of 7 males and no females. The error bars represent standard error.

Figure 7.16 shows the distribution of the rankings for the (A) males and (B) females. The median ranking across all tasks was “some difficulty” for both sexes. There were originally 9 respondents (1 male youth and 8 male adults) who listed having challenges with “other” tasks. For one of the “other” tasks, a male youth stated “I use it to play games” which was more appropriate for “gaming and eSports,” so his response was moved into that section. There was also one male adult who reported that “when drawing, it is incredibly difficult to use the colour wheel to get the correct colour. Often, he will have to take the colour from a source image, which is unreliable with low-quality images” but did not rank the difficulty, so both responses were excluded this section. Table 7.3 lists the “other tasks” for the remaining 7 male adults. These differences were not significant across the six tasks based on the Mann-Whitney test ($p \geq 0.069$; adjusted p-value for significance = 0.0083). No females reported difficulties with “other tasks,” so it was excluded from this analysis.



(A) Male



(B) Female

Figure 7.16. The distribution of ranked difficulty by (A) male (N=126) and (B) female (N=47) respondents having difficulty when making colour-related judgements using digital displays for hobbies and recreational activities. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

Table 7.3. The “other tasks or images” that were listed by 7 male adults who use digital displays for hobbies or recreational activities.

Sex	Age Group	Task	Level of Difficulty
Male	Adult	“coloured electrical wires and coloured crayons/markers”	“a lot of difficulty”
		“multi-coloured posters, pages, flyers and diagrams”	“a lot of difficulty”
		“when painting sometimes cannot tell the difference between blues and blacks”	“some difficulty”
		“graphic design”	“some difficulty”
		“red lights”	“some difficulty”
		“photoshop”	“some difficulty”
		“colour-coded electronic components like hole resistors”	“a little difficulty”

7.3.2 Difficulty Rankings of Colour-Related Tasks in Hobbies or Recreational Activities: Age-Group Differences

Of the 173 who ranked these tasks, 38.7% were youth (67) and 61.3% were adults (106). There were 89.3% of youth and 79.7% of adults who reported using devices for hobbies or recreational activities ranked at least a little difficulty with one of the tasks. Figure 7.17 shows the distribution of the rankings based on both age groups who ranked at least a little difficulty with these tasks. The tasks that youth most frequently encountered problems with were “colour-coded diagrams” (64.2%; 43), “maps” (59.7%; 40), and “colour-coded plans/instructions” (58.2%; 39). For adults, the three tasks were “colour-coded plans/instructions” (59.4%; 63), “colour-coded diagrams” (58.5%; 62), and “editing coloured images (including photos)” (52.8%; 56). Both age groups displayed similar distributions. There were no significant differences across the seven tasks based on age group ($\chi^2 = 6.3$, $df = 6$, $p = 0.39$). The “other” category included the responses of 7 male adults.

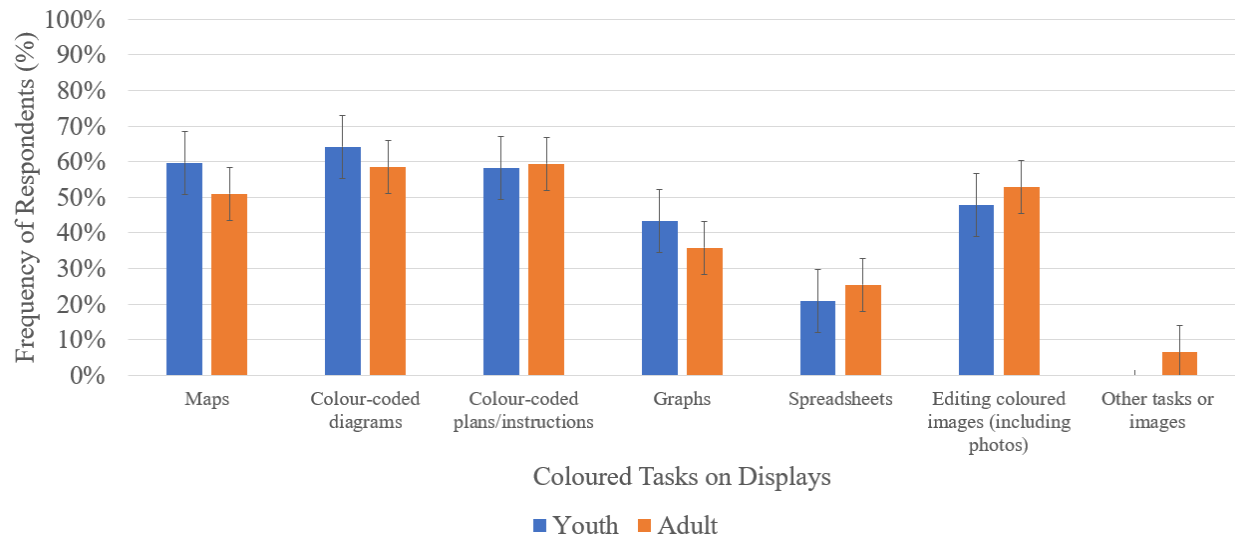
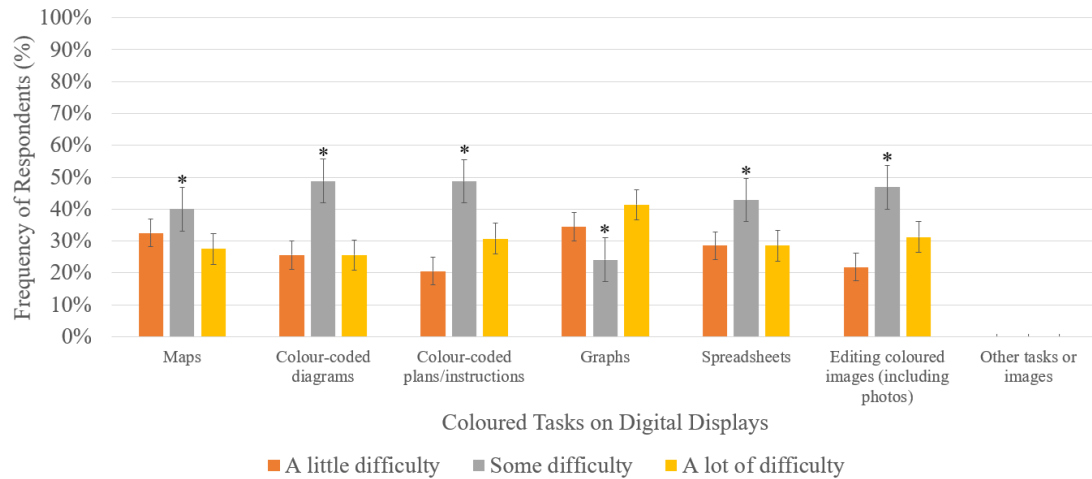
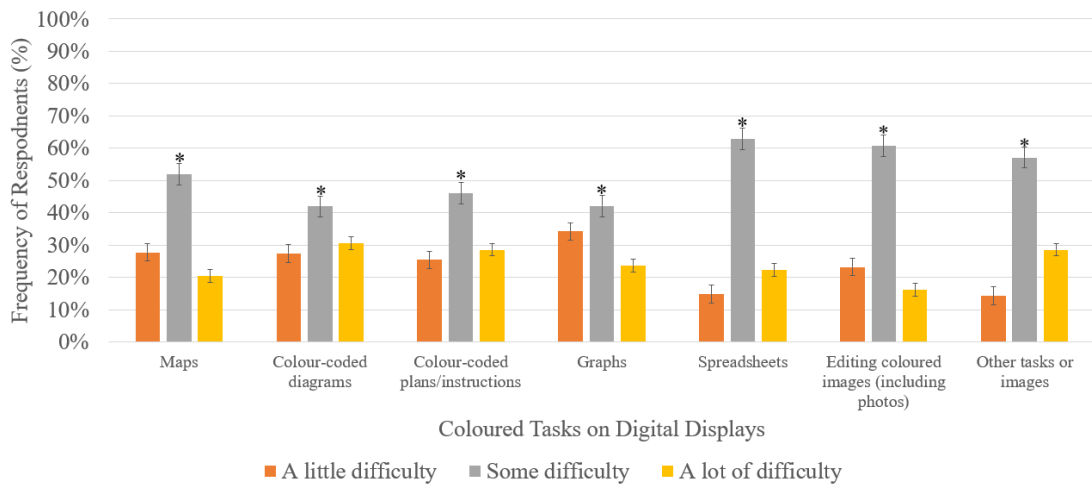


Figure 7.17. The frequency of youth and adult respondents who ranked at least a little difficulty for the coloured tasks in hobbies or recreational activities (N=173). The “other tasks” include the responses of no youth and 7 adults. The error bars represent standard error.

Figure 7.18 shows the distributions of rankings for (A) youth and (B) adults. The median ranking for both age groups was “some difficulty.” The rankings within a task were not significantly different across the six tasks according to the Mann-Whitney test ($p \geq 0.27$; adjusted p-value for significance = 0.0083). No youth respondents reported challenges with “other tasks” so it was excluded from this analysis.



(A) Youth



(B) Adult

Figure 7.18. The distribution of ranked difficulty by (A) youth (N=67) and (B) adult (N=106) respondents having difficulty when making colour-related judgements using digital displays for hobbies and recreational activities. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.3.3 Difficulty Rankings of Colour-Related Tasks in Hobbies or Recreational Activities: Severity Differences

Table 7.4 shows the results from the Kruskal-Wallis test for the pooled-subject rankings and severity for the six tasks. The tasks that displayed significant differences in the rankings were “colour-coded diagrams” ($H = 26.4$, $df = 4$, $p < 0.001$), “colour-coded plans/instructions” ($H = 18.7$, $df = 4$, $p < 0.001$), and “editing coloured images (including photos)” ($H = 14.9$, $df = 4$, $p = 0.005$; adjusted p-value for

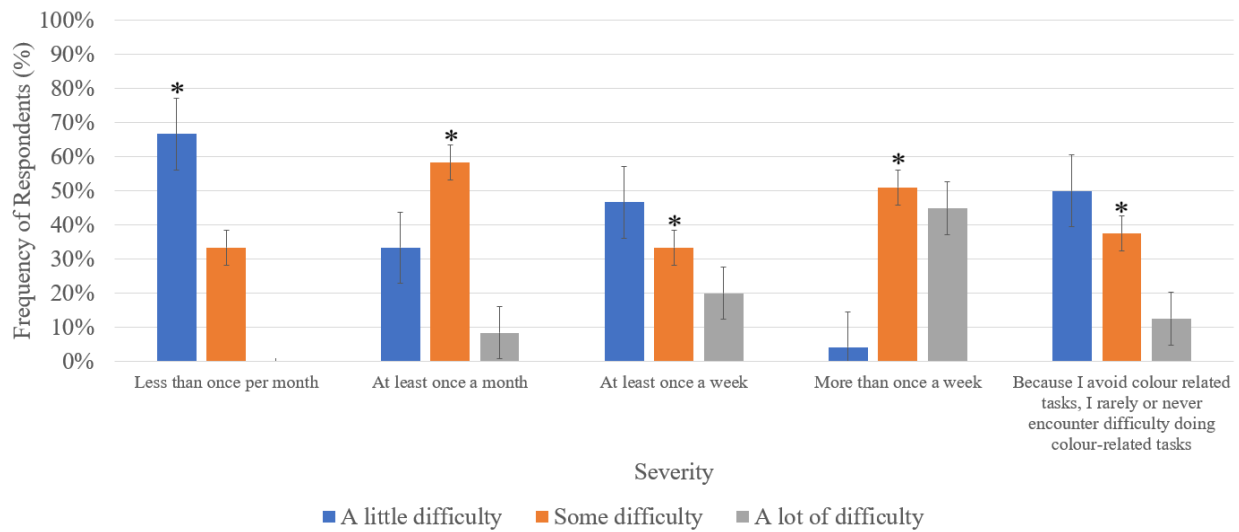
significance = 0.0083). The pairwise comparisons showed significant differences between milder (“less than once per month,” “at least once a month,” and “at least once a week”) and most severe defects (“more than once a week”) for all three tasks (diagrams: adj. $p \geq 0.001$; plans/instructions: adj. $p \geq 0.002$; editing: adj. $p = 0.024$). The “other tasks or images” were excluded from this analysis since it was omitted in the Mann-Whitney analyses for sex and age group.

Table 7.4. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed in hobbies or recreational activities based on severity. The values in parentheses indicated p-values that are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0083$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Colour-coded diagrams	105	26.4	4	(< 0.001)	“less than once per month”	“more than once a week”	(0.009)
					“at least once a week”	“more than once a week”	(0.001)
Colour-coded plans/instructions	102	18.7	4	(< 0.001)	“at least once a month”	“more than once a week”	(0.002)
					“at least once a week”	“more than once a week”	(0.032)
Editing coloured images (including photos)	88	14.9	4	(0.005)	“at least once a month”	“more than once a week”	(0.024)
Maps	94	6.9	4	0.14	N/A		
Graphs	67	6.3	4	0.18	N/A		
Spreadsheets	41	5.8	4	0.22	N/A		

Figure 7.19 shows the distribution of the difficulty rankings based on severity for the significantly different task of (A) “colour-coded diagrams” ($p < 0.001$) and a task where the differences were not significant for (B) “graphs” ($p = 0.18$). The figure shows the change in median ranking as severity increases beyond “less than once a month” and the systematic increase in the “a lot of difficulty” responses. On the other hand, the rankings for graphs do not show a systematic change with severity.

(A) Colour-coded diagrams ($p < 0.001$)



(B) Graphs ($p = 0.18$)

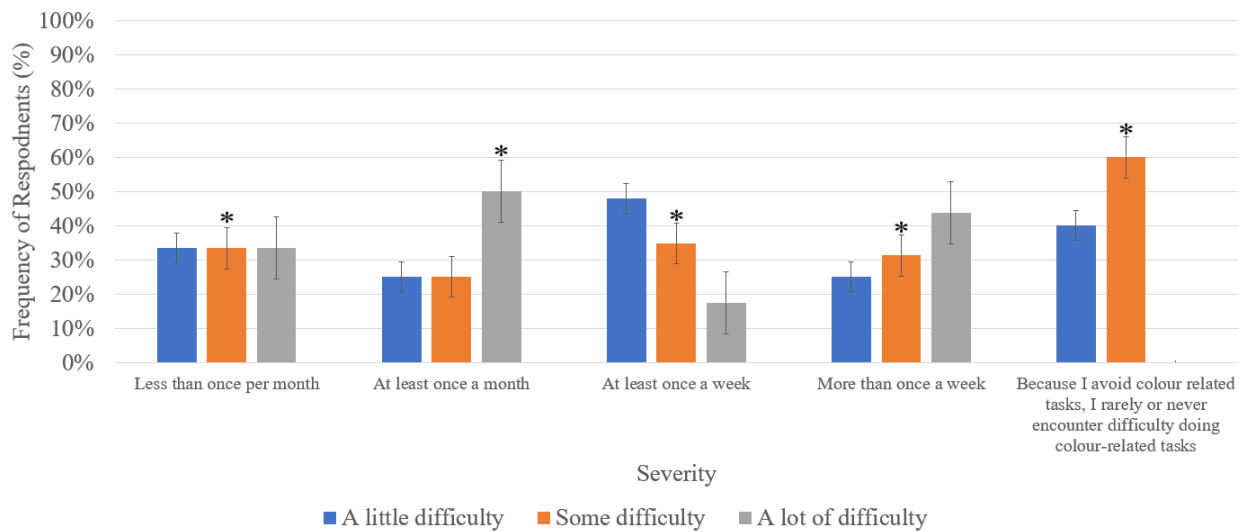


Figure 7.19. The distribution of ranked difficulty by all respondents with (A) colour-coded diagrams and (B) graphs. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.3.4 Digital Displays where Difficulties are Encountered

A total of 184 respondents selected displays that they found challenging, which consisted of 72.3% males (133) and 27.7% females (51). Within the age groups were 37.5% youth (69) and 62.5% adults (115). There were more respondents who selected displays than 173 respondents who ranked the difficulty of tasks because some respondents did not rank the tasks. This means that 88.5% of respondents who participated in hobbies or recreational activities selected a display, more specifically 86.4% of males, 94.4% of females, 92.0% of youth, and 86.5% of adults. Figure 7.20 shows the distribution of the chosen displays based on (A) sex and (B) age group. There were relatively similar distributions between both sexes. The chi-square test did not reveal a significant association for sex ($\chi^2 = 1.0$, $df = 5$, $p = 0.96$). However, there were some differences between age groups. Youth were more likely to report problems with tablets and whiteboards, but fewer problems with cell phones. The association of age group with distribution was significant ($\chi^2 = 18.5$, $df = 5$, $p = 0.0023$). There were “other” displays listed by 9 adults which included: “television/television with gaming consoles” by one female adult and four male adults, “digital camera” by one female adult, “digital testing equipment (e.g. oscilloscopes)” by one male adult, “car infotainment centres” by one male adult, and “red dot sights on firearms” by another male adult.

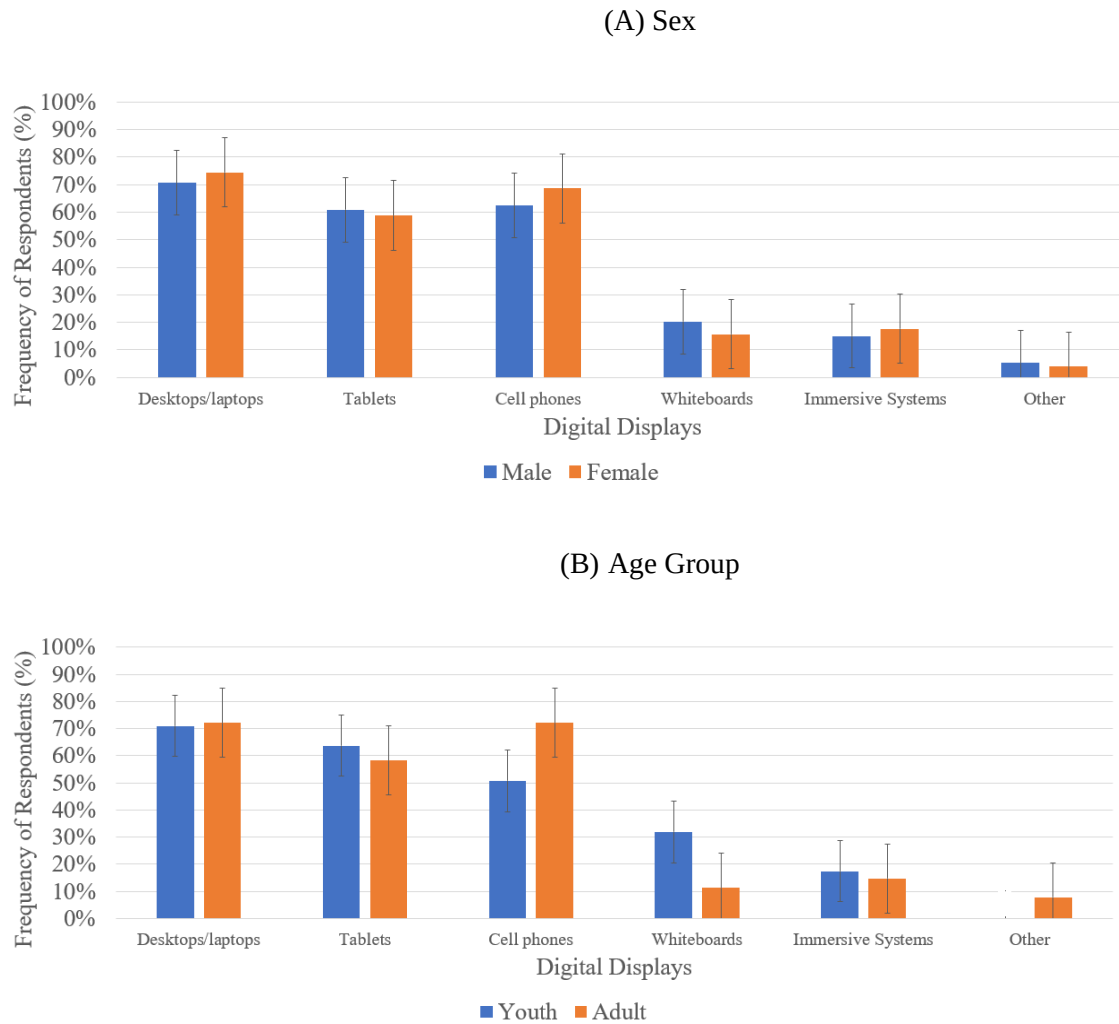


Figure 7.20. The distribution of digital displays that respondents found challenging when using for hobbies or recreational activities based on (A) sex and (B) age group (N=184). The “other displays” include the responses of 7 male adults and 2 female adults. The error bars represent standard error.

7.4 Social Media

This section will focus on the experiences of individuals with CVD in social media activities. Out of the 381 respondents who completed the survey, 321 respondents (84.3%) use devices for one of the social media platforms listed in the survey, 3 respondents (0.8%) use other social media applications, 55 respondents (14.4%) do not use any devices for social media and 2 respondents (0.5%) preferred not to answer. The other social media apps listed were “Tumblr” by one male youth, “Twitch” by another male youth, and “all” reported by one female adult. Of those respondents who use devices for social media activities, it was comprised of 21.3% male youth (69), 52.5% male adults (170), 11.4% female youth (37),

and 14.8% female adults (48). This means that 80.2% of male youth, 87.6% of male adults, 86.0% of female youth, and 82.8% of female adults who completed the survey use a device for social media activities.

7.4.1 Difficulty Rankings of Colour-Related Tasks on Social Media Platforms: Sex Differences

Respondents were asked about the types of tasks in which they experienced difficulties using digital displays when interacting with social media platforms. A total of 298 selected at least one task, but only 283 of them ranked at least a little difficulty with one of the tasks. This means that 88.2% of the respondents experienced trouble with at least one of the tasks on social media platforms. The breakdown based on sex was 74.6% males (211) and 25.4% females (72). There were 88.3% of males and 84.7% of females who use devices for social media ranked difficulty with one of the tasks.

Figure 7.21 shows the distribution of males and females who ranked having at least a little difficulty with the tasks. The tasks that both sexes most frequently experienced challenges with were “reading coloured text” (male: 71.1%, 150; female: 75.0%, 54), “interpreting coloured images” (male: 64.9%, 137; female: 55.6%, 40), and “editing images and videos using various filters and effects to create content” (male: 36.0%, 76; female: 45.8%, 33). There was no significant association between sex and the frequency of responses across the various tasks ($\chi^2 = 3.1$, $df = 5$, $p = 0.69$).

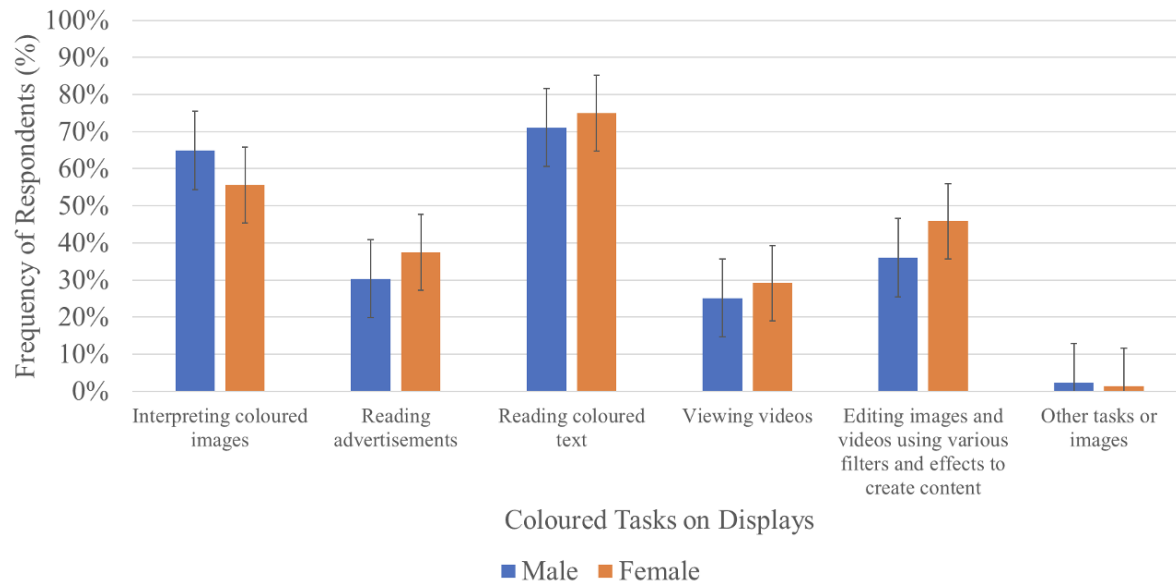


Figure 7.21. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks on social media platforms (N=283). The “other tasks” include the responses of 5 males and one female. The error bars represent standard error.

Figure 7.22 shows the rankings of the (A) males and (B) females for the coloured tasks. The median rankings for all coloured tasks were “some difficulty” for both sexes. There were 6 respondents who reported difficulties with “other tasks” (2 male youths, 3 male adults and 1 female youth), as shown in Table 7.5. Because there was only one female in the “other” category, no median ranking is shown. Based on the Mann-Whitney test, there were no significant differences in the rankings for each of the six tasks ($p \geq 0.14$; adjusted p-value for significance = 0.0083).

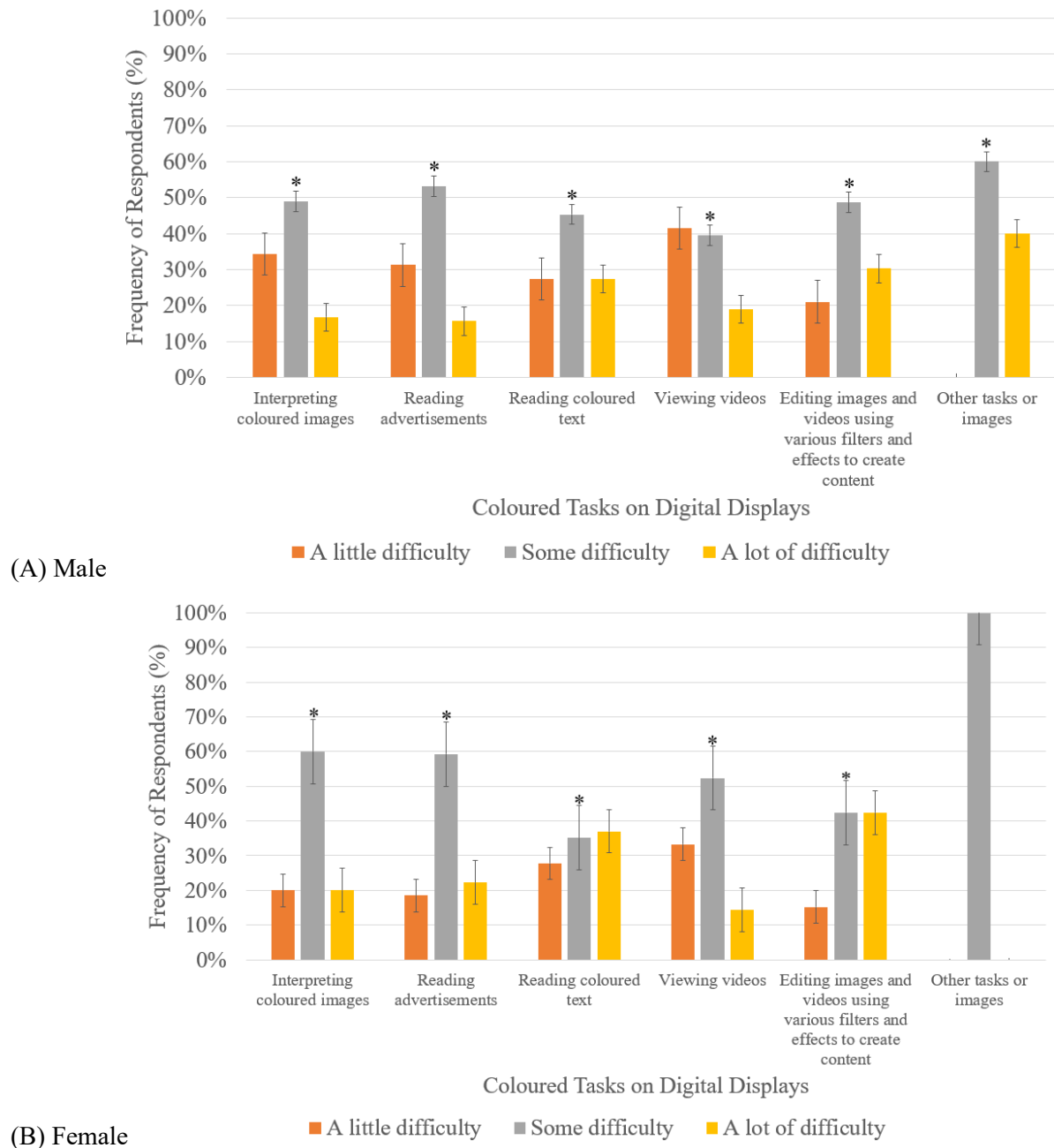


Figure 7.22. The distribution of ranked difficulty by (A) male (N=211) and (B) female (N=72) respondents having difficulty when making colour-related judgements using digital displays for social media activities. The percentages are based on respondents who ranked the difficulty of each particular task. The 100% in the “other” category for females is n=1. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

Table 7.5. The “other tasks or images” that were listed by 6 respondents who use digital displays on social media platforms.

Sex	Age Group	Task	Level of Difficulty
Male	Adult	“bar graphs and other dashboards that use coloured legends”	“some difficulty”
		“reading red letters on dark background or even blue background are very difficult”	“a lot of difficulty”
		“Captcha colours always mess them up when they are all similar light depths even though they are different colours”	“some difficulty”
Male	Youth	“digital art”	“some difficulty”
		“everything I do”	“a lot of difficulty”
Female	Youth	“watching multi-coloured movie titles”	“some difficulty”

7.4.2 Difficulty Rankings of Colour-Related Tasks on Social Media Platforms: Age-Group Differences

Of the 283 respondents who reported using devices for social media platforms, 35.3% were youth (100) and 64.7% were adults (183). This means that 94.3% of youth and 83.9% of adults who use devices for social media activities ranked difficulty with a task. Figure 7.23 shows the frequency of youth and adult respondents who ranked at least a little difficulty with the tasks. The tasks that the age groups most frequently encountered problems with were “reading coloured text” (youth: 71.0%, 71; adult: 72.7%; 133), “interpreting coloured images” (youth: 50.0%; 50; adult: 69.4%; 127), and “editing images and videos using various filters and effects to create content” (youth: 44.0%, 44; adult: 35.5%, 65). There was a significant association between the six tasks and age group ($\chi^2 = 12.8$, $df = 5$, $p = 0.025$), with youth reporting fewer problems with “interpreting coloured images” but more problems with “reading advertisements, viewing videos and editing images.”

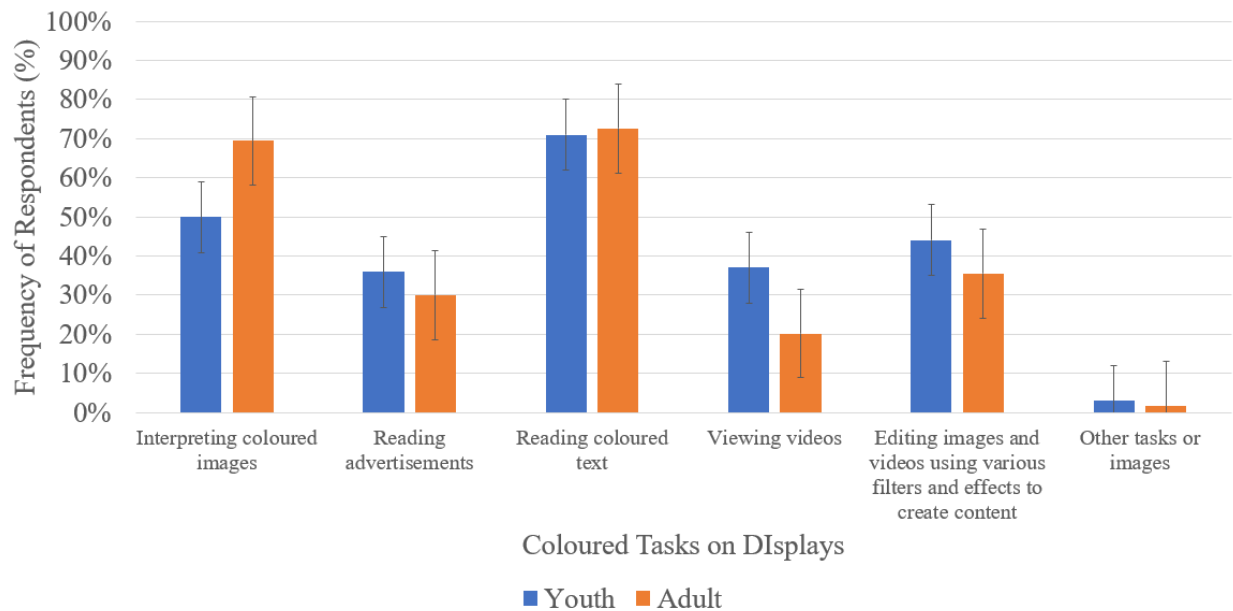
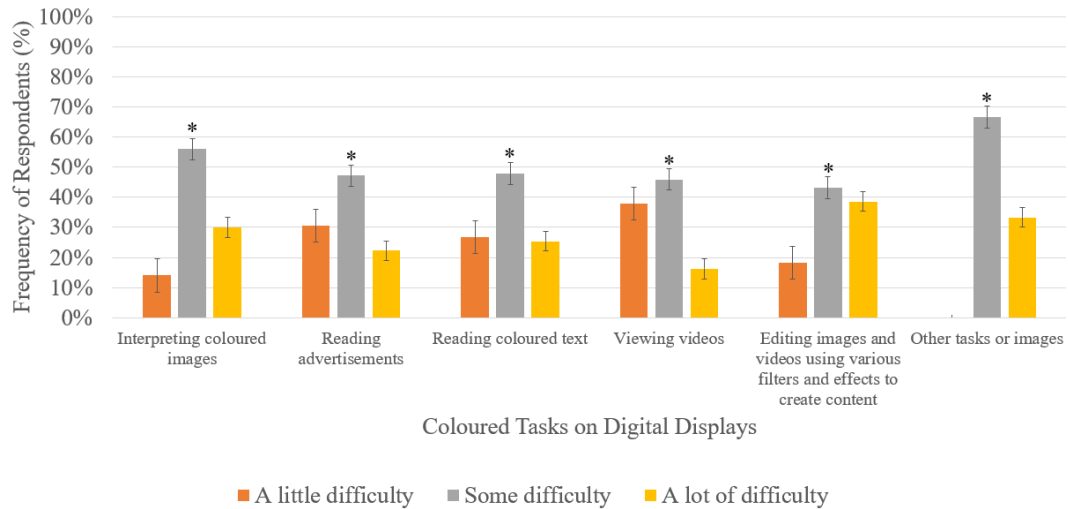
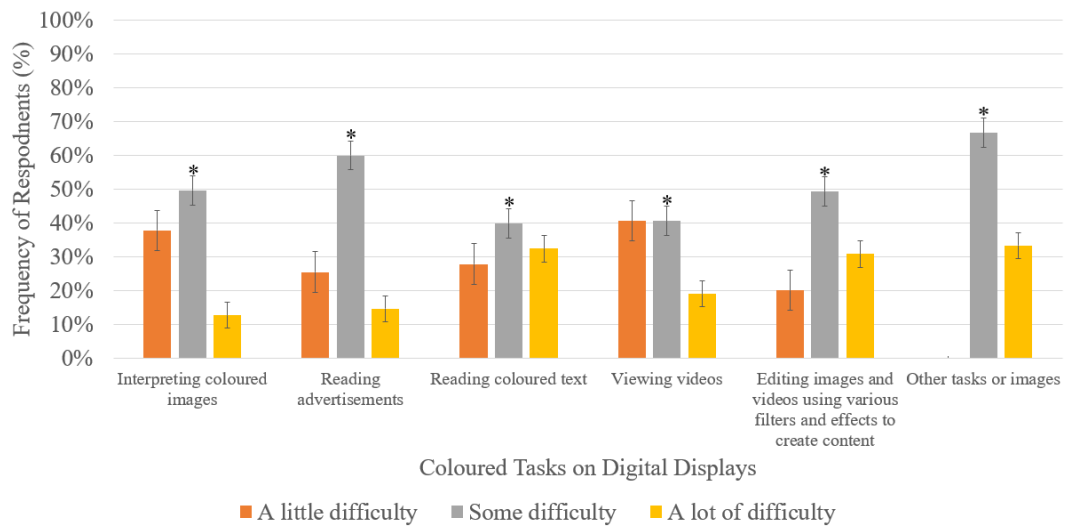


Figure 7.23. The frequency of youth and adult respondents who ranked at least a little difficulty for the coloured tasks on social media platforms (N=283). The “other tasks” include the responses of 3 youths and 3 adults. The error bars represent standard error.

Figure 7.24 shows the distribution of the rankings for the (A) youth and (B) adult respondents across the different tasks. The median rankings for all coloured tasks were “some difficulty” for both age groups. The rankings within a task across the six tasks for the two age groups were significantly different for “interpreting coloured images” (Mann Whitney, $U = 177.0$, $p < 0.001$), but not for the other tasks ($p \geq 0.47$; adjusted p-value for significance = 0.0083). The adults had fewer “a lot of difficulty” and more “a little difficulty” relative to the youth responses.



(A) Youth



(B) Adult

Figure 7.24. The distribution of ranked difficulty by (A) youth (N=100) and (B) adult (N=183) respondents having difficulty when making colour-related judgements using digital displays for social media activities. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.4.3 Difficulty Rankings of Colour-Related Tasks on Social Media Platforms: Severity Differences

The effect of severity was explored across all respondents to examine whether it impacts the rankings. Table 7.6 shows the results from the Kruskal-Wallis test for the rankings of the six tasks. The tasks that showed significant differences in their rankings were “interpreting coloured images” ($H = 23.7$, $df = 4$, p

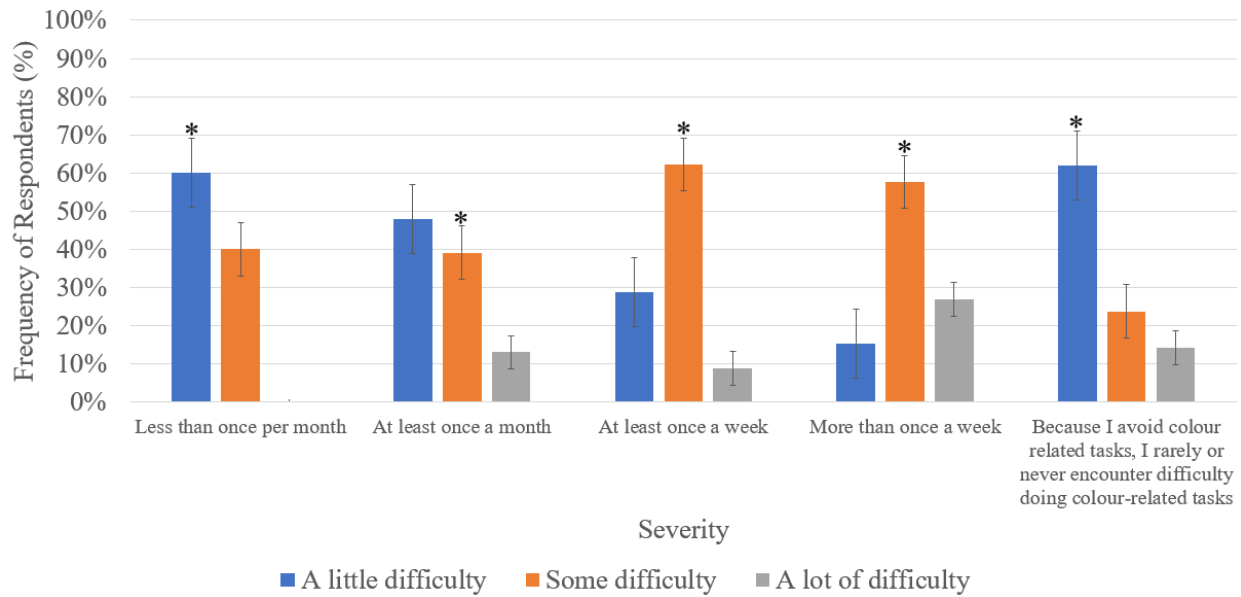
< 0.001), “reading coloured text” ($H = 22.5$, $df = 4$, $p < 0.001$), and “editing images and videos using various filters and effects to create content” ($H = 16.5$, $df = 4$, $p = 0.002$; adjusted p-value for significance = 0.0083). Based on the pairwise comparisons, there were significant differences between the mild (e.g. “less than once a month” and “at least once a month”) and severe (“more than once a week”) defects (images: $p \geq 0.003$; text: $p \geq 0.002$; editing: $p = 0.010$).

Table 7.6. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed on social media platforms based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0083$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Interpreting coloured images	177	23.7	4	(< 0.001)	“more than once a week”	“because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks”	(0.003)
					“less than once per month”	“more than once a week”	(0.018)
					“at least once a month”	“more than once a week”	(0.037)
Reading coloured text	204	22.5	4	(< 0.001)	“at least once a month”	“more than once a week”	(0.002)
					“less than once per month”	“more than once a week”	(0.021)
					“at least once a week”	“more than once a week”	(0.036)
Editing images and videos using various filters and effects to create content	109	16.5	4	(0.002)	“less than once per month”	“more than once a week”	(0.010)
Reading advertisements	91	5.4	4	0.25	N/A		
Other tasks or images	6	1.3	1	0.26	N/A		
Viewing videos	74	4.9	4	0.30	N/A		

Figure 7.25 shows the distribution of the rankings based on severity for the significantly different task of (A) “interpreting coloured images” ($p < 0.001$) and a task where the differences were not significant, (B) “reading advertisements” ($p = 0.25$). The median ranking of most of the severity levels was “some difficulty” for both tasks, except for “less than once a month” and “rarely or never encounter difficulty because avoid colour-related tasks” for “interpreting coloured images” and “at least once a month” for “reading advertisements” was “a little difficulty.” Overall, the distribution is shifting towards a lot of difficulty as severity increases. The distribution of the rankings as a function of severity for reading advertisements did not show a schematic change.

(A) Interpreting coloured images ($p < 0.001$)



(B) Reading advertisements ($p = 0.25$)

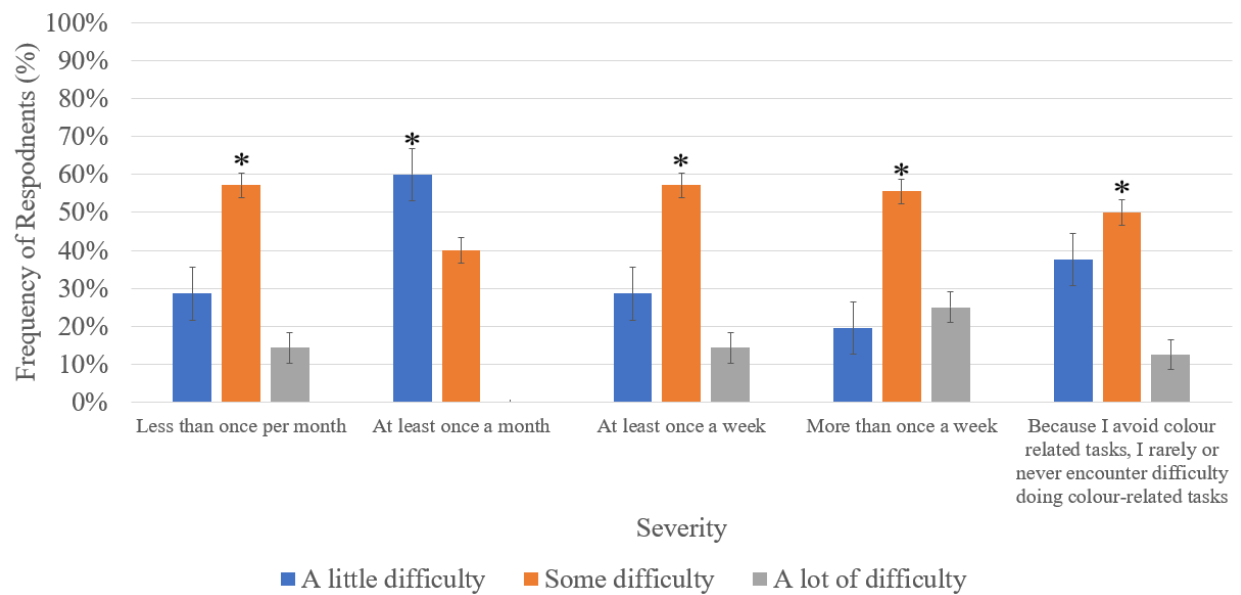


Figure 7.25. The distribution of ranked difficulty by all respondents with (A) interpreting coloured images and (B) reading advertisements. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.4.4 Digital Displays that Respondents Encountered Difficulties on Social Media Platforms

There were 298 respondents who selected a display that they encountered challenges, which means that 92.8% of those who use displays for social media platforms selected a display. This group was comprised of 73.2% males (218), 26.8% females (80), 33.9% youth (101), and 66.1% adults (197). There were more respondents who selected a display than 283 respondents who ranked the difficulty of the tasks. There were 91.2% of males, 94.1% of females, 95.3% of youth, and 90.4% of adults using devices for social media experienced difficulty with a display. One female youth initially reported “not knowing what that is” in the “other” category for the displays, so her response was changed to unselected.

Figure 7.26 shows the distribution of the displays that respondents encountered troubles with based on (A) sex and (B) age group. There were relatively similar distributions based on sex, and there was no significant association between the six displays and sex ($\chi^2 = 3.2$, $df = 5$, $p = 0.67$). Although youth were more likely to have problems with tablets and fewer problems with desktops/laptops, there was also no significant association based on age group ($\chi^2 = 9.4$, $df = 5$, $p = 0.092$). There were 7 respondents (1 male youth and 6 male adults) who listed having problems with “other” displays, with the most popular response being “television/television with gaming consoles (e.g. PlayStation 4, Scepter television)” which was reported by 6 respondents (1 male youth and 5 male adults) and “red dot sights on firearms” reported by one male adult.

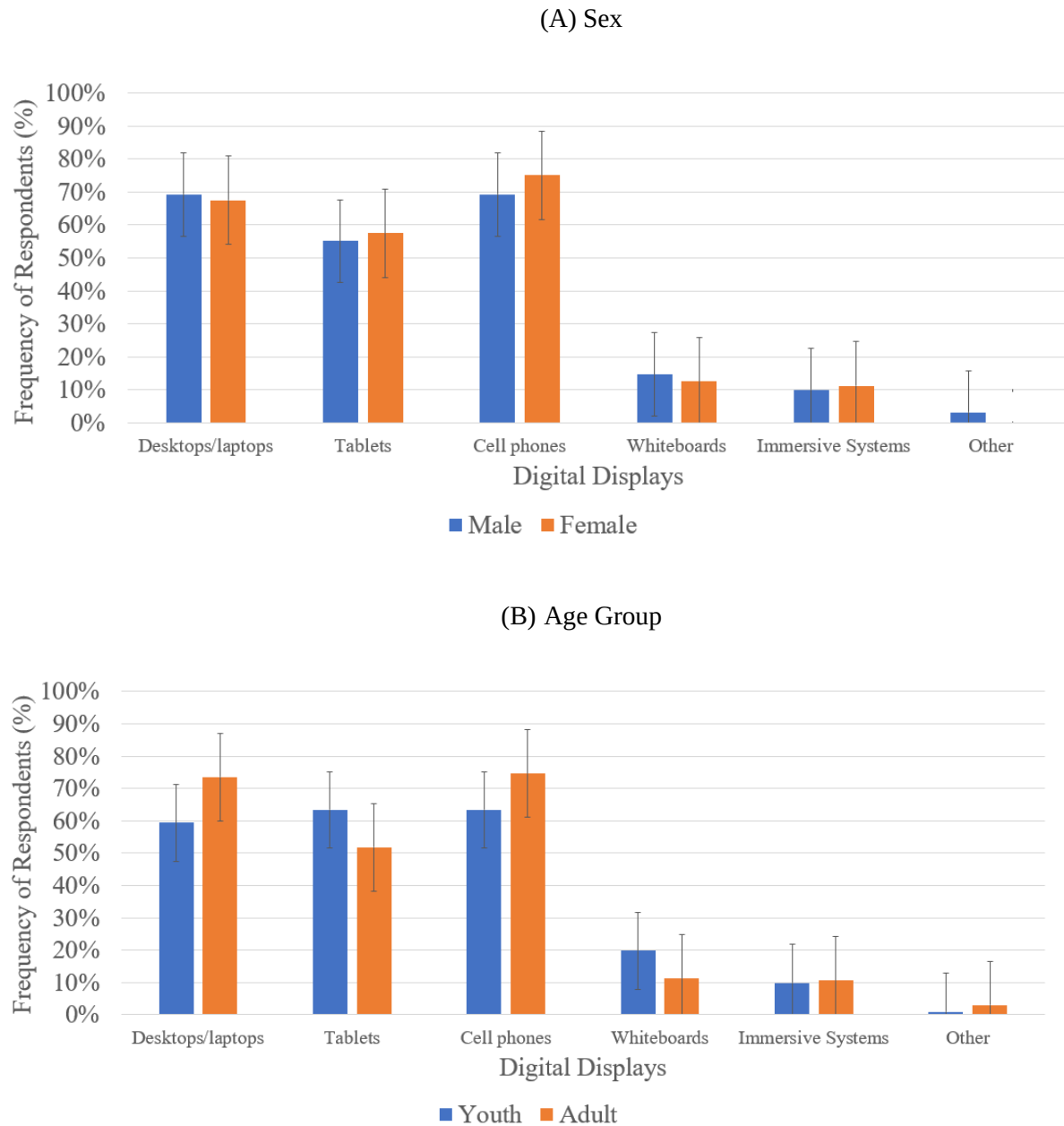


Figure 7.26. The distribution of digital displays that respondents found challenging when using for social media activities based on (A) sex and (B) age group (N=298). The “other displays” include the responses of one male youth and 6 male adults. The error bars represent standard error.

7.5 Gaming & eSports

The experiences of people with CVD when playing games or participating in eSports will be covered in this section. Out of the 381 respondents who completed the survey, there were 241 respondents (63.3%) who reported using digital displays when playing games (e.g. Solitaire, Wordle, Call of Duty) or

participating in eSports (multi-player competitive games with an audience), 135 respondents (35.4%) who did not play any games, and 5 respondents (1.3%) who preferred not to answer. Of the 241 respondents who played games or participated in eSports, there were 25.3% male youth (61), 54.8% male adults (132), 8.7% female youth (21), and 11.2% female adults (27). There were 70.9% of male youth, 68.0% of male adults, 48.8% of female youth, and 46.6% of female adults who completed the survey reported playing games or participating in eSports.

7.5.1 Difficulty Rankings of Colour-Related Tasks When Playing Games or Participating in eSports: Sex Differences

Respondents were asked about the tasks they had difficulty with when reading, identifying or interpreting information on digital displays while playing games or participating in eSports. There were 220 respondents who selected tasks but only 212 of them ranked at least a little difficulty with one of these tasks. Eighty-eight percent (88.0%) of the respondents experienced trouble with at least one of the tasks while gaming or participating in eSports. This consisted of 80.7% males (171) and 19.3% females (41). This means that 88.6% of males and 85.4% of females who game or participate in eSports ranked at least a little difficulty with a task.

Figure 7.27 shows the distribution of the males and females who experienced at least a little difficulty with the various tasks. The three tasks that caused the most challenges for males were: “reading coloured letters on various backgrounds” (63.7%; 109), “matching colours” (60.2%; 103), and “identifying targets/objects” (57.9%; 99). For females, they most frequently encountered problems with “matching colours” (70.7%; 29), “experiencing objects disappearing or having difficulty seeing as the background/scene colours change” (70.7%; 29), and “reading coloured letters on various backgrounds” (65.9%; 27). Although there were some differences, there was no significant association for the six tasks based on sex ($\chi^2 = 8.2$, $df = 5$, $p = 0.15$).

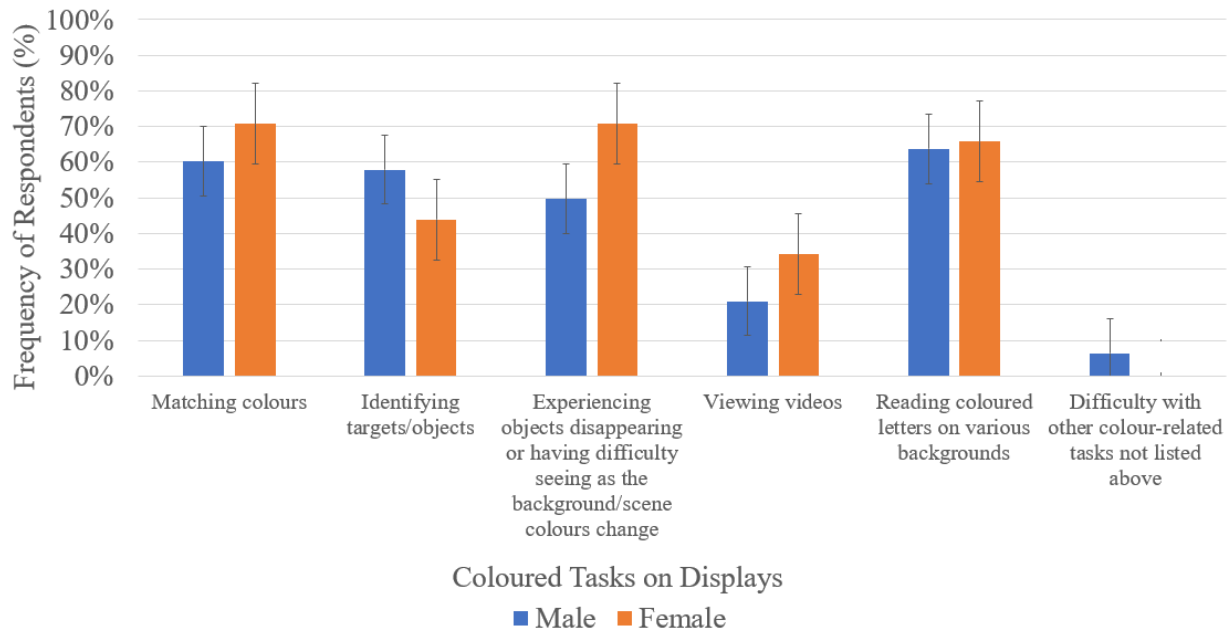
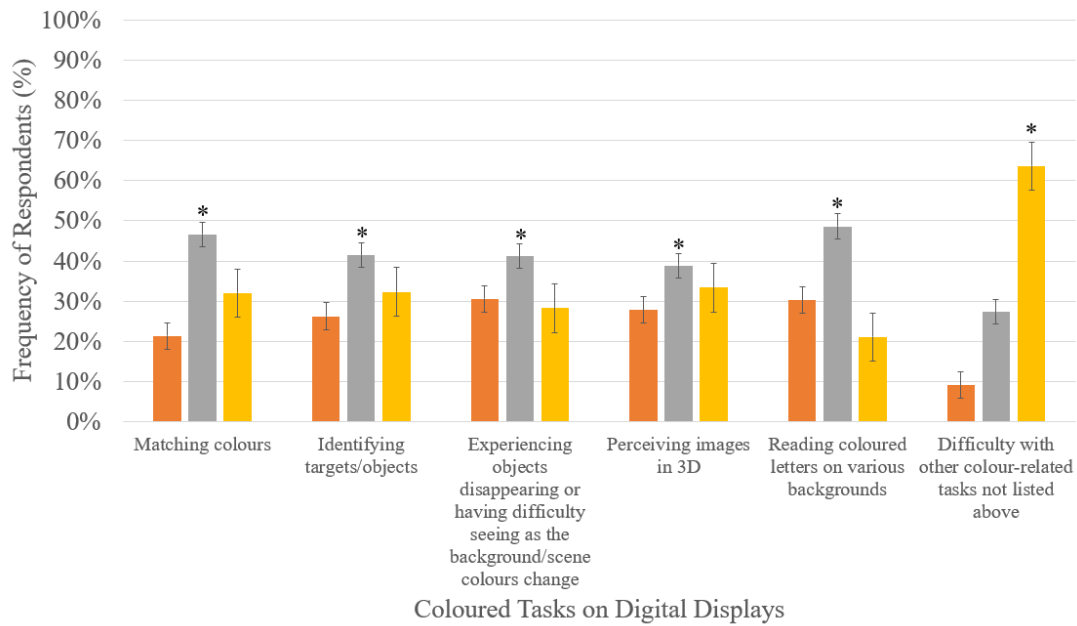
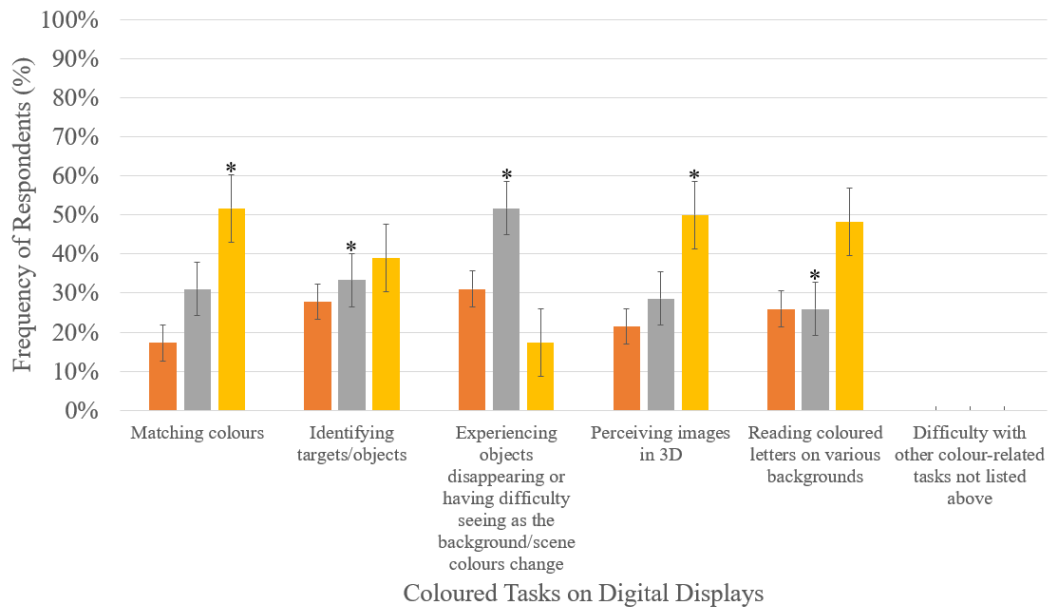


Figure 7.27. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks when playing games or participating in eSports (N=212). The “other tasks” include the responses of 11 males and no females. The error bars represent standard error.

Figure 7.28 shows the distribution of the rankings for the (A) males and (B) females. Several individuals already listed one of the specific tasks in the questionnaire in the “other” response box. The data in the figure are the distributions after moving these responses to the correct task. The “other” category consists of 10 male adults and 1 male youth. Table 7.7 lists the other tasks. For males, the median rankings were “some difficulty” for most tasks. The exception was “other” which had a median ranking of “a lot of difficulty.” For females, the median rankings were similar to those of males (“some difficulty”), except for “matching colours” and “perceiving images in 3D” which had median rankings of “a lot of difficulty.” Nevertheless, these differences were not significant across the five tasks for each task (Mann Whitney; $p \geq 0.055$; adjusted p-value for significance = 0.01). No females reported challenges with “other tasks” so it was excluded from this analysis.



(A) Male



(B) Female

Figure 7.28. The distribution of ranked difficulty by (A) male (N=171) and (B) female (N=41) respondents having difficulty when making colour-related judgements using digital displays for playing games or participating in eSports. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

Table 7.7. The “other” tasks that were mentioned by 11 male respondents who game or participate in eSports.

Sex	Age Group	Task	Level of Difficulty
Male	Youth	“I use it to play games”	“a little difficulty”
	Adult	“always hesitate which colour I see between two options”	“a lot of difficulty”
		“different levels in different colours or some colour differences on maps”	“some difficulty”
		“I simply do not play games that rely on colour association”	“a lot of difficulty”
		“some of the online games have colourblind settings, but sometimes these settings just make it worse than better”	“some difficulty”
		“confusing friends and foes”	“a lot of difficulty”
		“my problem is almost exclusively HUD (heads-up displays) colours are too similar and cannot tell what is on the colour-coded maps and radars, such as Halo 5 which has team colours which give an outline of the teams. Red blends in with a lot of greys and greens they use. It is also incredibly difficult to discern blood on almost any surface which is debilitating in some games”	“a lot of difficulty”
		“colour-based sorting/puzzle games or mini games”	“a lot of difficulty”
		“PUBG is a good example where did not know blood when shown when you are shot until changed to colourblind settings and played for a year before doing that”	“some difficulty”
		“with games, most maps/radars or teams identifying information is conveyed with colour and can cause mix-ups when there is a quick decision, but most modern games have colourblind modes”	“a lot of difficulty”
		“colour matched objects that represent different levels of equipment and non-verbal communications involving colours”	“a lot of difficulty”

7.5.2 Difficulty Rankings of Colour-Related Tasks When Playing Games or Participating in eSports: Age-Group Differences

Of the 212 respondents who ranked the tasks, 34.0% were youth (72) and 66.0% were adults (140). There were 87.8% of youth and 88.1% of adult gamers ranked difficulty with at least one of the tasks. Figure 7.29 shows the distribution of youth and adult respondents who experienced at least a little difficulty with the coloured tasks. The tasks that caused the most difficulty for both age groups were “reading coloured letters on various backgrounds” (youth: 56.9%, 41; adult: 67.9%, 95) and “matching colours” (youth: 56.9%, 41; adult: 65.0%, 91), along with “experiencing objects disappearing or having difficulty seeing as the background/scene colours change” which tied with two previously mentioned tasks (56.9%; 41) for youth and “identifying targets/objects” (60.0%; 84) for adults. Both age groups displayed relatively similar distributions. There was no significant association between the six tasks and age group ($\chi^2 = 6.8$, $df = 5$, $p = 0.23$).

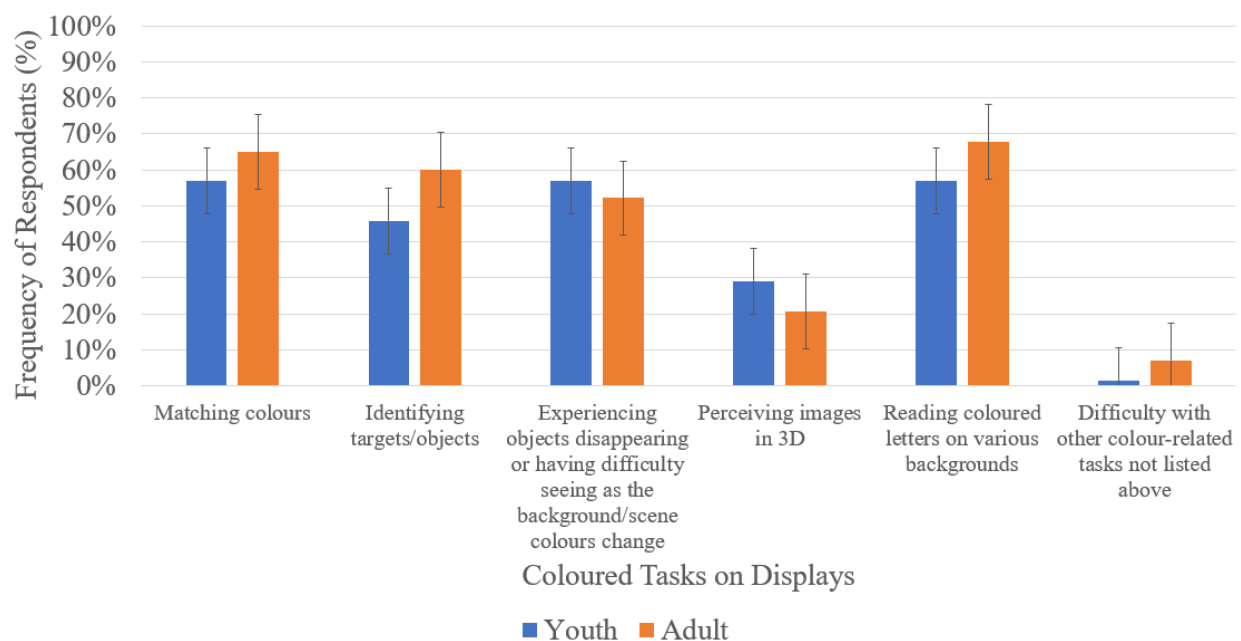
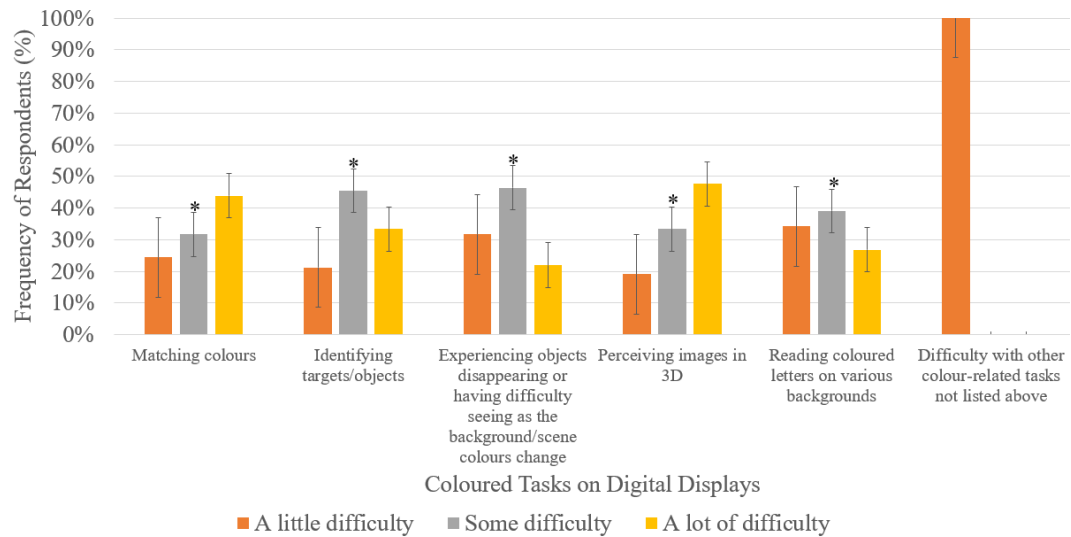


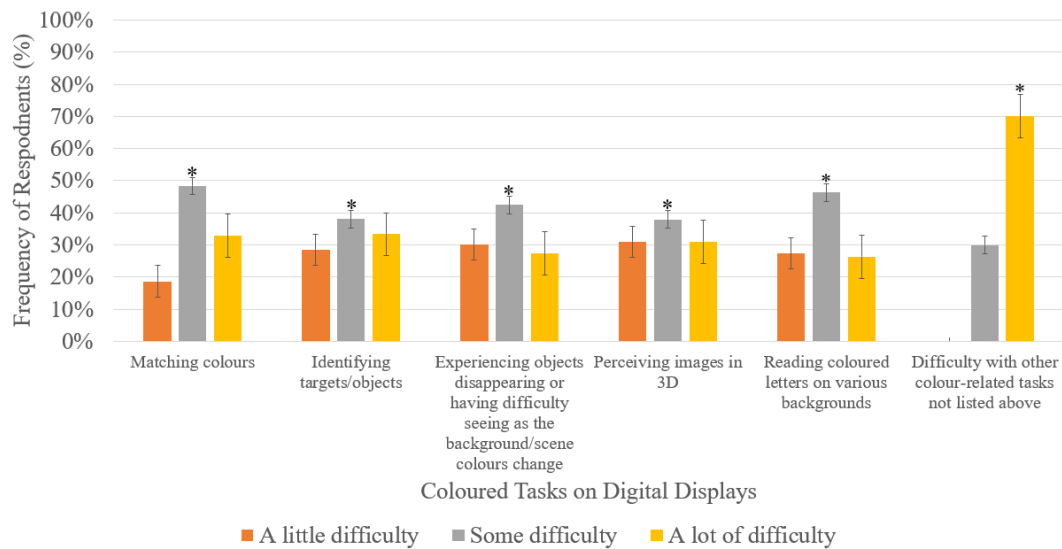
Figure 7.29. The frequency of male and female respondents who ranked at least a little for the coloured tasks when playing games or participating in eSports (N=212). The “other tasks” include the responses of one youth and 10 adults. The error bars represent standard error.

Figure 7.30 shows the distribution of the rankings for (A) youth and (B) adults for each task. The median ranking was “some difficulty” across most tasks for both age groups, except for “other” which had a median ranking of “a lot of difficulty” based on the responses of 10 adults. There was only one youth respondent who reported difficulties with “other tasks,” so the median ranking could not be

indicated. The rankings within a task were not significantly different for the six tasks based on age group according to the Mann-Whitney test ($p \geq 0.18$; adjusted p-value for significance = 0.0083).



(A) Youth



(B) Adult

Figure 7.30. The distribution of ranked difficulty by (A) youth (N=72) and (B) adult (N=140) respondents having difficulty when making colour-related judgements using digital displays when playing games or participating in eSports. The percentages are based on respondents who ranked the difficulty of each particular task. There was one youth respondent who ranked the difficulty of the “other tasks,” which accounts for the 100% ranking. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.5.3 Difficulty Rankings of Colour-Related Tasks When Playing Games or Participating in eSports: Severity Differences

The effect of severity was analyzed across all the respondents on the difficulty rankings. Table 7.8 shows the results from the Kruskal-Wallis test for the rankings of the six tasks based on severity. The tasks that showed significant differences were “matching colours” ($H = 19.9$, $df = 4$, $p < 0.001$), “experiencing objects disappearing or having difficulty seeing as the background/scene” ($H = 19.5$, $df = 4$, $p < 0.001$), and “reading coloured letters on various backgrounds” ($H = 20.2$, $df = 4$, $p < 0.001$; adjusted p-value for significance = 0.0083). Based on the pairwise comparisons, the severity levels that showed significant differences were between milder (“less than once per month,” “at least once a month,” and “at least once a week”) and more severe (“more than once a week”) individuals (matching: adj. $p \geq 0.002$; objects disappearing: adj. $p \geq 0.006$; reading: adj. $p \geq 0.003$).

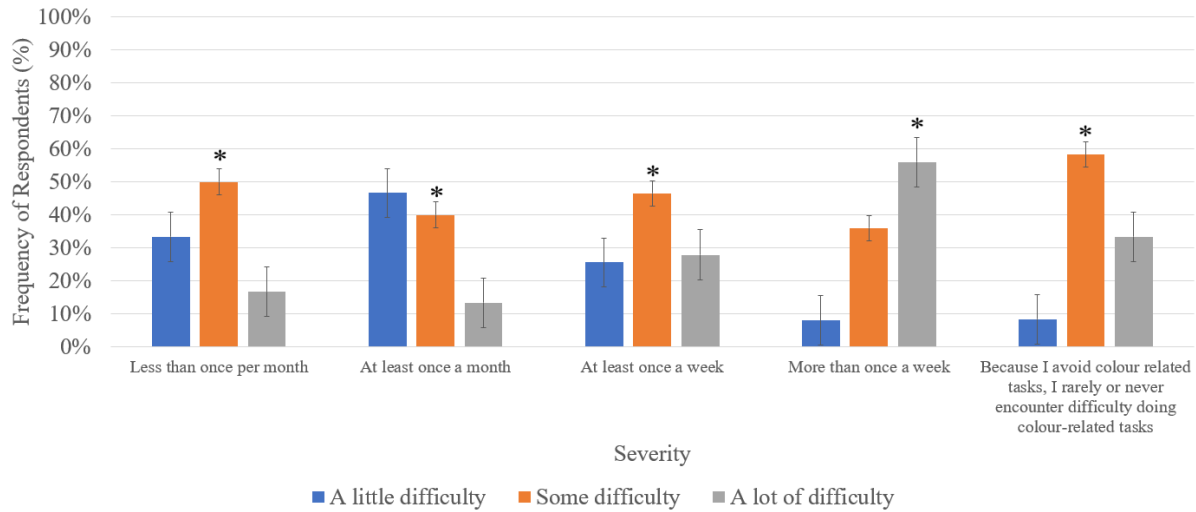
Table 7.8. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed when gaming or participating in eSports based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0083$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Matching colours	132	19.9	4	(< 0.001)	“at least once a month”	“more than once a week”	(0.002)
					“at least once a week”	“more than once a week”	(0.027)
Experiencing objects disappearing or having difficulty seeing as the background/ scene colours change	114	19.5	4	(< 0.001)	“at least once a month”	“more than once a week”	(0.006)
					“less than once per month”	“more than once a week”	(0.010)
Reading coloured letters on various backgrounds	136	20.2	4	(< 0.001)	“less than once per month”	“more than once a week”	(0.003)
					“at least once a month”	“more than once a week”	(0.013)
Identifying targets/objects	117	8.2	4	0.085	N/A		
Perceiving images in 3D	50	4.1	4	0.40	N/A		
Difficulty with other colour-related tasks not listed	11	1.6	3	0.67	N/A		

Figure 7.31 shows the distribution of rankings as a function of severity for the significantly different task of (A) “matching colours” ($p < 0.001$) and a task where the differences were not significant (B) “perceiving images in 3D” ($p = 0.40$). The general trend for “matching colours” was greater difficulty as severity increases. This is shown through the significant difference in the rankings between milder (“less than once per month,” “at least once a month,” and “at least once a week”) and most severe (“more than

once a week”) defects from the pairwise comparisons. The results for “perceiving images in 3D” show a median ranking of “some difficulty,” except for the avoidance group which had a median ranking of “a lot of difficulty.” This last group of respondents had a small number of subjects which resulted in low statistical power.

(A) Matching colours ($p < 0.001$)



(B) Perceiving images in 3D ($p = 0.40$)

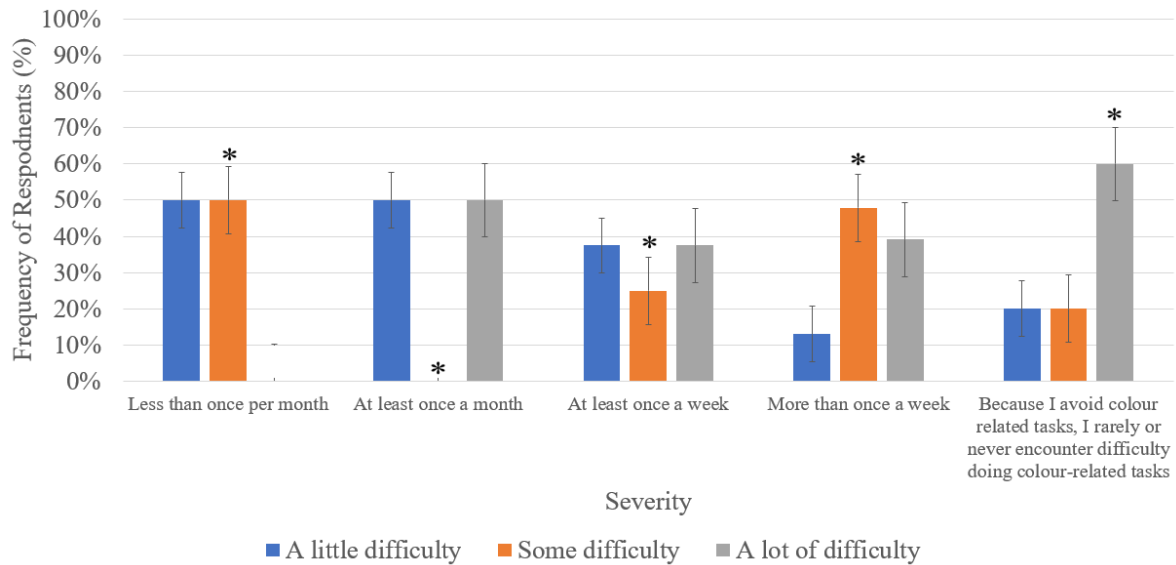


Figure 7.31. The distribution of ranked difficulty by all respondents with (A) matching colours and (B) perceiving images in 3D. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.5.4 Digital Displays where Difficulties are Encountered

There were 220 respondents who selected displays, which means that 91.3% of those who gamed or participated in eSports selected a display. Based on sex, there were 79.5% males (175) and 20.5% females (45). For the age group, 33.6% were youth (74) and 66.4% were adults (146). There were more respondents who selected a display than 212 respondents who ranked the difficulty of tasks. This means that 90.7% of males, 93.8% of females, 90.2% of youth, and 91.8% of adults selected a display that they experience difficulty when playing games or participating in eSports. Figure 7.32 shows the distribution of the displays that respondents reported troubles with based on (A) sex and (B) age group. There were 7 respondents who reported difficulties with “gaming consoles (e.g. PlayStation4, xBox, Nintendo Switch, and GameCube)” in the “other” category, but they already selected having challenges with “monitors used with gaming devices” so their responses were omitted. There was no significant association between the seven displays with sex ($\chi^2 = 8.8$, $df = 6$, $p = 0.18$), whereas there was a significant association in the frequencies for the age group ($\chi^2 = 29.3$, $df = 6$, $p < 0.0001$). The younger users were more likely to report problems with tablets and whiteboards, but a few problems with desktops/laptops and cell phones. There were 17 respondents (16 male adults and 1 female adult) who reported “television.”

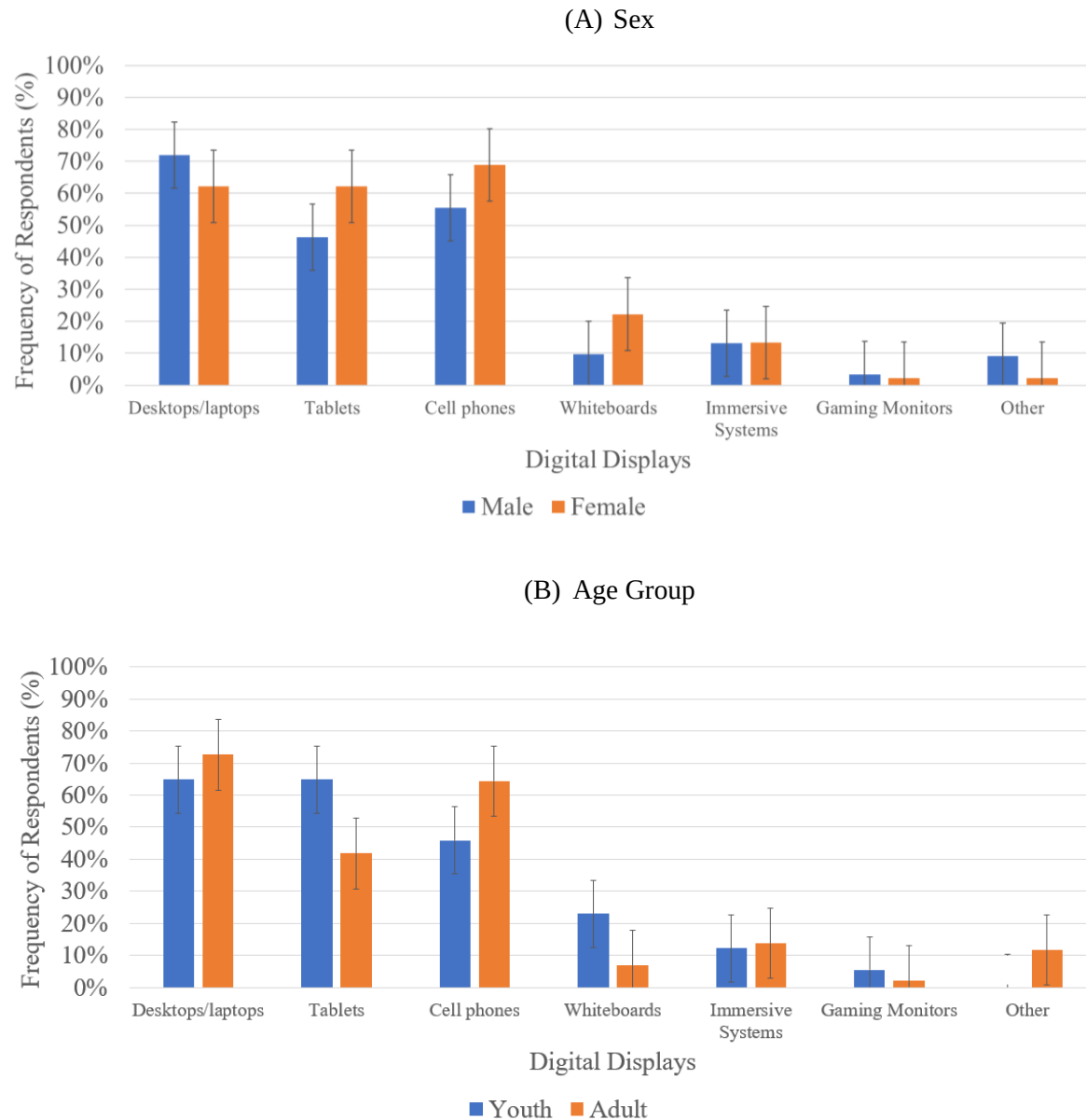


Figure 7.32. The distribution of digital displays that respondents found challenging when playing games or participating in eSports based on (A) sex and (B) age group (N=220). The “other displays” include the responses of 16 male adults and one female adult. The error bars represent standard error.

7.5.5 Games that Respondents Had Difficulty Playing When Using Digital Displays

Respondents were asked to list up to 5 games they had difficulty playing when using any digital display. There were 576 entries. There were 201 respondents who listed at least one specific game, and another 6

indicated that they “do not know” or “cannot think of a specific one.” Of the respondents who reported playing games or participating in eSports, 80.1% were males (161) and 19.9% were females (40). For age group, the breakdown was 34.8% youth (70) and 65.2% adults (131). There were 83.4% of males, 83.3% of females, 85.4% of youth, and 82.4% of adults who game or participate in eSports listed difficulty with at least one game when using a display. Table 7.9 shows the five most frequent games reported by respondents as difficult. There was remarkably one game that both sexes and age groups found the most problematic which was “Call of Duty.” Other games that were commonly mentioned were “Candy Crush/Candy,” Fortnite,” and “Super Mario Bros.”

Table 7.9. The top five games that the respondents reported difficulties playing on any digital displays based on male, female, youth and adult (N=201).

Demographic Factor	Top 5 Games that Respondents Experienced Difficulty Playing Using Any Digital Display
Male	1. <u>Call of Duty</u> (42.2%; 68) 2. <u>Fortnite</u> (9.3%; 15) 3. <u>Candy Crush/Candy & Solitaire</u> (8.7%; 14) 4. <u>Super Mario Bros</u> (6.2%; 10) 5. <u>Minecraft, PUBG & Wordle</u> (5.6%; 9)
Female	1. <u>Call of Duty</u> (22.5%; 9) 2. <u>Candy Crush</u> (17.5%; 7) 3. <u>Halo</u> (12.5%; 5) 4. <u>Super Mario Bros</u> (12.5%; 5) 5. <u>Minecraft</u> (10.0%; 4) 6. <u>Solitaire</u> (10.0%; 4)
Youth	1. <u>Call of Duty</u> (40.0%; 28) 2. <u>Minecraft</u> (12.9%; 9) 3. <u>Candy Crush/Candy, Fortnite & Super Mario Bros</u> (11.4%; 8) 4. <u>Halo</u> (10.0%; 7) 5. <u>Roblox</u> (8.6%; 6)
Adult	1. <u>Call of Duty</u> (37.4%; 49) 2. <u>Solitaire</u> (12.2%; 16) 3. <u>Candy Crush</u> (9.9%; 13) 4. <u>Wordle</u> (7.6%; 10) 5. <u>Fortnite, PUBG & Super Mario Bros</u> (5.3%; 7)

The remaining games were listed by no more than 2 respondents. The list consisted of over 170 responses that comprised of games, genres (e.g. “colour matching games,” “puzzle games,” “multiverse,” and “board games”), gaming consoles (e.g. “PlayStation,” “xBox,” “Nintendo Switch,” and “Oculus”) and gaming platforms (e.g. “Facebook,” “WhatsApp,” and “Google”). Some games in this group were “Bejeweled,” “God of War,” “Clash of Clans,” “Genshin Impact,” “Madden NFL 2022,” “The Legend of Zelda,” “Spiderman,” “Uncharted,” and “Wordle.” There were also responses that were uninterpretable (including extreme spelling mistakes) or too vague where no interruptions could be made. There were 37 of these responses.

7.6 Online Shopping/Banking

Online shopping or banking challenges are presented in this section. Of the 381 respondents who completed the survey, there were 249 respondents (65.4%) who reported using digital devices for online shopping/banking, 130 respondents (34.1%) did not, and 2 respondents (0.5%) preferred not to answer. The 249 respondents who use devices for online shopping/banking consisted of 13.7% male youth (34), 62.7% male adults (156), 7.2% female youth (18), and 16.5% female adults (41). This means that 39.5% of male youth, 80.4% of male adults, 41.9% of female youth, and 70.7% of female adults who completed the survey use displays while online shopping or banking.

7.6.1 Difficulty Rankings of Colour-Related Tasks While Online Shopping or Banking: Sex Differences

Respondents ranked the difficulty of various tasks when shopping/banking online. There were 212 respondents who selected tasks that they encountered challenges with, but only 200 of them ranked at least a little difficulty with one of these tasks. Eighty percent (80.3%) of the respondents experienced trouble with at least one of the tasks. This consisted of 77.0% males (154) and 23.0% females (46). There were 81.1% of males and 78.0% of females who use displays for online shopping or banking ranked difficulty with at least one of the tasks.

Figure 7.33 shows the distributions of the males and females who experienced at least a little difficulty across all tasks. The tasks that males most frequently encountered trouble with were “identifying colours without labels” (61.0%; 94), “selecting colours that match without labels” (50.0%; 77), and “reading coloured letters on various backgrounds” (49.4%; 76). For females, the three tasks that caused the most frequent difficulties were “reading coloured letters on various backgrounds” (65.2%; 30), “selecting colours that match without labels” (60.9%; 28), and “detecting patterns in items” (52.2%; 24). Even though there were some variations in the distribution, there was no significant association between the eight tasks and sex ($\chi^2 = 7.0$, $df = 7$, $p = 0.43$). The “other” category was removed from this analysis since none were reported by any females.

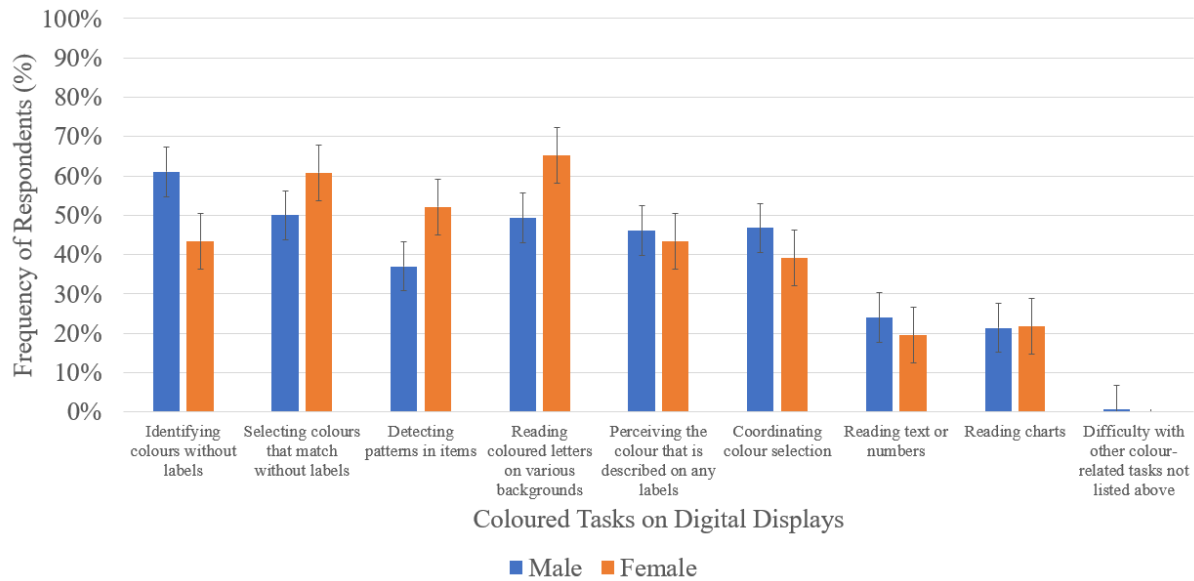
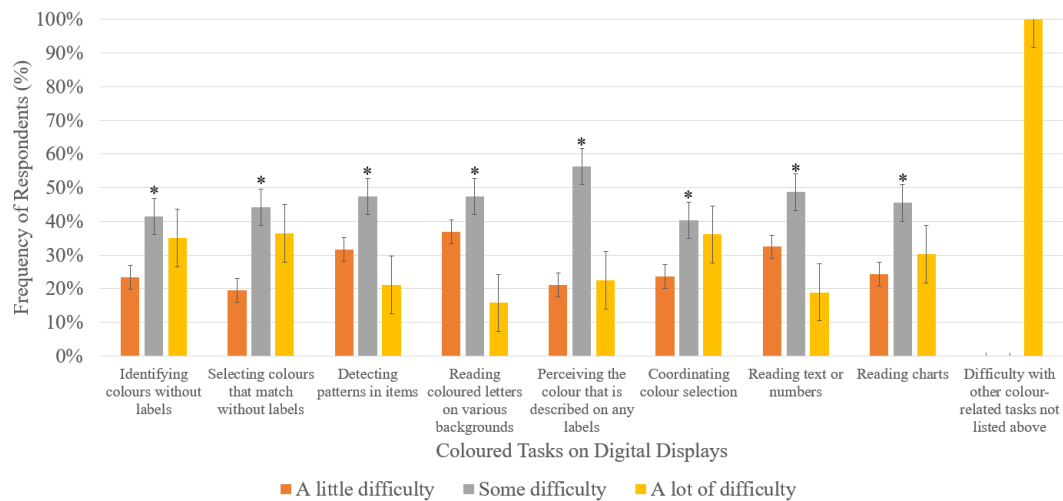
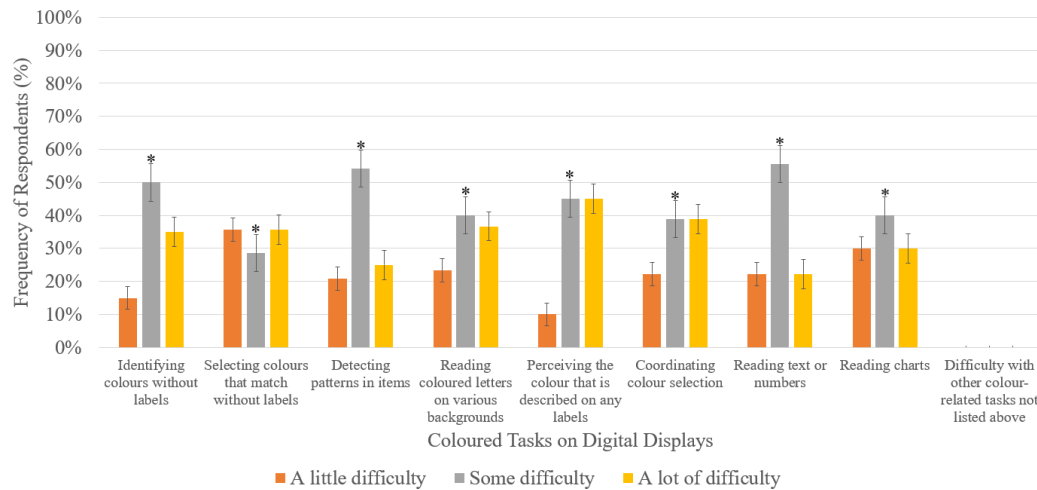


Figure 7.33. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks while online shopping or banking (N=200). The “other tasks” include the responses of one male and no females. The error bars represent standard error.

Figure 7.34 shows the distributions of the rankings for (A) males and (B) females across the various tasks. The median rankings for all coloured tasks were “some difficulty” for both sexes. The median ranking for the “other tasks” cannot be determined for the males since there was only one male adult who reported difficulties with “html links and error messages that are red can be very frustrating” with a ranking of “a lot of difficulty.” These differences were not significant across the eight tasks according to the Mann-Whitney test for each task based on sex ($p \geq 0.034$; adjusted p-value for significance = 0.0063). The “other” category was removed from this analysis because no other tasks were reported by any females.



(A) Male



(B) Female

Figure 7.34. The distribution of ranked difficulty by (A) male (N=154) and (B) female (N=46) respondents having difficulty when making colour-related judgements using digital displays while online shopping or banking. The percentages are based on respondents who ranked the difficulty of each particular task. One male reported difficulty with “other tasks ” accounting for 100% of the ranking. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.6.2 Difficulty Rankings of Colour-Related Tasks While Online Shopping or Banking: Age-Group Differences

There were 200 respondents who provided a difficulty ranking which consisted of 22.5% youth (45) and 77.5% adults (155). This means that 86.5% of youth and 78.7% of adults who use displays while online shopping or banking reported difficulty with at least one of the tasks. Figure 7.35 shows the distribution

of youth and adult respondents who reported at least a little difficulty with the tasks. The three tasks that youth most frequently encountered trouble with were “identifying colours without labels” (53.3%, 24), “detecting patterns in items” (48.9%; 22), and “selecting colours that match without labels” (44.4%, 20). For adults, the three tasks were “identifying colours without labels” (58.1%; 90), “reading coloured letters on various backgrounds” (58.1%; 90), and “selecting colours that match without labels” (54.8%, 85). Although there were some variations in the distribution, there was no significant association between the eight tasks and age group ($\chi^2 = 11.8$, $df = 7$, $p = 0.11$). The “other” category consisted of responses from no youth and one adult, which was removed from this analysis for reasons similar to those mentioned for sex.

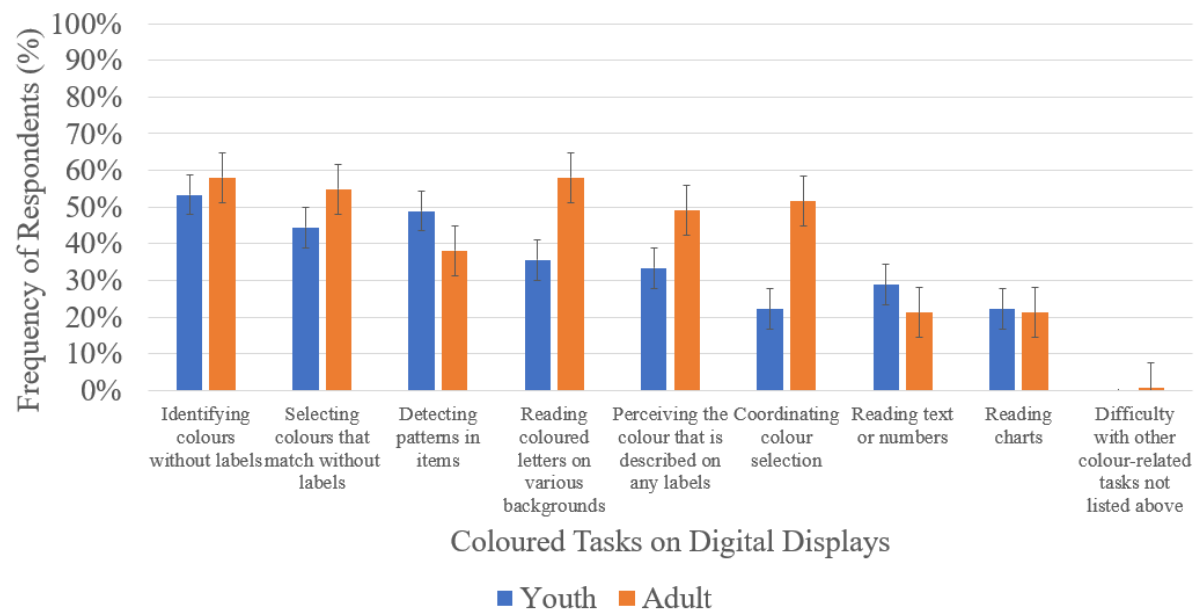


Figure 7.35. The frequency of youth and adult respondents who ranked at least a little difficulty for the coloured tasks while online shopping or banking (N=200). The “other tasks” include the responses of no youth and one adult. The error bars represent standard error.

Figure 7.36 shows the distributions of the difficulty rankings for (A) youth and (B) adults. The median ranking across all tasks was “some difficulty” for both age groups. Since only one adult reported difficulties with the “other tasks,” the median ranking could not be indicated. Regardless of the rankings of a task, they were not significantly different for the eight tasks based on the Mann-Whitney test ($p \geq 0.019$; adjusted p-value for significance = 0.0063). The “other” category was excluded from the analysis because there was none reported by any youth.

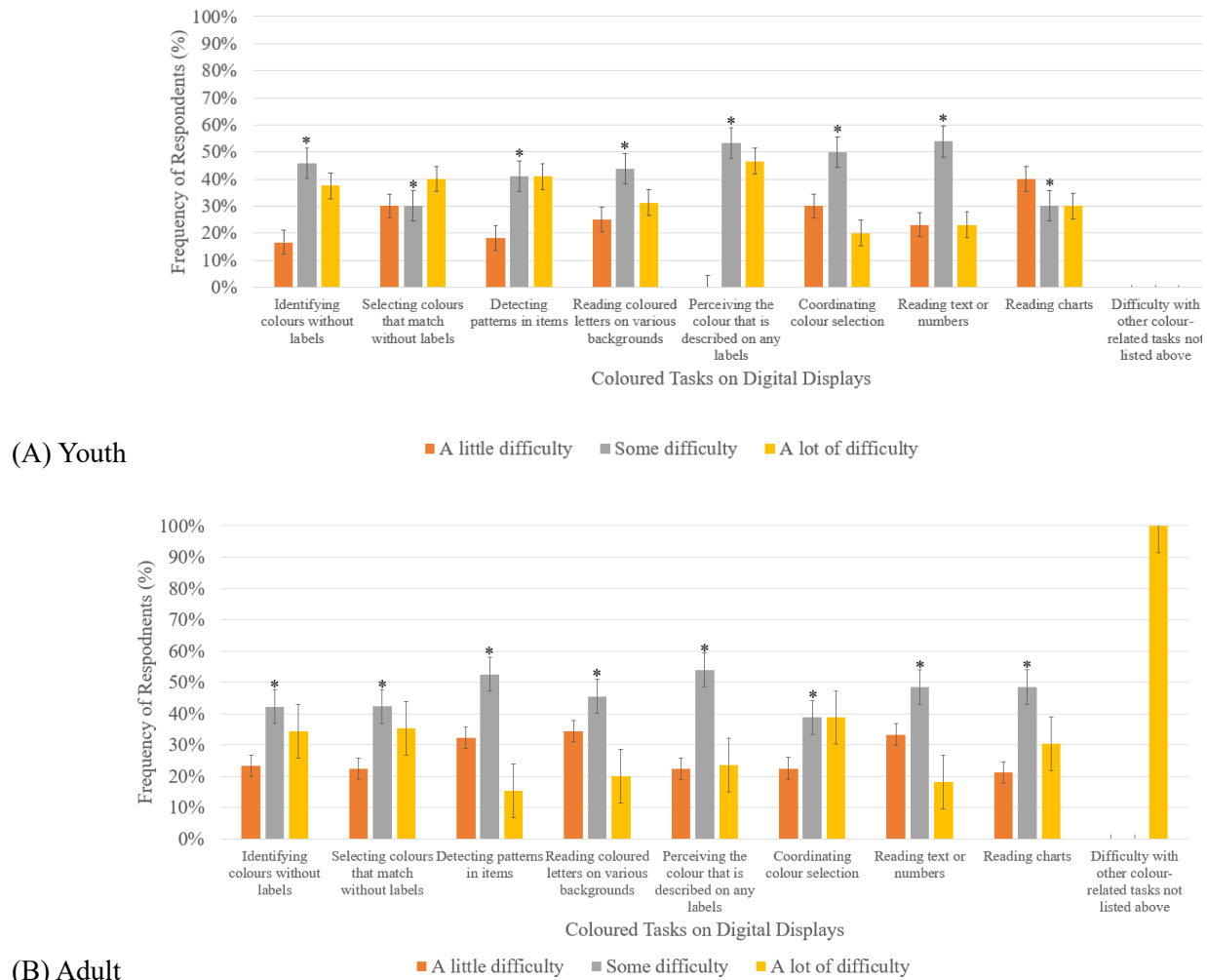


Figure 7.36. The distribution of ranked difficulty by (A) youth (N=45) and (B) adult (N=155) respondents having difficulty when making colour-related judgements using digital displays while online shopping or banking. The percentages are based on respondents who ranked the difficulty of each particular task. One adult reported difficulty with “other tasks” accounting for 100% of the ranking. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.6.3 Difficulty Rankings of Colour-Related Tasks While Online Shopping or Banking: Severity Differences

Table 7.10 shows the results from the Kruskal-Wallis test for differences in the rankings as a function of severity for the eight tasks. The “other” category was removed as there was none reported by any females or youth. The task that showed significant differences was “reading coloured letters on various backgrounds” ($H = 19.5$, $df = 4$, $p < 0.001$; adjusted p -value for significance = 0.0063). The pairwise

comparison showed that there were significant differences between “at least once a week” and “more than once a week” (adj. $p = 0.022$), “less than once per month” and “more than once a week” (adj. $p = 0.026$), and “at least once a month” and “more than once a week” (adj. $p = 0.050$).

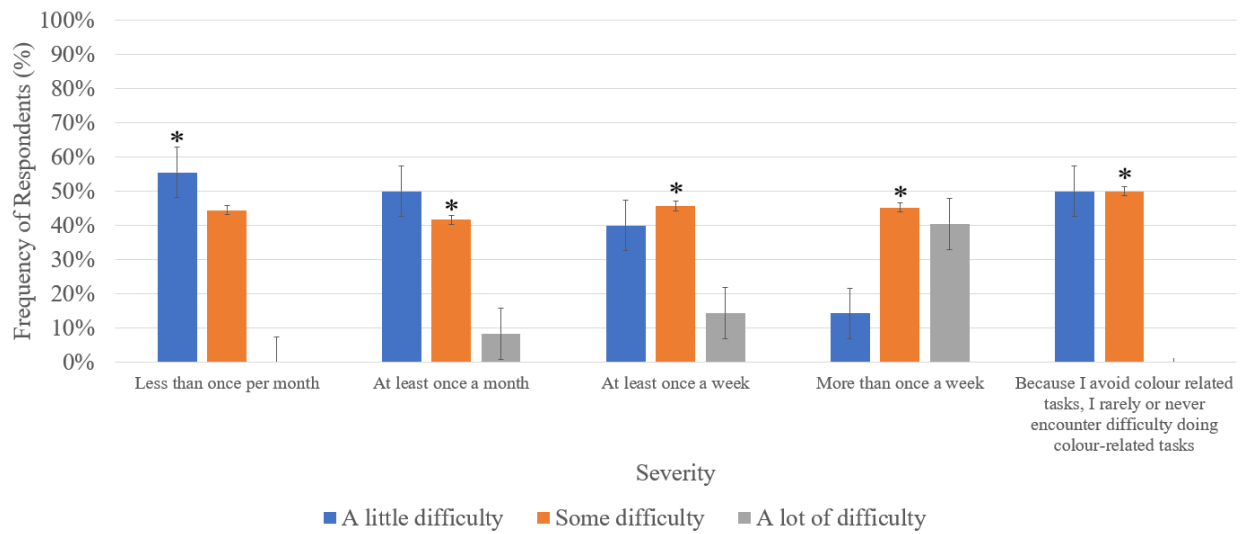
Table 7.10. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed while online shopping or banking based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0063$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Reading coloured letters on various backgrounds	106	19.5	4	(< 0.001)	“at least once a week”	“more than once a week”	(0.022)
					“less than once per month”	“more than once a week”	(0.026)
					“at least once a month”	“more than once a week”	(0.050)
Perceiving the colour that is described on any labels	91	13.1	4	0.011	N/A		
Selecting colours that match without labels	105	12.8	4	0.012	N/A		
Reading text or numbers	46	10.2	4	0.037	N/A		
Coordinating colour selection	90	10.1	4	0.039	N/A		
Detecting patterns in items	81	8.4	4	0.077	N/A		
Identifying colours without labels	114	6.0	4	0.20	N/A		
Reading charts	43	2.7	3	0.44	N/A		

Figure 7.37 shows the distribution of rankings as a function of severity for the significantly different task of (A) reading coloured letters on various backgrounds ($p < 0.001$) and a task where the differences were not significant (B) “coordinating colour selection” ($p = 0.039$). Both show a change in the median rankings from “a little difficulty” at “less than once a month” to “some difficulty” for the other severities.

The difference between the two distributions is the more obvious systematic increase in the “a lot of difficulty” responses as the severity increases.

(A) Reading coloured letters on various backgrounds ($p < 0.001$)



(B) Coordinating colour selection ($p = 0.039$)

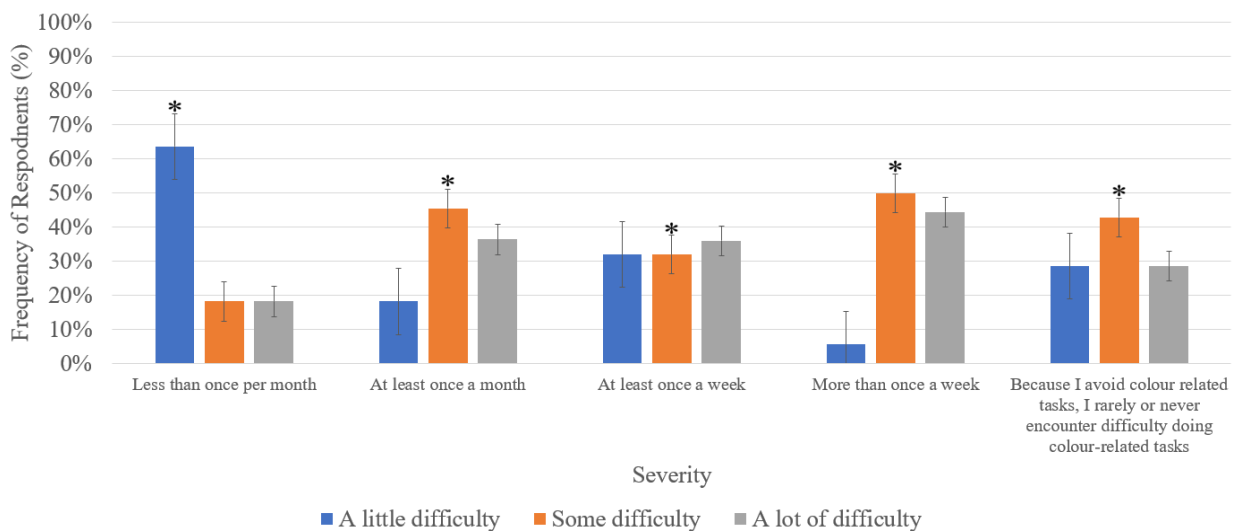


Figure 7.37. The distribution of ranked difficulty by all respondents with (A) reading coloured letters on various backgrounds and (B) coordinating colour selection. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.6.4 Digital Displays where Difficulties are Encountered

There were 212 respondents who selected displays with which they experienced difficulties. Eighty-five percent (85.1%) of those who use displays for shopping or banking online selected at least one display. This consisted of 75.5% males (160) and 24.5% females (52). For the age group, 22.2% were youth (47) and 77.8% were adults (165). There were more respondents who selected a display than 200 respondents who ranked the difficulty of a task. There were 84.2% of males, 88.1% of females, 90.4% of youth, and 83.8% of adults who use displays for online shopping/banking experienced troubles with a display. Figure 7.38 shows the distributions of displays selected based on (A) sex and (B) age group. There was no significant association for the five displays with sex ($\chi^2 = 5.1$, $df = 4$, $p = 0.28$), but there was a significant association based on age group ($\chi^2 = 18.7$, $df = 3$, $p = 0.0003$). The “other displays” were excluded from this analysis because none were reported by any respondents. “Whiteboards” and “immersive systems” were combined into one category for the age group analysis. Adults encountered more problems with cell phones and desktops/laptops, but fewer reported problems with tablets.

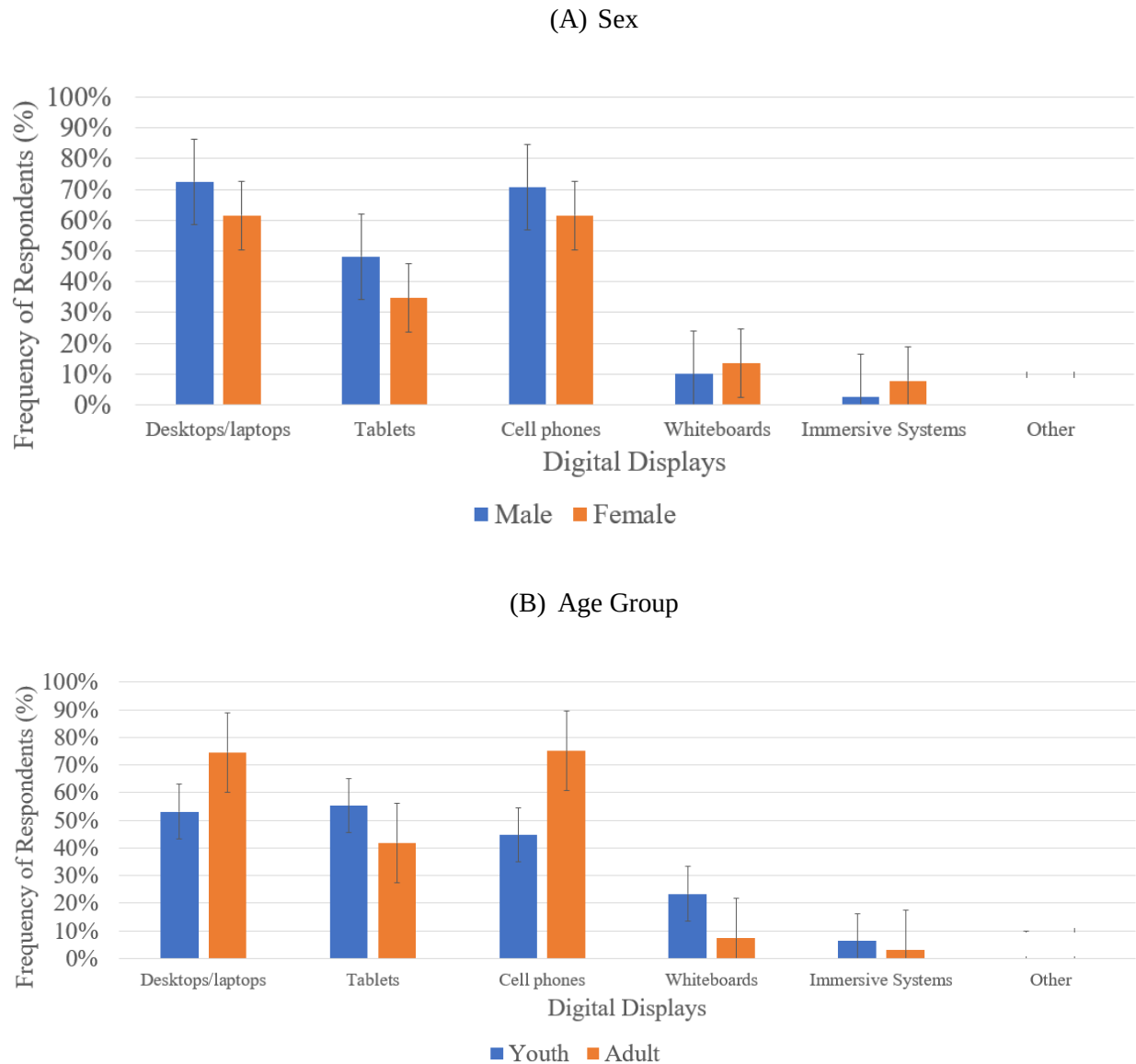


Figure 7.38. The distribution of digital displays that respondents found challenging while online shopping or banking based on (A) sex and (B) age group (N=212). There were no respondents who reported difficulty with “other displays.” The error bars represent standard error.

7.7 In-Person Shopping/Banking

This section focuses on the challenges that individuals with CVD encounter when shopping or banking in-person. Out of the 381 respondents who completed the survey, 286 respondents (75.1%) reported using devices for shopping/banking in person. This consisted of 21.7% male youth (62), 48.3% male adults (138), 13.3% female youth (38), and 16.8% female adults (48). This means that 72.1% of male youth,

71.1% of male adults, 88.4% of female youth, and 82.8% of female adults who completed the survey have difficulty with displays while shopping/banking in-person.

7.7.1 Difficulty Rankings of Colour-Related Tasks While Shopping or Banking In-Person: Sex Differences

Respondents were asked about the extent of difficulty that they experienced when performing several tasks. Out of the 286 respondents who selected tasks, 269 (94.1%) of them ranked at least a little difficulty with one of these tasks. This consisted of 71.4% males (192) and 28.6% females (77). There were 96.0% of males and 89.5% of females who use displays for in-person shopping/banking ranked at least a little difficulty with a task.

Figure 7.39 shows the distributions of the rankings for the males and females. The tasks that both sexes most frequently experienced challenges with were “identifying colours” (male: 68.8%, 132; female: 61.0%, 47), “reading coloured letters on various backgrounds” (male: 56.3%, 108; female: 57.1%, 44), and “experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours changes” (male: 39.1%, 75; female: 40.3%, 31). There were relatively similar distributions between the sexes, and there was no significant association between the six tasks and sex ($\chi^2 = 3.0$, $df = 5$, $p = 0.70$). The “other” category was omitted in this analysis since there were none reported by any respondents.

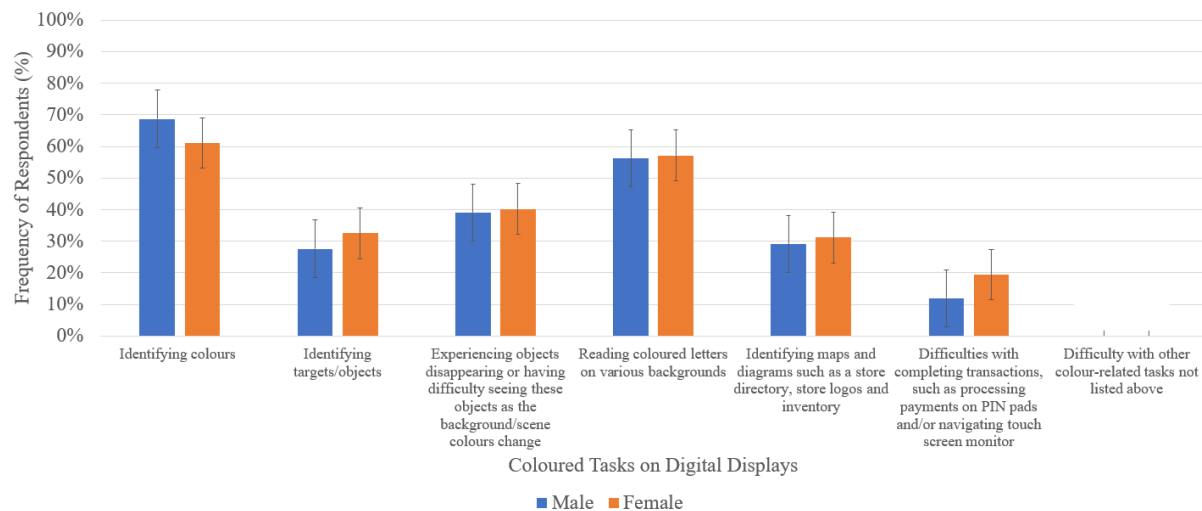
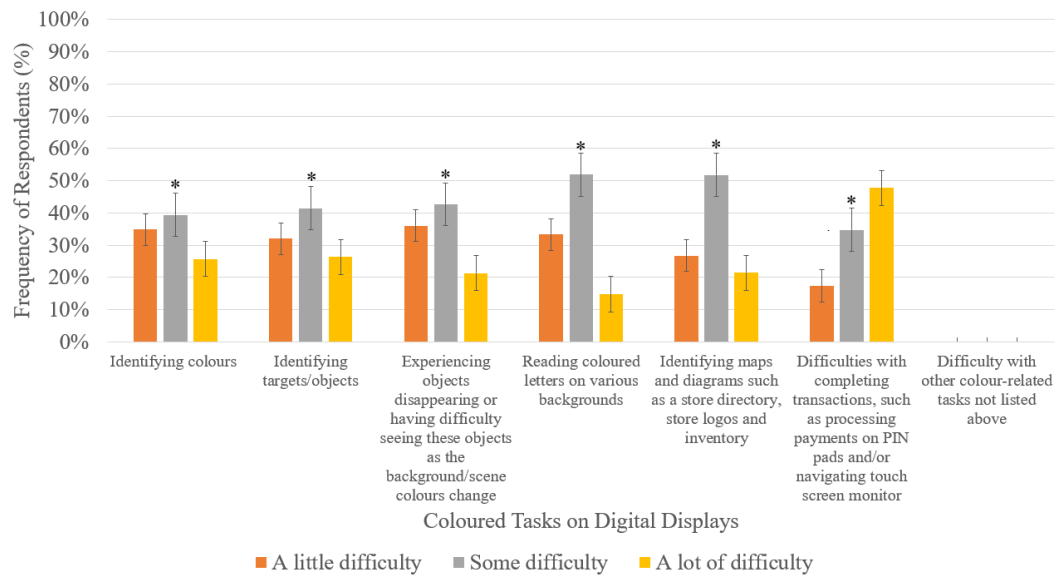
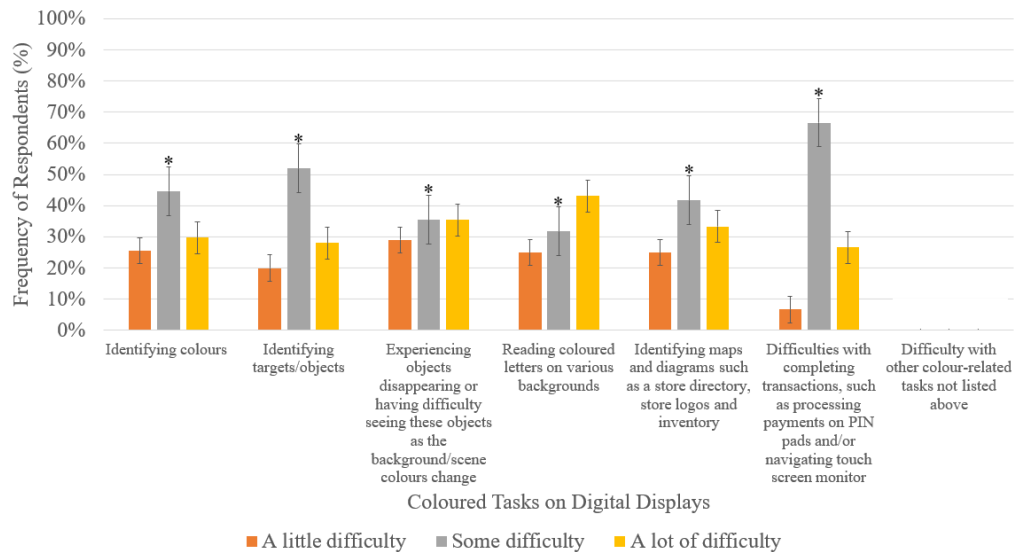


Figure 7.39. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks while shopping or banking in-person (N=269). There were no respondents who reported difficulty with any “other tasks.” The error bars represent standard error.

Figure 7.40 shows the distributions of the rankings for (A) males and (B) females across the colour-related tasks. The median ranking was “some difficulty” across all tasks for both sexes. There were no “other” responses after moving one male response to the “travelling” section and another male response to “identifying colours.” The differences in the rankings were significant for “reading coloured letters on various backgrounds” (Mann Whitney, $U = 2994.0$, $p = 0.007$), but not for the other five tasks ($p \geq 0.21$; adjusted p -value for significance = 0.0083). More females reported “a lot of difficulty” for this task as compared to males.



(A) Male



(B) Female

Figure 7.40. The distribution of ranked difficulty by (A) male (N=192) and (B) female (N=77) respondents having difficulty when making colour-related judgements using digital displays while shopping or banking in-person. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.7.2 Difficulty Rankings of Colour-Related Tasks While Shopping or Banking In-Person: Age-Group Differences

Of the 269 respondents who reported using devices while shopping or banking in-person, 35.7% were youth (96) and 64.3% were adults (173). This means that 96.0% of youth and 93.0% of adults reported

using displays for shopping or banking in-person who ranked difficulty with at least one task. Figure 7.41 shows the distributions of youth and adults who ranked at least a little difficulty with the tasks. The tasks that both age groups most frequently encountered problems with were “identifying colours” (youth: 64.6%, 62; adult: 67.6%, 117), “reading coloured letters on various backgrounds” (youth: 53.1%, 51; adult: 58.4%, 101), and “experiencing objects disappearing or having difficulty seeing these objects as the background/scene colour changes” (youth: 38.5% 37; adult: 39.9%, 69). Both age groups displayed similar distributions, and there was no significant association between the six tasks and age groups ($\chi^2 = 0.7$, $df = 5$, $p = 0.98$). The “other” category was removed from the analysis since there was none reported by any respondents.

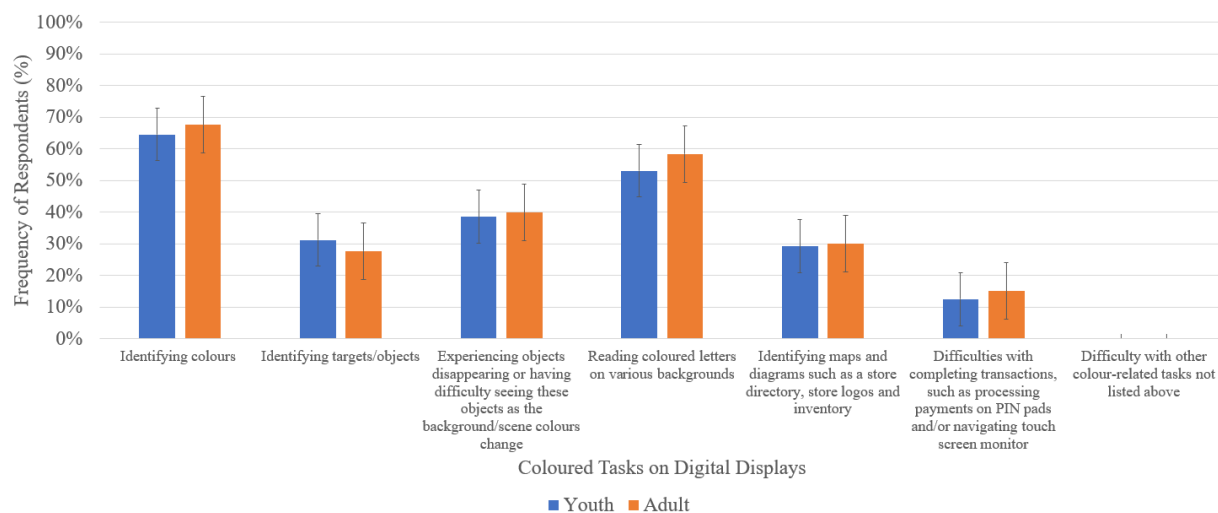
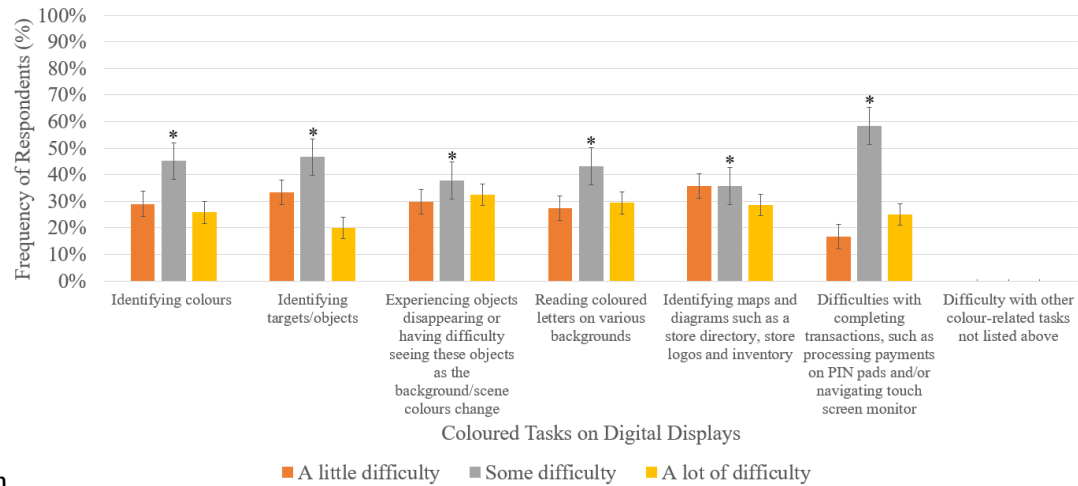
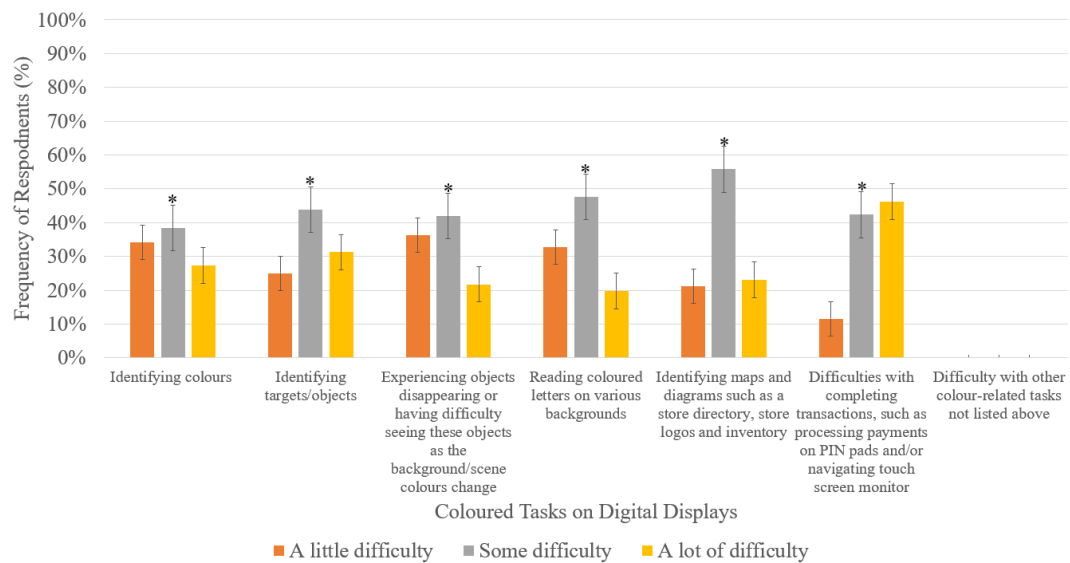


Figure 7.41. The frequency of youth and adult respondents who ranked at least a little difficulty for the coloured tasks while shopping or banking in-person (N=269). There were no respondents who reported difficulty with any “other tasks.” The error bars represent standard error.

Figure 7.42 shows the distributions of the difficulty rankings for (A) youth and (B) adults across the various tasks. The median ranking across all coloured tasks was “some difficulty” for both age groups. There were no significant differences in the rankings of the six tasks for the age group based on the Mann-Whitney test ($p \geq 0.25$; adjusted p-value for significance = 0.0083).



(A) Youth



(B) Adult

Figure 7.42. The distribution of ranked difficulty by (A) youth (N=96) and (B) adult (N=173) respondents having difficulty when making colour-related judgements using digital displays while shopping or banking in-person. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.7.3 Difficulty Rankings of Colour-Related Tasks While Shopping or Banking In-Person: Severity Differences

Severity was examined across all the respondents to determine whether it affects the difficulty rankings. Table 7.11 shows the results from the Kruskal-Wallis test for the rankings of the six tasks based on

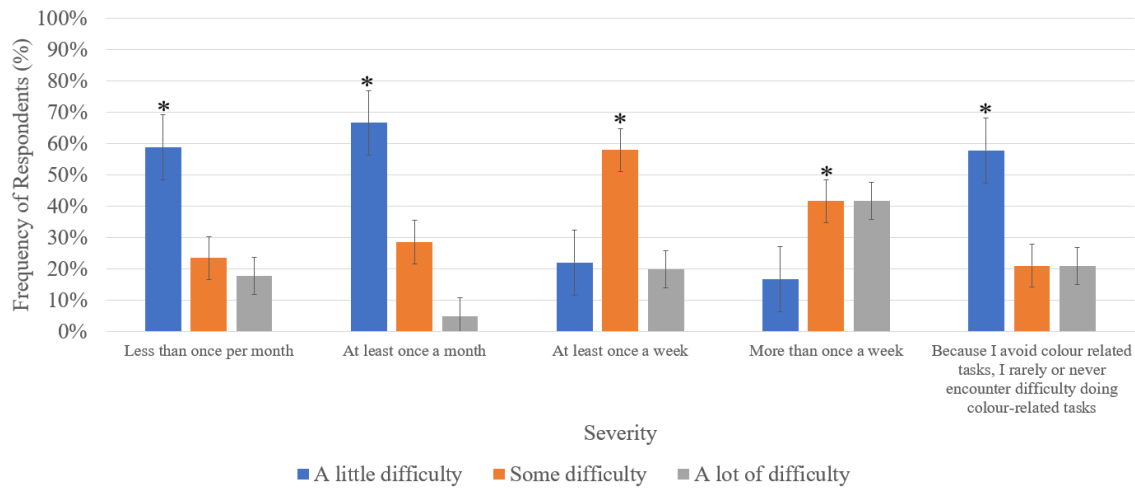
severity. The tasks that showed significant differences were “identifying colours” ($H = 29.9$, $df = 4$, $p < 0.001$), “experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours change” ($H = 21.0$, $df = 4$, $p < 0.001$), and “reading coloured letters on various backgrounds” ($H = 21.2$, $df = 4$, $p < 0.001$; adjusted p-value for significance = 0.0083). The pairwise comparison revealed significant differences between “less than once per month” and “more than once a week” (colours: adj. $p = 0.013$; reading: adj. $p = 0.042$), “at least once a month” and “more than once a week” (colours: adj. $p = 0.00$; reading: adj. $p = 0.004$), “at least once a month” and “at least once a week” (colours: adj. $p = 0.023$), “at least once a week” and “more than once a week” (disappearing: adj. $p = 0.042$), and “more than once a week” and “because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks” (colours: adj. $p = 0.016$; disappearing: adj. $p = 0.010$; reading: adj. $p = 0.048$).

Table 7.11. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed while shopping or banking in-person based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0083$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Identifying colours	179	29.9	4	(< 0.001)	"at least once a month"	"more than once a week"	(0.00)
					"less than once per month"	"more than once a week"	(0.013)
					"more than once a week"	"because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks"	(0.016)
					"at least once a month"	"at least once a week"	(0.023)
Experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours change	106	21.0	4	(< 0.001)	"more than once a week"	"because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks"	(0.010)
					"at least once a week"	"more than once a week"	(0.042)
Reading coloured letters on various backgrounds	152	21.2	4	(< 0.001)	"at least once a month"	"more than once a week"	(0.004)
					"less than once per month"	"more than once a week"	(0.042)
					"more than once a week"	"because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks"	(0.048)
Identifying targets/objects	78	12.2	4	0.016	N/A		
Identifying maps and diagrams such as store directory, store logos and inventory	80	8.0	4	0.093	N/A		
Difficulties with completing transactions, such as processing payments on PIN pads and/or navigating touch screen monitor	38	6.7	4	0.16	N/A		

Figure 7.43 shows an example of rankings distribution as a function of severity for the significantly different task of (A) identifying colours ($p < 0.001$) and a task where the differences were not significant (B) “identifying maps and diagrams such as store directory, store logos and inventory” ($p = 0.093$). The figure shows that the median ranking for the “identifying colours” task is higher for the more severe CVD of once and more than once a week with a corresponding increase in the “a lot of difficulty” response. The median ranking for the identifying maps and diagrams task is the same across severity (“some difficulty”) except for “less than once a month” (“a little difficulty”).

(A) Identifying colours ($p < 0.001$)



(B) Identifying maps and diagrams such as store directory, store logos and inventory ($p = 0.093$)

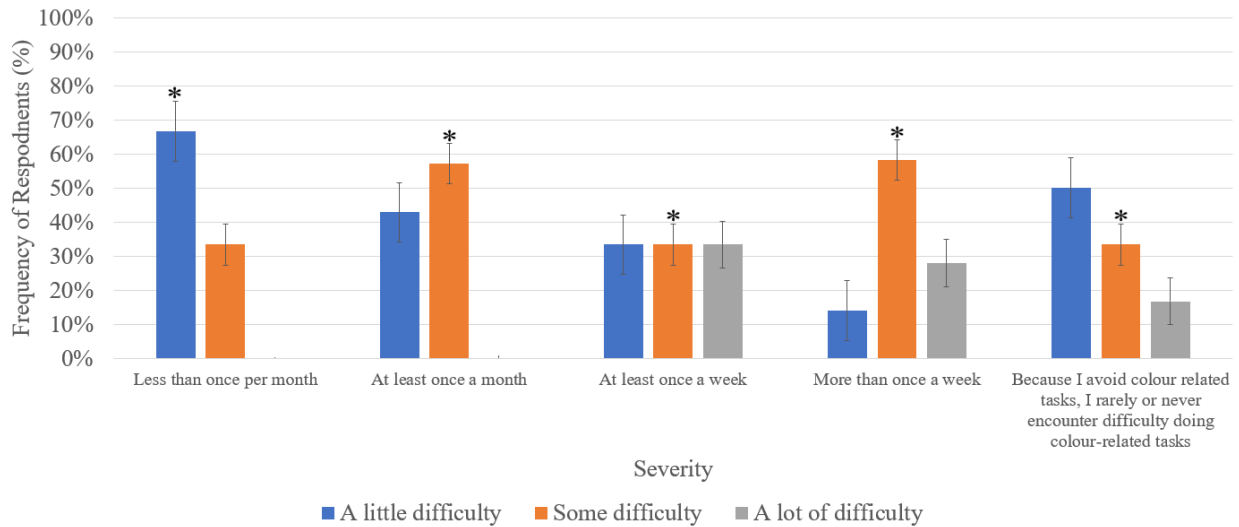


Figure 7.43. The distribution of ranked difficulty by all respondents with (A) identifying colours and (B) identifying maps and diagrams such as store directory, store logos and inventory. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.7.4 Digital Displays that Respondents Encountered Difficulties While Shopping or Banking In-Person

There were 281 respondents who selected displays for which they encountered challenges. Ninety-eight percent (98.3%) reported using displays for shopping or banking in-person selected a display. This group consisted of 70.1% males (197) and 29.9% females (84). Based on age group, 34.9% were youth (98) and 65.1% were adults (183). When compared to 269 respondents who ranked the difficulty of tasks, more respondents selected a display than those ranking the difficulty of the tasks. There were 98.5% of males, 97.7% of females, 98.0% of youth, and 98.4% of adults who used displays for in-person shopping or banking experienced difficulties with at least one display. Figure 7.44 shows the distributions of the displays that they found challenging based on (A) sex and (B) age group. Most males (66.5%; 131) and females (61.9%; 52) experienced difficulties with “in-store digital advertisements or other in-store information which could be a single monitor or multiple monitors mounted on the walls in shopping areas.” A similar trend was found for both age groups (youth: 71.4%, 70; adult: 61.8%, 113), where a majority also frequently encountered challenges with “in-store digital advertisements.” The “other” category consisted of 3 respondents. One male adult reported troubles with “whatever displays certain shades,” and 2 respondents (1 male adult and 1 female adult) reported “computer/laptop.” The “other displays” category was excluded from further analyses as it did not meet the assumptions for the chi-square test. There was no significant association between the two displays and the demographic factors of sex ($\chi^2 = 0.2$ with Yates correction, $df = 1$, $p = 0.70$) and age group ($\chi^2 = 0.9$ with Yates correction, $df = 1$, $p = 0.34$).

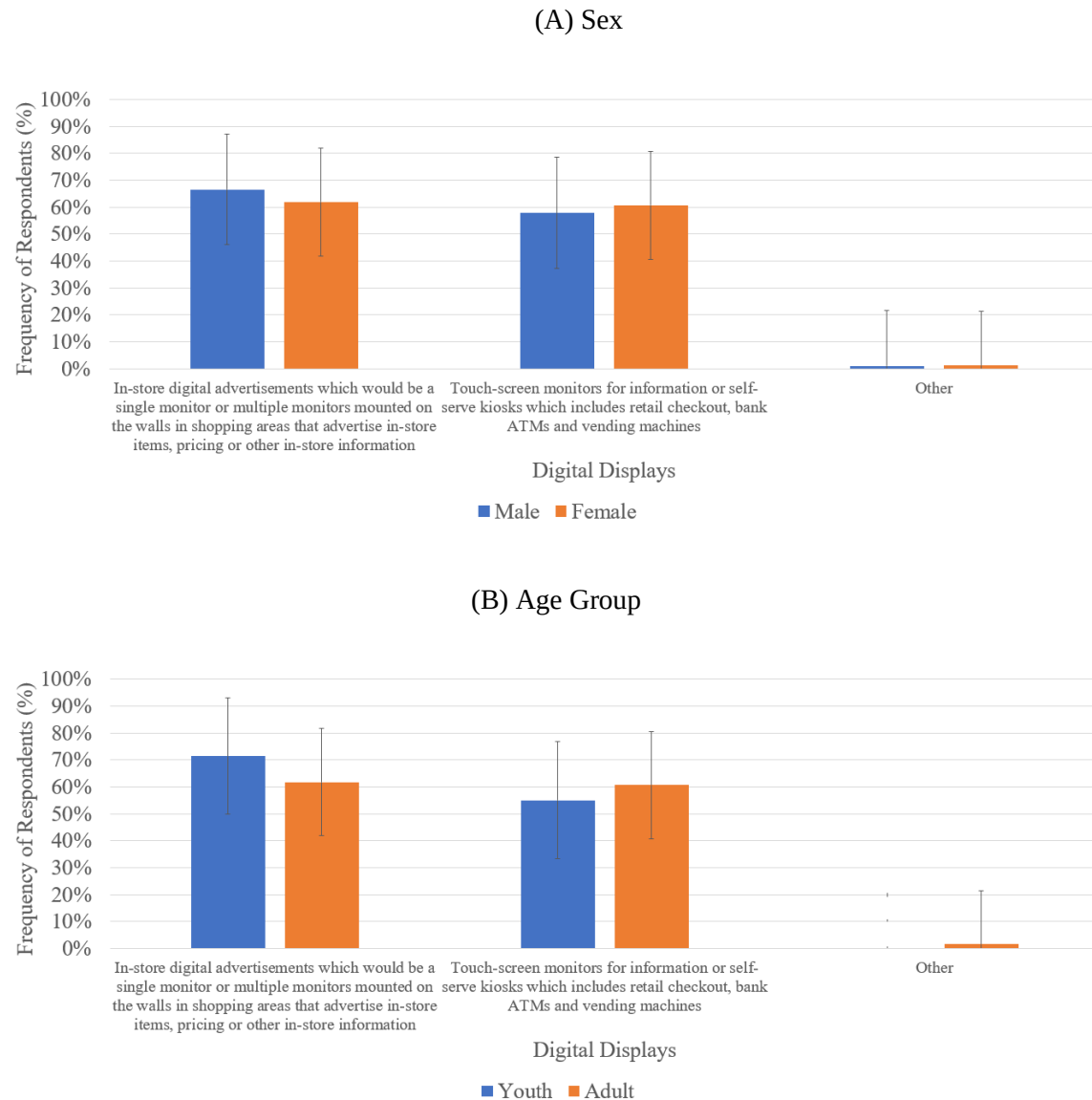


Figure 7.44. The distribution of digital displays that respondents found challenging while in-person shopping or banking based on (A) sex and (B) age group (N=281). The “other displays” include the responses of 2 male adults and one female adult. The error bars represent standard error.

7.8 Driving/Motorized Vehicles

This section examines the problems that people with CVD encounter when using digital displays to operate a motorized vehicle or assisting the driver with directions. Of the 381 respondents who completed the survey, there were 149 respondents (39.1%) detect, identify, or interpret information on digital displays in motorized vehicles as a driver, passenger or both, 156 respondents (40.9%) did not use displays in a motorized vehicle, 37 respondents (9.7%) did not interact with the digital displays in any of

the vehicles that they use, 33 respondents (8.7%) reported that none of their vehicles use digital displays, and 6 respondents (1.6%) preferred not to answer. The 149 respondents who reported using displays in their motorized vehicles consisted of 26.2% using them as a driver (39), 32.9% as a passenger (49) and 40.9% as both a driver and passenger (61). The group was composed of 25.5% male youth (38), 45.0% male adults (67), 12.8% female youth (19), and 16.8% female adults (25). This means that 44.2% of male youth, 34.5% of male adults, 44.2% of female youth, and 43.1% of female adults who completed the survey have difficulty with displays in motorized vehicles.

7.8.1 Difficulty Rankings of Colour-Related Tasks in Motorized Vehicles: Differences in Background Settings

Respondents were also asked about the types of background settings that they had trouble with when using digital displays while driving or in motorized vehicles. They had the option of selecting between “daytime,” “nighttime,” “both,” or blank (“non-respondent”). “Both” means that respondents experience difficulties during the daytime and nighttime. There were 144 respondents who selected tasks and 128 respondents who selected a background setting for at least one of the tasks. Figure 7.45 shows the distributions of background settings selected for each sex ((A) male and (B) female) and age groups ((C) youth and (D) adult). There were 87.6% of males, 81.8% of females, 91.2% of youth, and 82.6% of adults who used displays for motorized vehicles selected a background setting. For each sex, “both” was the background setting where most respondents frequently experienced difficulty performing each task. A higher proportion of females reported challenges in “nighttime” than males. However, relatively similar distributions were present in both age groups, where most respondents reported challenges during “both” daytime and nighttime. Regardless of the distributions, there was no significant association between the background settings of the six tasks based on sex ($\chi^2 = 2.5$, $df = 5$, $p = 0.78$) and age group ($\chi^2 = 5.1$, $df = 5$, $p = 0.41$). The general trend is that most respondents reported problems using digital displays in both daytime and nighttime regardless of the tasks performed in a motorized vehicle.

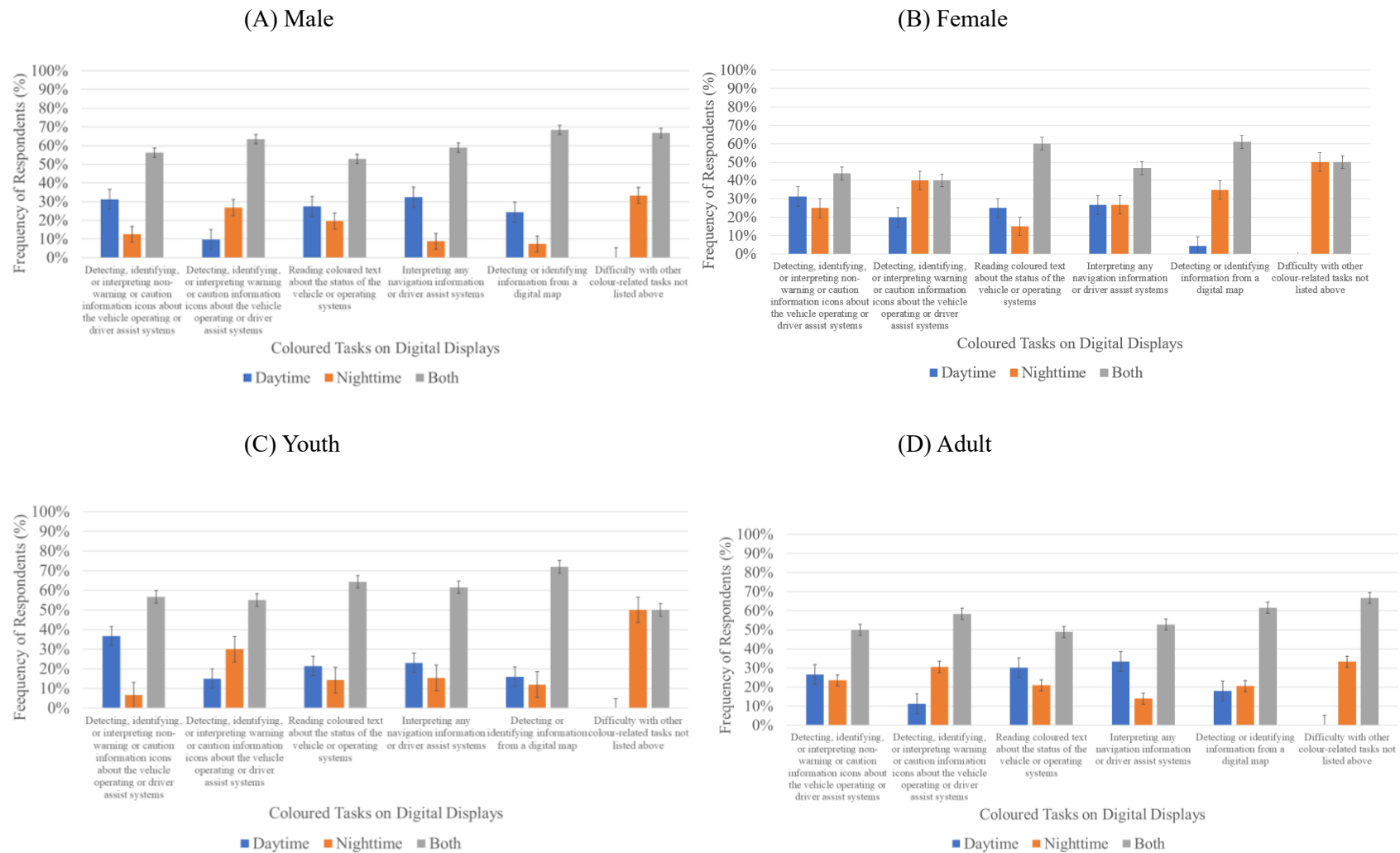


Figure 7.45. The distribution of background setting selected that (A) males (N=92), (B) females (N=36), (C) youth (N=52), and (D) adults (N=76) had difficulty when performing tasks using digital displays when in motorized vehicles. “Both” represents both “daytime” and “nighttime.” The error bars represent standard error.

The Kruskal-Wallis test was also performed to examine whether the background setting has a significant effect on difficulty rankings of the six tasks when in a motorized vehicle, pooled across age group and sex (Table 7.12). There was no significant difference in the rankings for any tasks (adjusted p-value for significance = 0.0083).

Table 7.12. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed while in a motorized vehicle based on background settings. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0083$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)	
					Severity Pair	Adjusted Significance
Detecting, identifying or interpreting <u>warning and caution information icons</u> about the vehicle operating or driver assist systems	57	9.9	3	0.019	N/A	
Reading coloured text about the status of the vehicle or operating systems	70	9.1	3	0.027	N/A	
Detecting, identifying or interpreting <u>non-warning or caution information icons</u> about the vehicle operating or driver assist systems	63	7.0	2	0.031	N/A	
Detecting or identifying information from a digital map	65	7.9	3	0.047	N/A	
Interpreting any navigation information or driver assist displays	48	3.1	2	0.21	N/A	
Difficulty with other colour-related tasks	5	0.4	1	0.54	N/A	

7.8.2 Difficulty Rankings of Colour-Related Tasks in Motorized Vehicles: Sex Differences

Out of 144 respondents who selected tasks, 131 respondents ranked at least a little difficulty with one of the tasks. This means that 87.9% of the respondents experienced at least a little difficulty with one task. The distribution of respondents who ranked the tasks based on sex was 72.5% males (95) and 27.5% females (36). This means that 90.5% of males and 81.8% of females ranked at least a little difficulty with a task. Figure 7.46 shows the distribution of the male and female students who ranked at least a little difficulty across the tasks. The tasks that males most frequently encountered challenges with were: “reading coloured text about the status of the vehicle or operating systems” (53.7%; 51), “detecting, identifying, or interpreting non-warning or caution information icons about the vehicle operating or driver assist systems” (49.5%; 47), and “detecting, identifying, or interpreting warning or caution information icons about the vehicle operating or driver assist systems” / “detecting or identifying information from a digital map” (45.3%; 43). For females, the three tasks that they most frequently experienced difficulties with were: “detecting or identifying information from a digital map” (61.1%; 22), “reading coloured text about the status of the vehicle or operating systems” (52.8%; 19), and “detecting, identifying, or interpreting non-warning or caution information icons about the vehicle operating or driver assist systems” (44.4%; 16). Although there were some variations in the distribution, there was no significant association between the six tasks and sex ($\chi^2 = 2.0$, $df = 5$, $p = 0.84$).

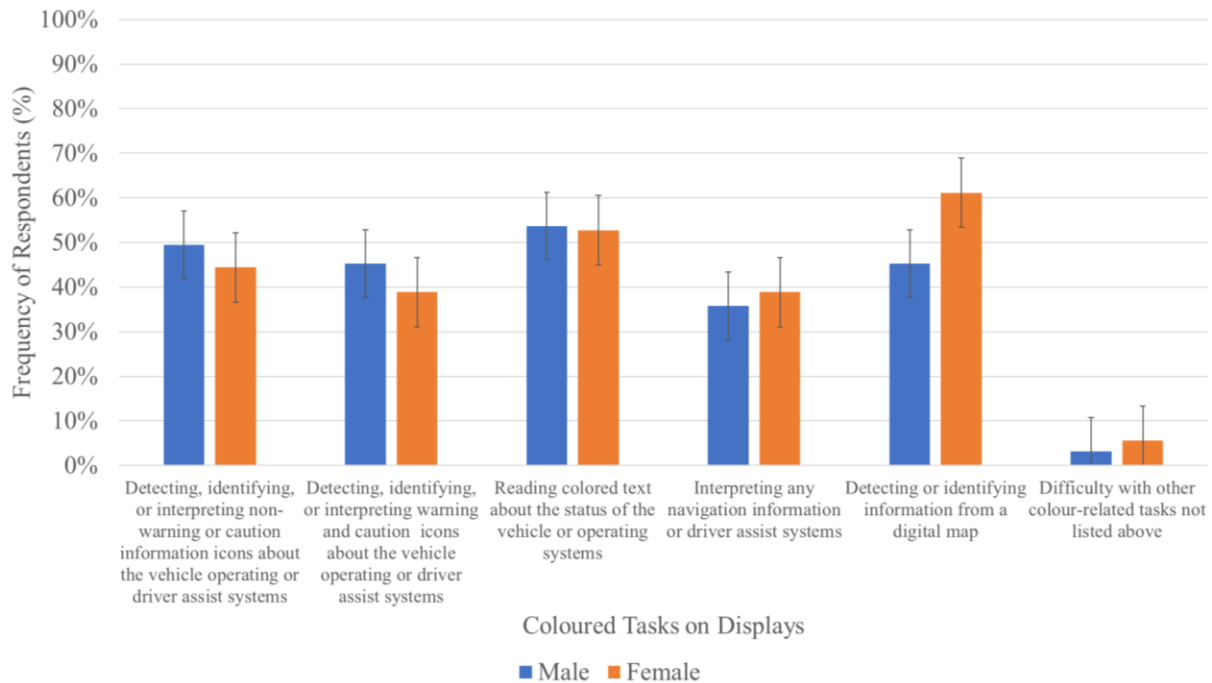
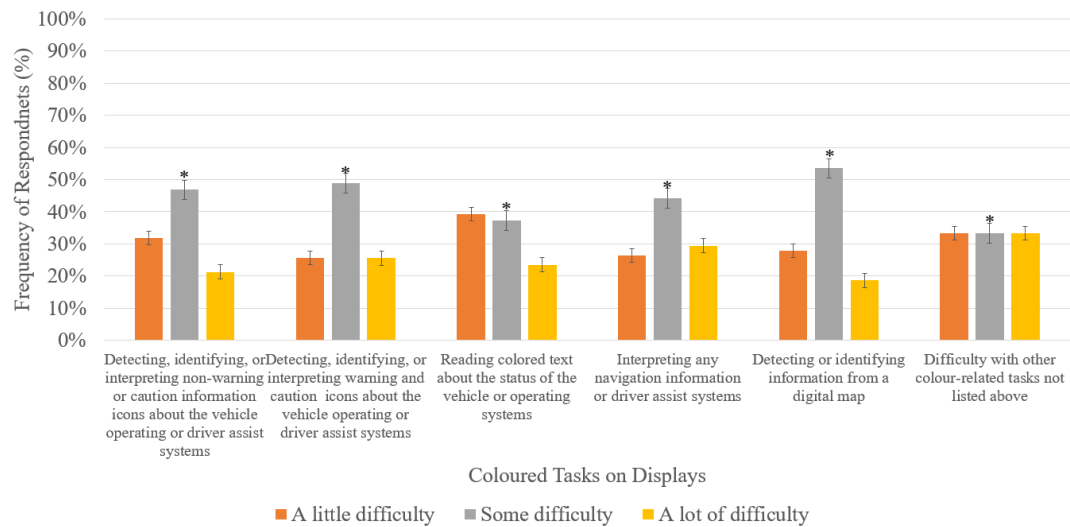
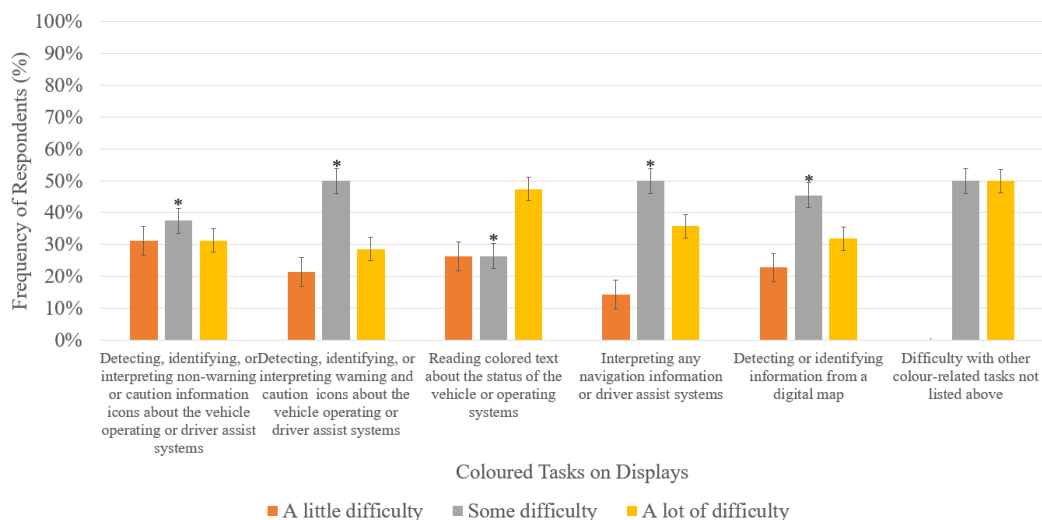


Figure 7.46. The frequency of male and female respondents who ranked at least a little difficulty in interpreting coloured displays in motorized vehicles (N=131). The “other tasks” include the responses of 3 males and 2 females. The error bars represent standard error.

Figure 7.47 shows the distributions of the rankings for (A) males and (B) females for the different tasks performed in motorized vehicles. The median ranking for all coloured tasks was “some difficulty” for both sexes. There were 5 respondents who had difficulty with “other colour-related tasks,” which included: two male adults having trouble with “traffic lights” with a median ranking of “some difficulty,” “screen reverts to the dark background during night time” reported by a male adult with “some difficulty,” “street signs” reported by one female youth with “a little difficulty,” and another female youth having “some difficulty” with “seeing the radio.” No median ranking was shown because only two females were in the “other” category. These differences were not significant across the six tasks (Mann Whitney, $U \leq 602.5$, $p \geq 0.098$; adjusted p-value for significance = 0.0083).



(A) Male



(B) Female

Figure 7.47. The distribution of ranked difficulty by (A) male (N=95) and (B) female (N=36) respondents having difficulty when making colour-related judgements using digital displays when in motorized vehicles. The percentages are based on respondents who ranked the difficulty of each particular task. There were 3 males and 2 females who ranked the difficulty of “other tasks,” accounting for the 50% and 33% rankings. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.8.3 Difficulty Rankings of Colour-Related Tasks in Motorized Vehicles: Age-Group Differences

Of the 131 respondents who ranked the difficulty of the tasks, 42.0% were youth (55) and 58.0% were adults (76). There were 96.5% of youth and 82.6% of adults who use displays for motorized vehicles ranked difficulty with a task. Figure 7.48 shows the distribution of difficulty rankings of youth and adults. For youth, the three tasks that they most frequently encountered problems were “reading coloured text about the status of the vehicle or operating systems” (54.6%; 30), “detecting, identifying or interpreting non-warning or caution information icons about the vehicle operating or driver assist systems” (52.7%; 29), and “detecting or identifying information from a digital map” (47.3%; 26). For adults, the tasks were similar to the youth: “reading coloured text about the status of the vehicle or operating systems” (52.6%; 40) and “detecting or identifying information from a digital map” (51.3%; 39). They also frequently encountered troubles with “detecting, identifying or interpreting warning and caution information icons about the vehicle operating or driver assist systems” (47.4%; 36). Although there were some variations, there was no significant association between the six tasks and age group ($\chi^2 = 4.7$, $df = 5$, $p = 0.45$).

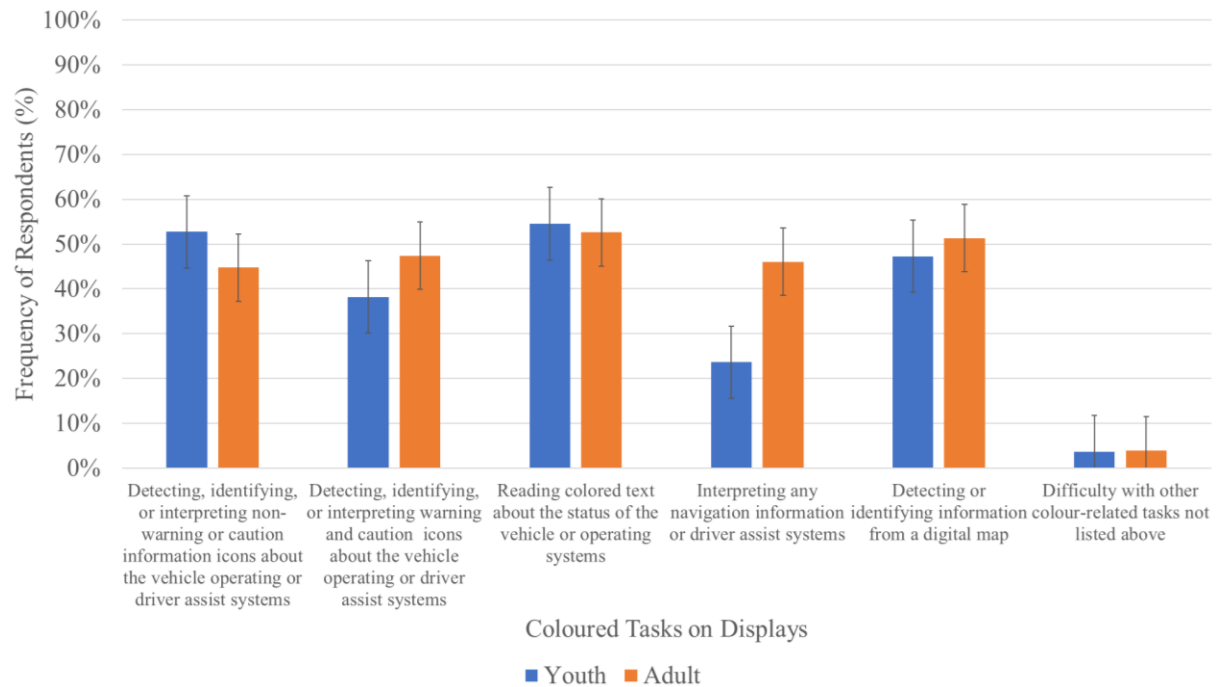


Figure 7.48. The frequency of youth and adult respondents who ranked at least a little difficulty in interpreting coloured displays in motorized vehicles (N=131). The “other tasks” include the responses of 2 youths and 3 adults. The error bars represent standard error.

Figure 7.49 shows the distributions of ranking for (A) youth and (B) adults across each of the tasks. The median ranking for most tasks in the two age groups was “some difficulty.” The exception was “interpreting any navigating information or driver assist displays” which had a median ranking of “a lot of difficulty” in the youth group. There was no median ranking for the “other tasks” since there were only 2 youth respondents. The rankings within a task for two age groups were not significantly different for the six tasks (Mann Whitney, $U \leq 558.0$, $p \geq 0.078$; adjusted p-value for significance = 0.0083).

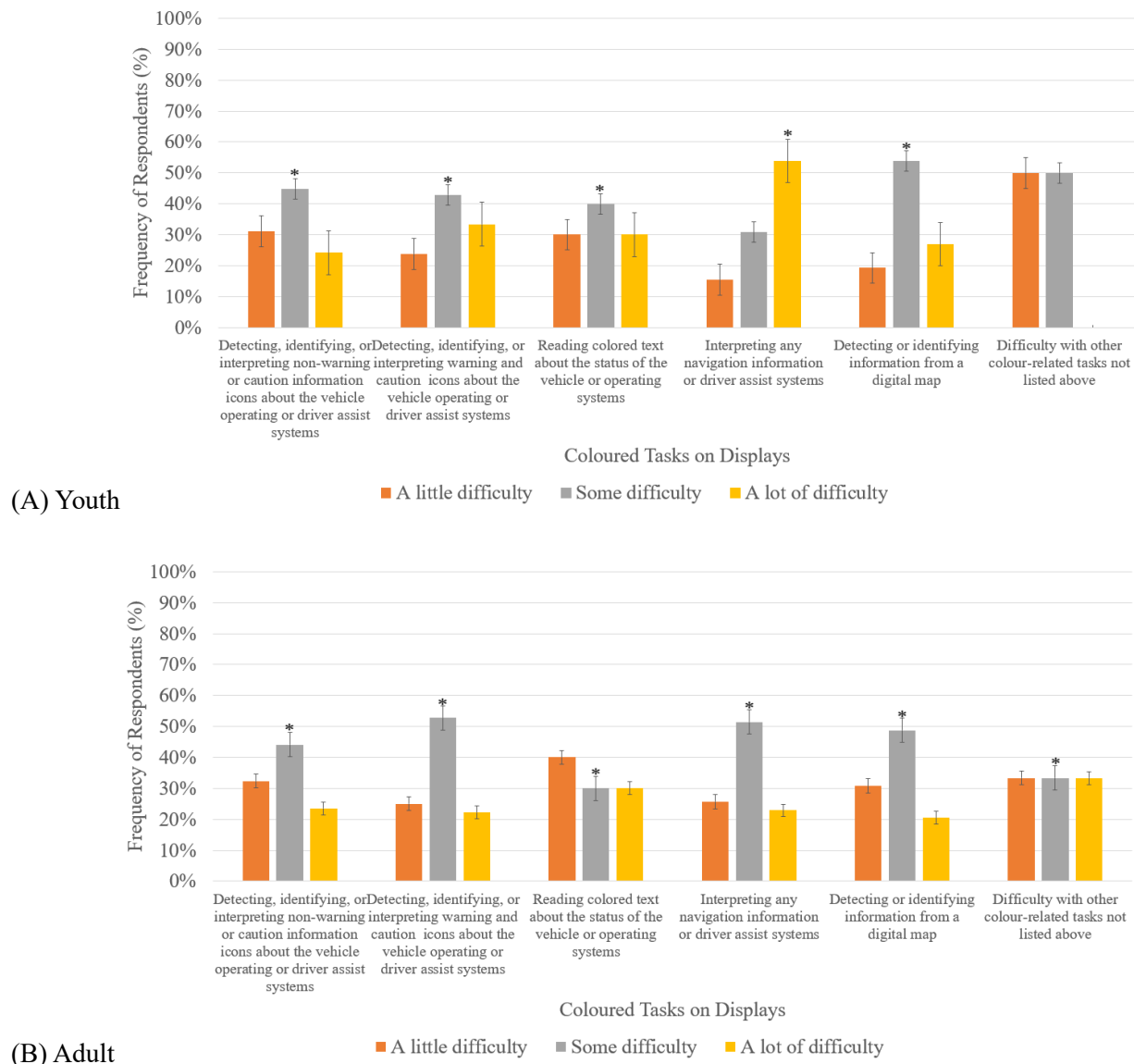


Figure 7.49. The distribution of ranked difficulty by (A) youth (N=55) and (B) adult (N=76) respondents having difficulty when making colour-related judgements using digital displays in motorized vehicles. The percentages are based on respondents who ranked the difficulty of each particular task. There were 2 youths and 3 adults who ranked the difficulty of “other tasks, ” accounting for the 50% and 33% rankings. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.8.4 Difficulty Rankings of Colour-Related Tasks in Motorized Vehicles: Severity Differences

The respondents were pooled together to examine the effect of severity on the rankings. Table 7.13 shows the results from the Kruskal-Wallis test for the six tasks. None of the tasks showed significant differences in the rankings based on severity.

Table 7.13. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks while driving or riding in a motorized vehicle based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0083$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)	
					Severity Pair	Adjusted Significance
Interpreting any navigation information or driver assist displays	48	10.3	4	0.036	N/A	
Detecting or identifying information from a digital map	65	9.3	4	0.053	N/A	
Reading coloured text about the status of the vehicle or operating systems	70	5.8	4	0.22	N/A	
Detecting, identifying, or interpreting <u>warning and caution icons</u> about the vehicle operating or driver assist systems	57	5.7	4	0.22	N/A	
Difficulty with other colour-related tasks not listed above	5	2.8	2	0.25	N/A	
Detecting, identifying, or interpreting <u>non-warning or caution information icons</u> about the vehicle operating or driver assist systems	63	3.7	4	0.45	N/A	

Figure 7.50 is an example of the distributions. The values are rankings for “detecting, identifying, or interpreting warning and caution icons about the vehicle operating or driver assist systems” ($p = 0.22$) for each severity. The median ranking for most severity levels was “some difficulty,” except for “less than once per month” which had a median ranking of “a little difficulty.” Although not statistically significant, their distributions shifted towards a greater difficulty level as the severity increased.

(A) Detecting, identifying, or interpreting warning and caution icons about the vehicle operating or driver assist systems ($p = 0.22$)

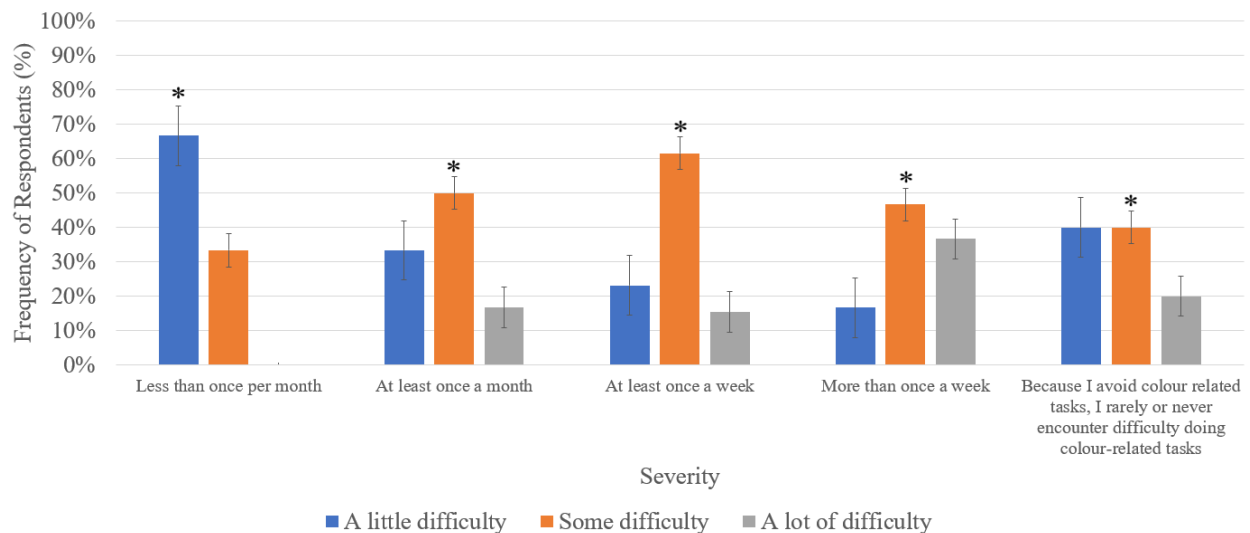


Figure 7.50. The distribution of ranked difficulty by all respondents with (A) “detecting, identifying, or interpreting warning and caution icons about the vehicle operating or driver assist systems.” The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.8.5 Digital Displays that Respondents Encountered Difficulties in Motorized Vehicles

A total of 142 respondents reported difficulty using digital displays in vehicles, which means that 95.3% of those who use digital displays in their motorized vehicles selected a display. The group consisted of 71.1% males (101) and 28.9% females (41). Based on age group, 39.4% were youth (56) and 60.6% were adults (86). There were more respondents who selected a display than 131 respondents who ranked at least a little difficulty with a task. This means that 96.2% of males, 93.2% of females, 98.2% of youth, and 93.5% of adults who use displays in motorized vehicles selected at least one display. Figure 7.51

shows the distributions of the displays selected by the respondents based on (A) sex and (B) age group. The distributions were similar based on sex and age group. There was no significant association between the four selected displays and demographic factors of sex ($\chi^2 = 0.2$, $df = 3$, $p = 0.98$) and age group ($\chi^2 = 1.5$, $df = 3$, $p = 0.69$). The “other displays” were excluded from this analysis because none were reported by either males or adults. One female youth listed a display in the “other” category which was “cell phone.” Another female youth originally commented “?” but her response was excluded and marked as unselected. Although there were no significant differences in the distribution, youth were more likely to select “heads-up displays” than adults.

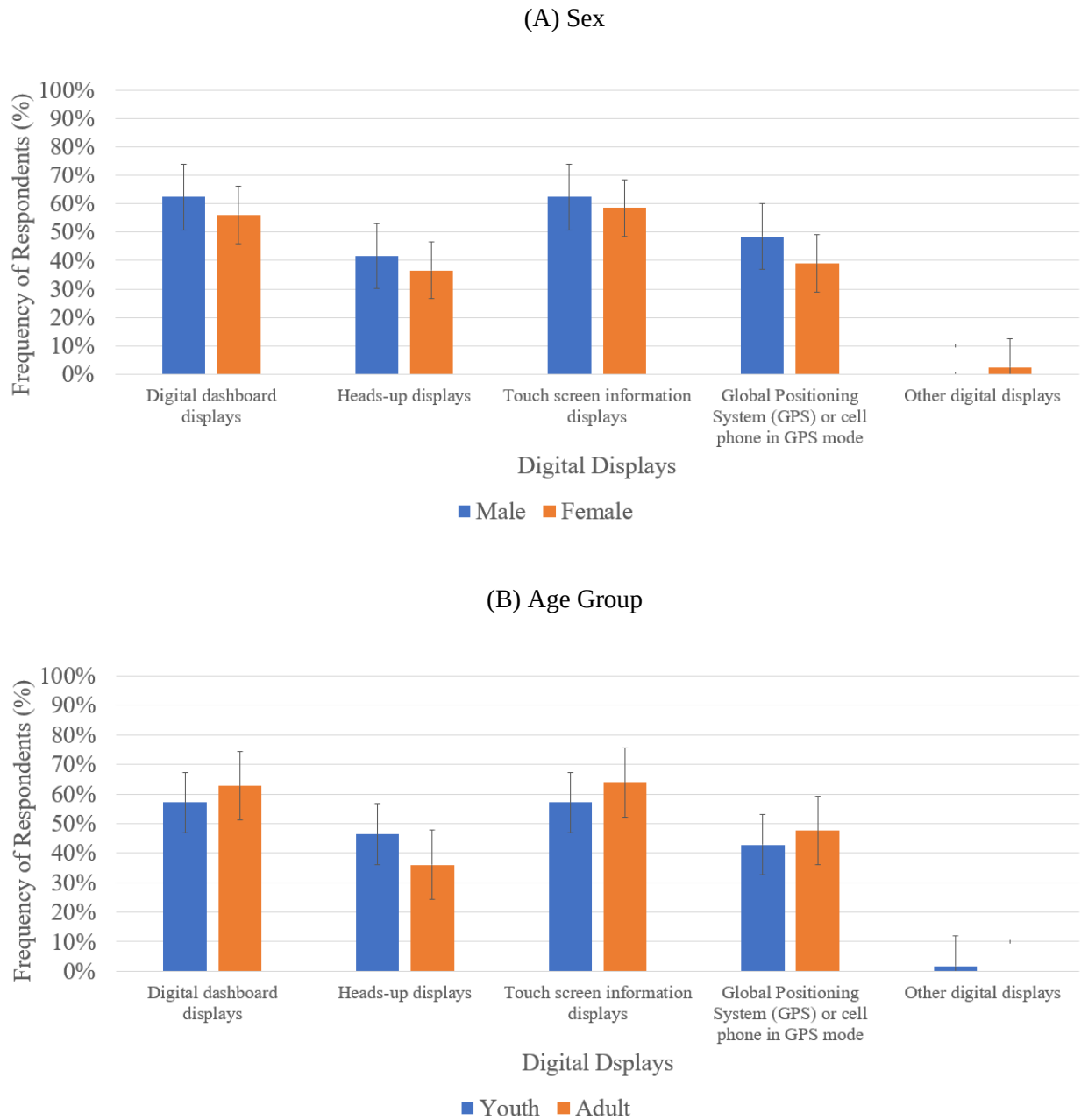


Figure 7.51. The distribution of digital displays that respondents found challenging when in motorized vehicles based on (A) sex and (B) age group (N=142). The “other displays” include the response of one female youth. The error bars represent standard error.

7.8.6 Difficulty in Interpreting or Identifying Information on Displays Affect Ability to Operate a Motorized Vehicle

Participants were asked to select the statement that best describes their ability to operate the vehicle, given their difficulty in interpreting or identifying the colour of text, symbols or icons displayed. There were 95 respondents who answered this question. It consisted of 80.0% males (76) and 20.0% females (19). Based on age group, there were 24.2% youth (23) and 75.8% adults (72). There were 72.4% of males, 43.2% of females, 40.4% of youth, and 78.3% of adults who use displays in motorized vehicles responded to the question. Figure 7.52 shows the distribution of respondents based on (A) sex and (B) age group. A majority of males (71.1%; 54), females (52.6%; 10), and adults (77.8%; 56) selected “it is challenging to identify or detect the coloured object(s), but there are other clues (shapes, size and sound) so operating the vehicle is not a concern.” The distribution was relatively similar between sexes, and there was no significant association for sex ($\chi^2 = 1.6$ with Yates correction, $df = 1$, $p = 0.21$). However, the majority of youth (65.2%; 15) selected “it is challenging to operate the vehicle or navigate to a destination because they cannot see or identify the coloured object(s) on the displays.” In contrast, most adults reported that operating the vehicle was not a concern. This association with age was significant ($\chi^2 = 12.8$ with Yates correction, $df = 1$, $p = 0.0004$).

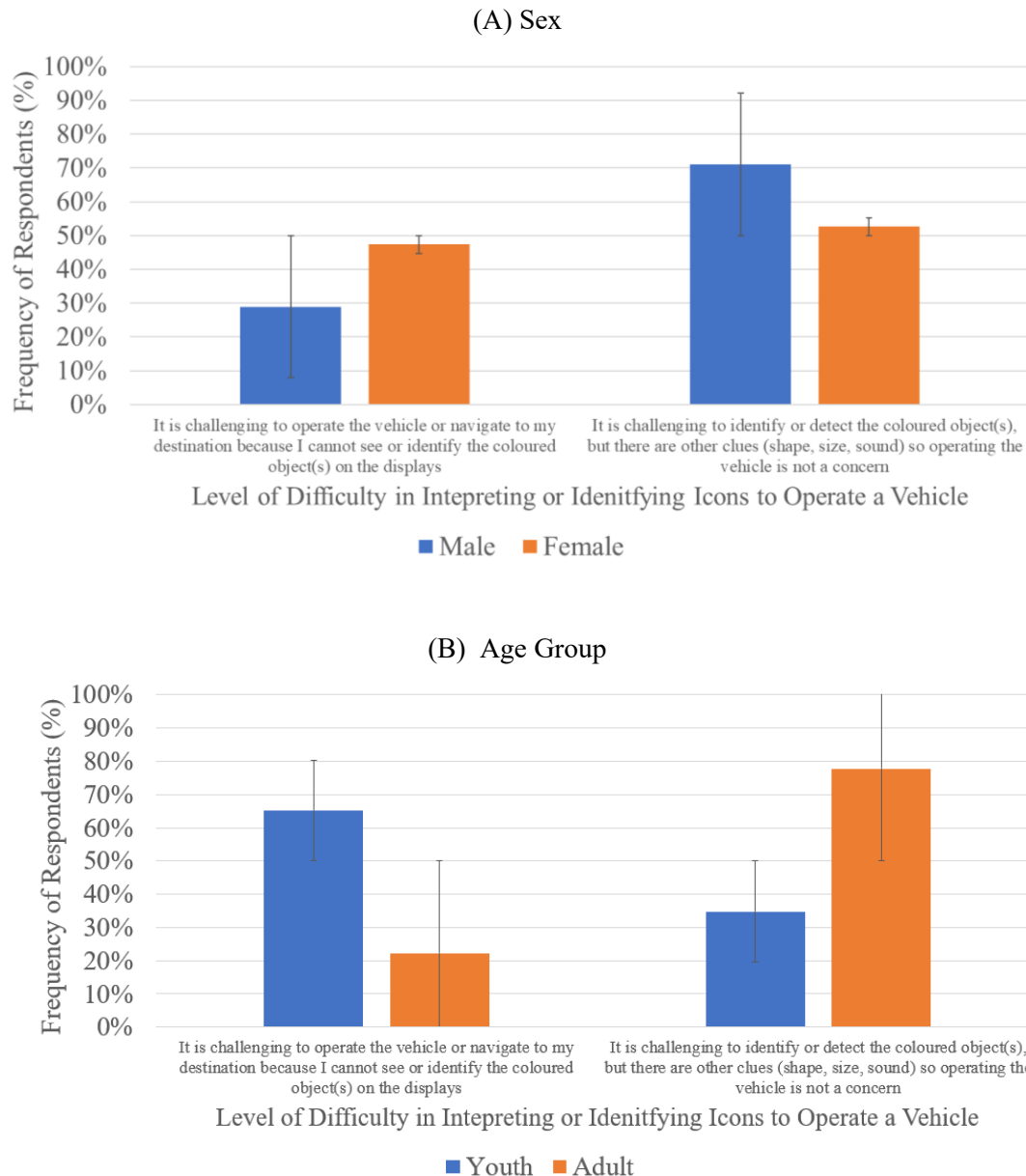


Figure 7.52. The frequency of respondents who selected background settings that they experienced difficulty using digital displays in motorized vehicles across the different tasks based on (A) sex and (B) age group (N=95). The error bars represent standard error.

7.8.6.1 Difficulty in Interpreting or Identifying Information on Displays Affect Ability to Operate a Motorized Vehicle: Effect of Severity within Age Group

Because the youth found operating the vehicles with displays challenging, we examined the effect of severity to determine whether the youth who felt that driving was challenging was due to a higher

number of youths with severe deficiencies. If there was no severity effect then some other factor, such as experience, is likely responsible. Figure 7.53 shows that, if anything, the youth with less severe defects felt that driving was challenging because they could not interpret the digital displays. The adults were not as challenged because they used other clues, but there was a slight tendency for individuals with less severe defects to report that driving was a challenge. The chi-square test could not be performed could not be performed because the data does not meet the assumption that all expected values must be greater than 1 and at least 20% of the expected values are greater than 5.

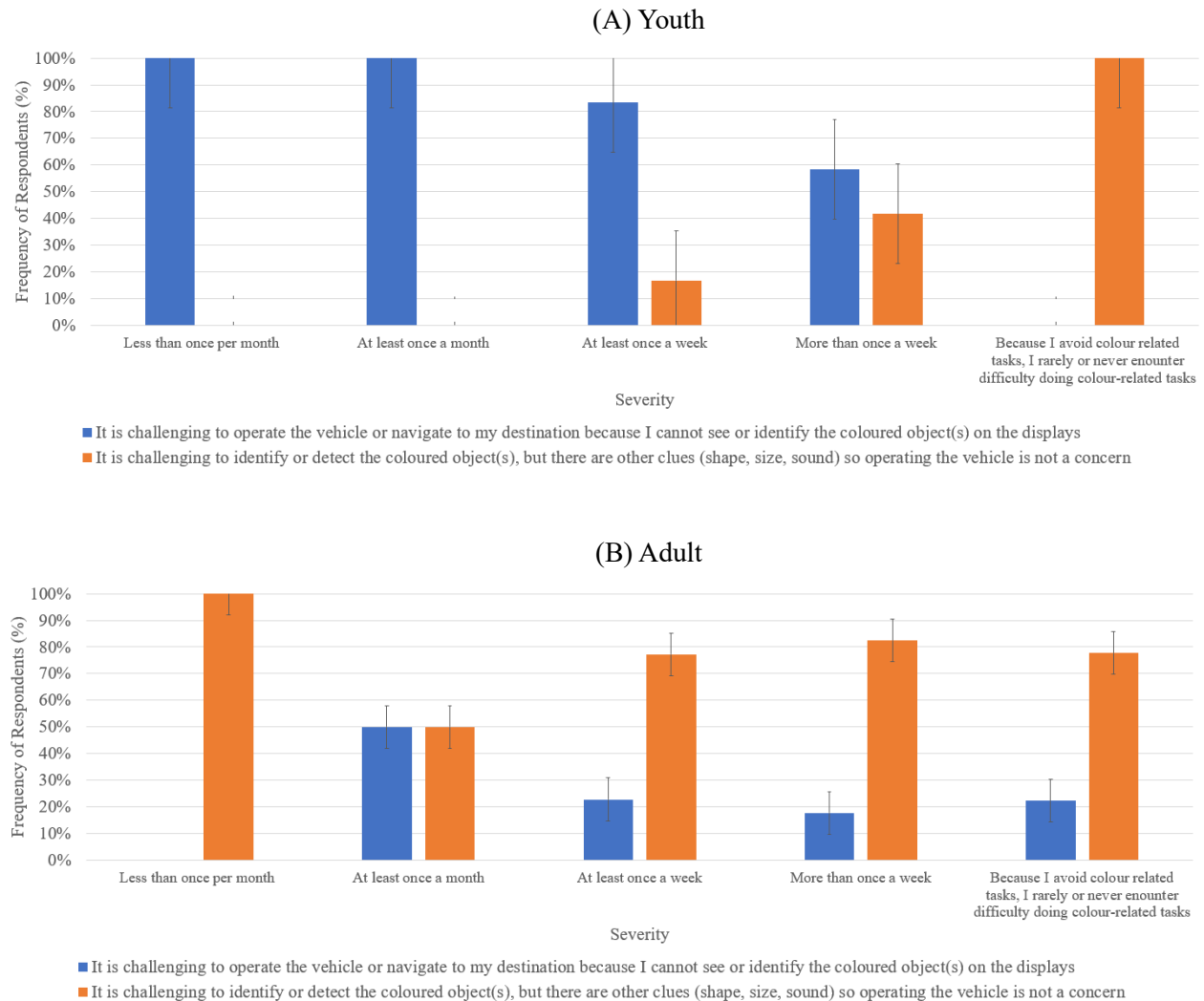


Figure 7.53. The distribution of (A) youth and (B) adults with “difficulty in interpreting or identifying the colour of text, symbols, or icons displayed in the information touch screen or GPS displays affecting their ability to operate a motorized vehicle” based on severity. There was one youth for “less than once per month,” two youths for “at least once a month” and “because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks,” and 1 adult for “less than once per month” which accounts for 100% frequency. And there are 6 adults for “at least once a month” accounting for the 50% frequency. The error bars represent standard error.

7.9 Travelling

The questions related to travel were restricted to only those individuals who travelled using public transportation, rail, ship or plane within the last 5 years. There were 255 respondents (66.9%) who met this criterion, 125 respondents (32.8%) who did not, and 1 respondent (0.3%) who preferred not to

answer. Included in this group was one respondent from the in-person shopping/banking section who mentioned difficulties with “ArriveCan during quarantine,” which was moved to this section's “other” category. Out of the 255 respondents who have travelled, 20.0% were male youth (51), 58.0% were male adults (148), 10.2% were female youth (26), and 11.8% female adults (30). This means that 59.3% of male youth, 76.3% of male adults, 60.5% of female youth, and 51.7% of female adults who completed the survey travelled in the past 5 years.

7.9.1 Difficulty Rankings of Colour-Related Tasks While Travelling: Sex Differences

The respondents were asked about the extent of their difficulty when reading, identifying or interpreting information on digital displays used for various tasks while travelling by plane, train, bus, or subway. There were 155 respondents who selected a task, but only 138 respondents ranked at least one of the tasks. Fifty-four percent (54.1%) of respondents ranked difficulty with at least one of the tasks while travelling. This group consisted of 78.3% males (108) and 21.7% females (30). There were 54.3% of males and 53.6% of females who travel ranked at least a little difficulty with a task.

Figure 7.54 shows the distribution of males and females who experienced at least a little difficulty with the tasks. For both sexes, the three tasks that respondents most frequently encountered problems with were: “reading the bus, train, or subway maps to find the correct route to take” (male: 70.4%, 76; female: 80.0%, 24), “distinguishing between departures and arrivals” (male: 36.1%, 39; female: 50.0%, 15), and “identifying cancellations or other schedule changes” (male: 34.3%, 37; female: 46.7%, 14). There were relatively similar distributions between both sexes, and there was no significant association for the four tasks based on sex ($\chi^2 = 0.4$, $df = 3$, $p = 0.95$). The “other” category consisted of 6 male adults whose tasks are shown in Table 7.14. It was removed from further analyses because the criterion that at least 20% of the expected values are greater than 5 was not met if it was included, and there were no females in this category.

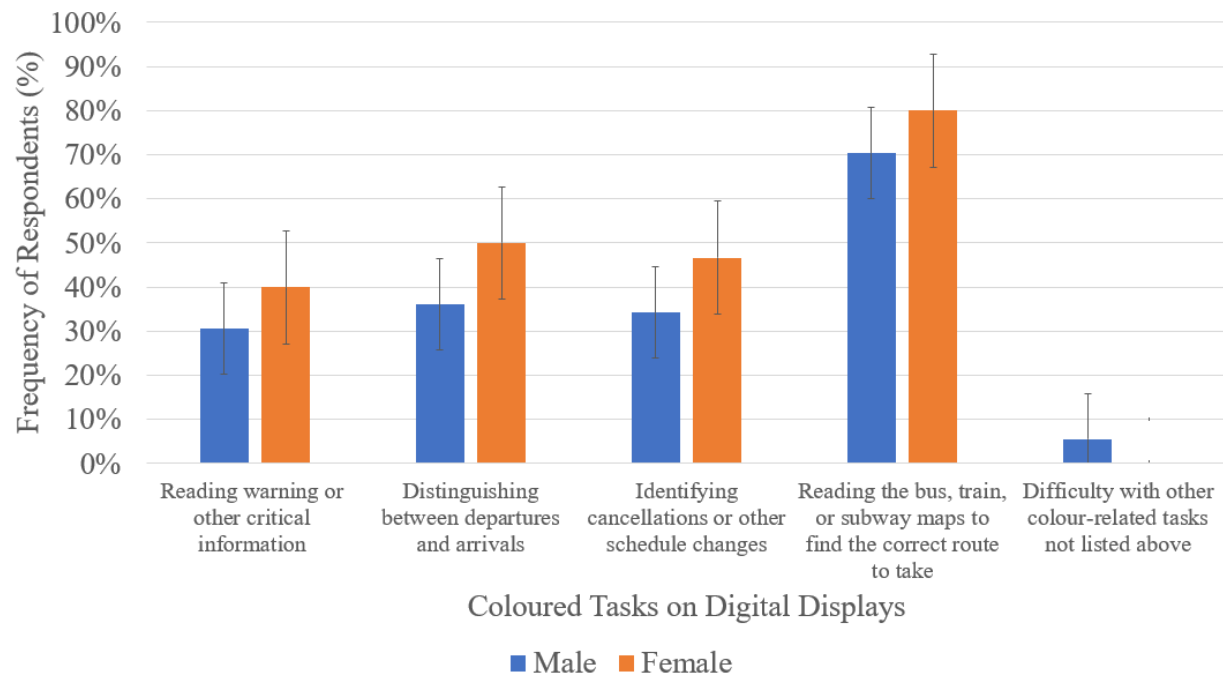


Figure 7.54. The frequency of male and female respondents who ranked at least a little difficulty for the coloured tasks while travelling (N=138). The “other tasks” include the response of 6 males and no females. The error bars represent standard error.

Table 7.14. The list of “other tasks or images” by 6 male adults who travelled by plane, bus or subway in the past 5 years.

Sex	Age Group	Task	Level of Difficulty
Male	Adult	“multi-coloured screen”	“some difficulty”
		“anything small print that is not high contrast”	“a little difficulty”
		“the track status lights are difficult to distinguish red for green”	“a little difficulty”
		“I got thrown into quarantine because I did not fill in the ArriveCan app properly, not because I was positive or anything like that”	“a lot of difficulty”
		“on the subway it is hard to tell from a distance whether the light is red or green, meaning it is hard to tell the station you are with the map”	“some difficulty”
		“anything that is not already labelled but relies on colours alone”	“a lot of difficulty”

Figure 7.55 shows the distributions of the rankings for (A) males and (B) females across the tasks. The median ranking was “some difficulty” across all tasks for both sexes. These differences were not significant across the four tasks ($p \geq 0.30$; adjusted p-value for significance = 0.013).

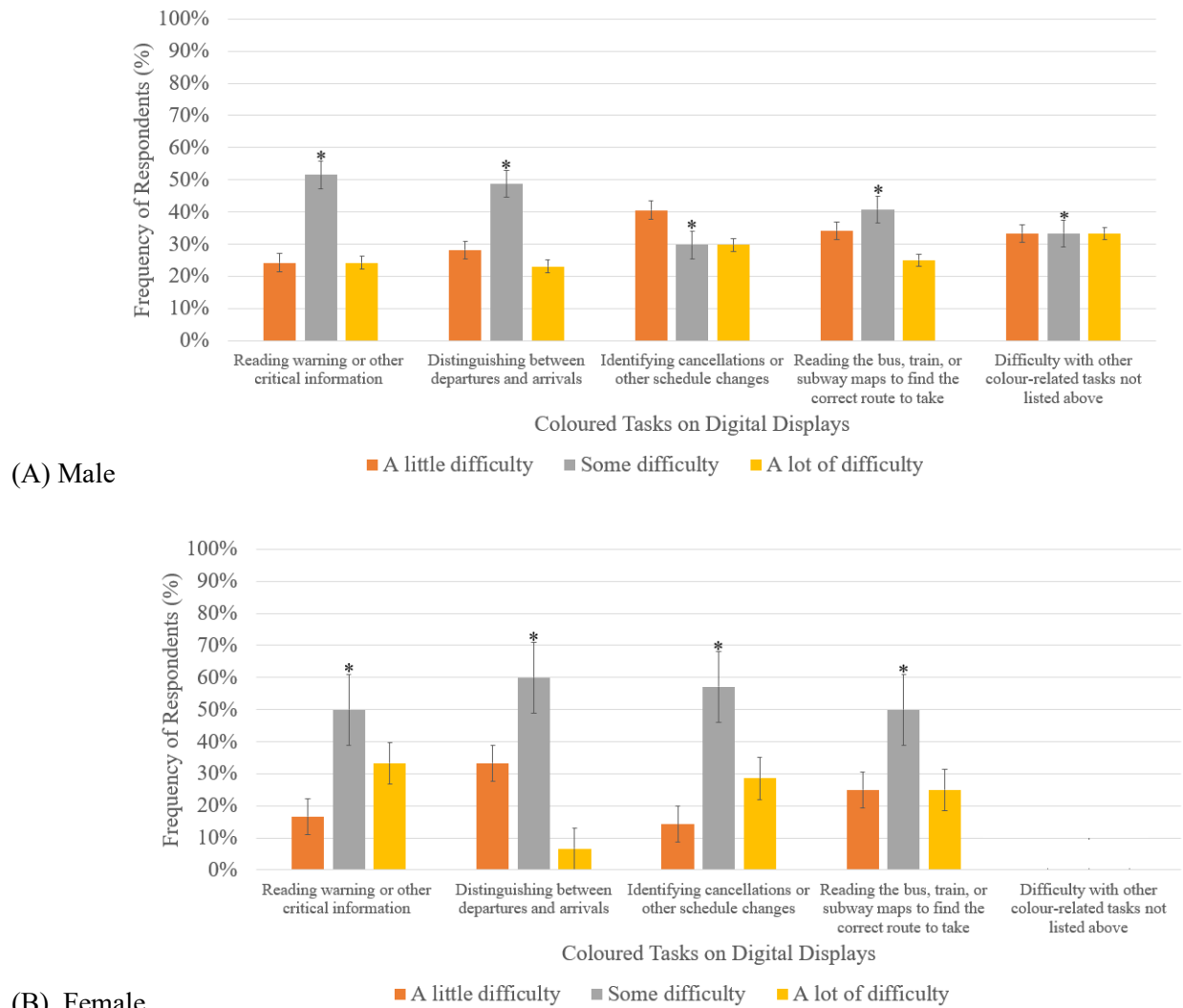


Figure 7.55. The distribution of ranked difficulty by (A) male (N=108) and (B) female (N=30) respondents having difficulty when making colour-related judgements using digital displays while travelling. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.9.2 Difficulty Rankings of Colour-Related Tasks While Travelling: Age-Group Differences

Of 138 respondents who ranked at least a little difficulty, 30.4% were youth (42) and 69.6% were adults (96). This means that 54.5% of youth and 53.9% of adult travellers experienced difficulty with a task. Figure 7.56 shows the distributions for the two groups. The three tasks that youth encountered the most challenges with were “reading the bus, train, or subway maps to find the correct route to take” (youth:

69.1%, 29), “distinguishing between departures and arrivals” (47.6%; 20) and “reading warning or other critical information” (42.9%; 18). For adults, the three tasks were “reading the bus, train, or subway maps to find the correct route to take” (74.0%, 71), “identifying cancellations or other schedule changes” (38.5%; 37), and “distinguishing between departures and arrivals” (35.4%; 34). Although there were some variations in the distribution, there was no significant association between the four tasks and age groups ($\chi^2 = 2.8$, $df = 3$, $p = 0.42$). The “other” category was removed from the analysis for reasons similar to those mentioned in sex.

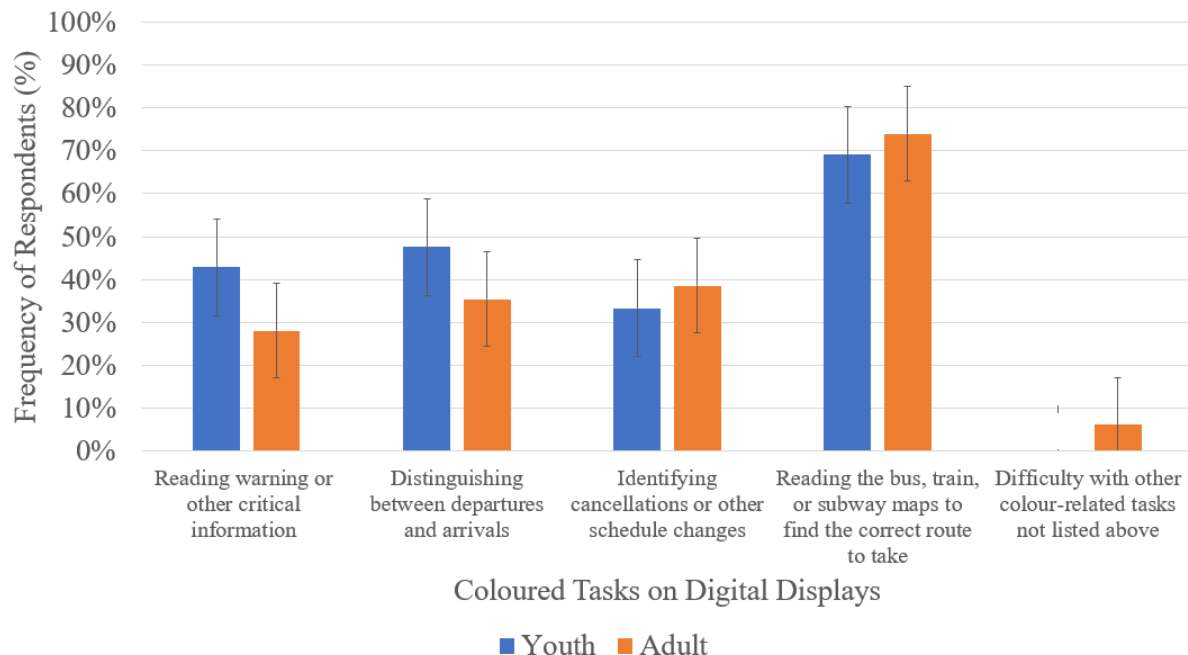
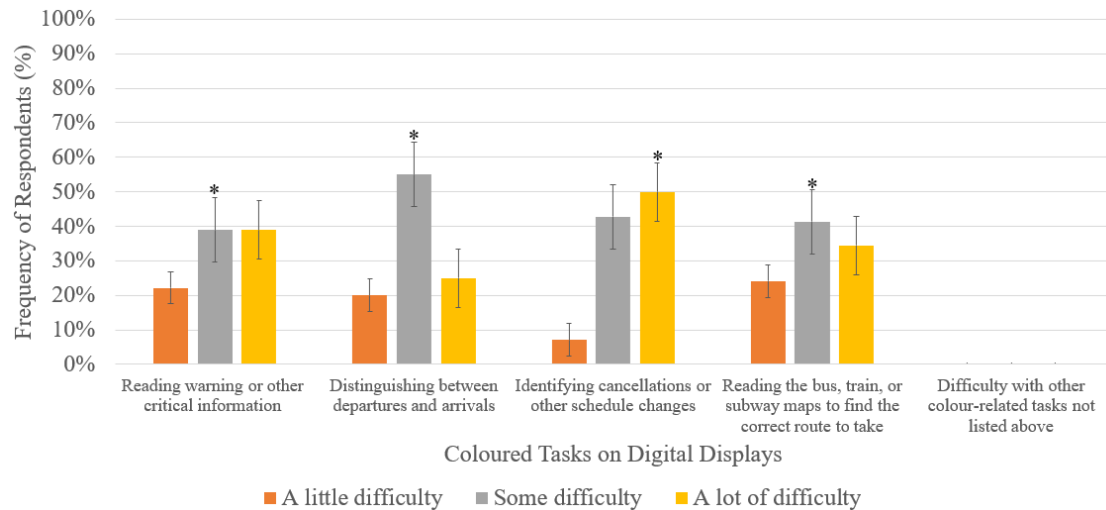
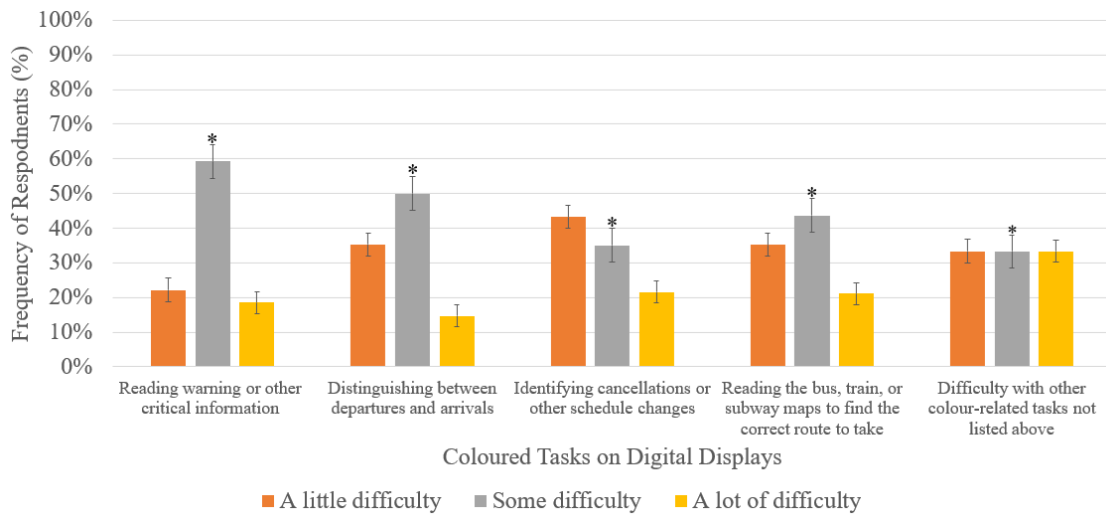


Figure 7.56. The frequency of youth and adult respondents who ranked at least a little difficulty for the coloured tasks while travelling (N=138). The “other tasks” include the response of no youth and 6 adults. The error bars represent standard error.

Figure 7.57 shows the distribution of the rankings of (A) youth and (B) adult respondents. The median ranking for most of the tasks was “some difficulty” for youth, except for “identifying cancellation or other schedule changes” which had a median ranking of “a lot of difficulty.” For adults, there were similar median rankings (“some difficulty”) across all tasks as found in youth. The youth ranking for “identifying cancellations or other schedule changes” was significantly different (Mann Whitney U = 144.0, $p = 0.010$) but not for the other tasks ($p \geq 0.15$; adjusted p-value for significance = 0.013). The “other” category was omitted from the analyses because there were no youth respondents.



(A) Youth



(B) Adult

Figure 7.57. The distribution of ranked difficulty by (A) youth (N=42) and (B) adult (N=96) respondents having difficulty when making colour-related judgements using digital displays while travelling. The percentages are based on respondents who ranked the difficulty of each particular task. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.9.3 Difficulty Rankings of Colour-Related Tasks While Travelling: Severity Differences

Table 7.15 shows the pooled results from the Kruskal-Wallis test for the rankings of the four tasks based on severity. “Identifying cancellations or other schedule changes” was the only task that showed significant differences in the rankings ($H = 17.2$, $df = 4$, $p = 0.002$; adjusted p -value for significance = 0.013). The pairwise comparisons revealed a significant difference between “at least once a month” and “more than once a week” (adj. $p = 0.013$), and “less than once per month” and “at least once a month”

(adj. $p = 0.028$). The “other” category was not included in this analysis since it was excluded in the Mann-Whitney tests for sex and age group.

Table 7.15. The results of the Kruskal-Wallis H test of the difficulty rankings of tasks performed while travelling based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.013$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Task	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)		
					Severity Pair		Adjusted Significance
Identifying cancellations or other schedule changes	51	17.2	4	(0.002)	“at least once a month”	“more than once a week”	(0.013)
					“less than once per month”	“at least once a month”	(0.028)
Reading the bus, train, or subway maps to find the correct route to take	100	12.5	4	0.014	N/A		
Reading warning or other critical information	45	8.9	4	0.064	N/A		
Distinguishing between departures and arrivals	54	6.4	4	0.17	N/A		

Figure 7.58 shows the distribution of rankings as a function of severity for the significantly different task of (A) identifying cancellations or other schedule changes ($p = 0.002$). Figure (B) is an example of a task where the differences were not significant distinguishing between departures and arrivals ($p = 0.17$). Figure (A) shows the expected result that the rankings for the “more than once a week” severity are higher than the rankings for “at least once a month.” However, the unexpected finding is that the rankings for “less than once a month” were higher than the other severity categories. One would expect that the supposedly less severe CVD would have a lower ranking. This is due to the median ranking of “less than once a month” being based on 2 respondents who ranked “a lot of difficulty,” as opposed to the

higher severity levels (“at least once a week” and “more than once a week”) which were based on 18 and 24 respondents, respectively. In contrast, figure (B) shows that the median ranking for most categories was “some difficulty” with “less than once a month” having a lower ranking.

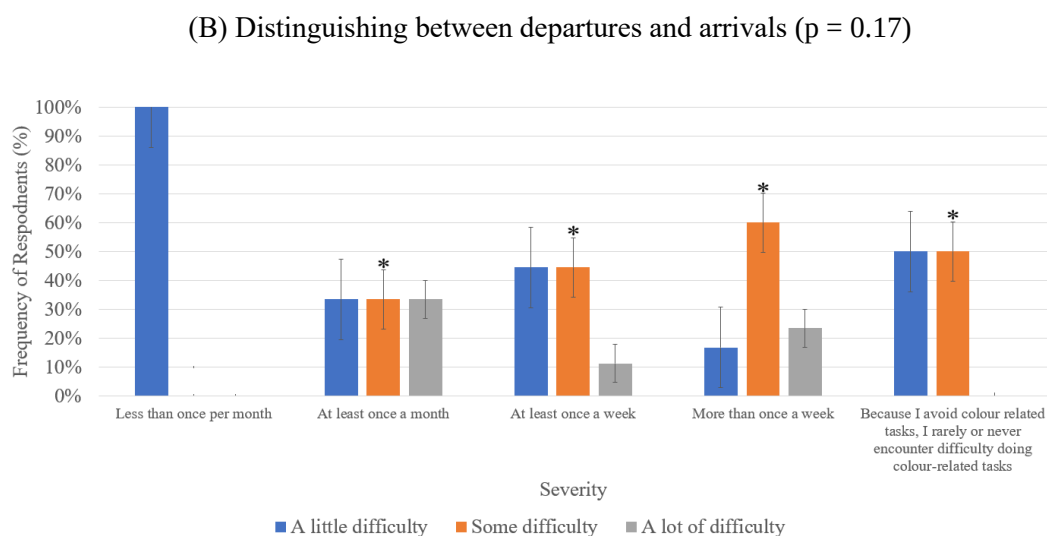
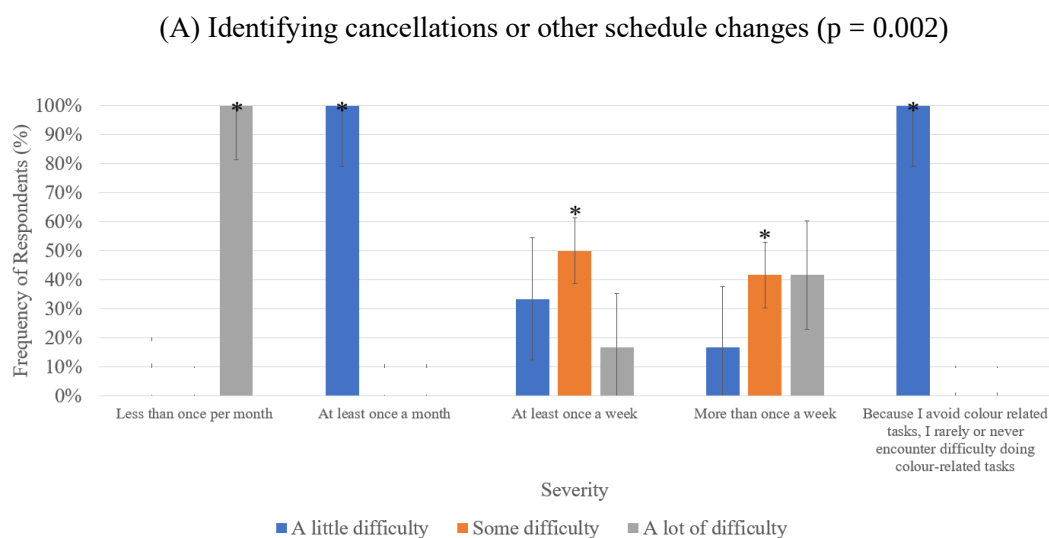


Figure 7.58. The distribution of ranked difficulty by all respondents with (A) identifying cancellations or other schedule changes and (B) distinguishing between departures and arrivals. The percentages are based on respondents who ranked the difficulty for each severity level. The median ranking could not be indicated for “less than once per month” for “distinguishing between departures and arrivals” since there was only one respondent in each. The data shown in “less than once per month” and “because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks” for identifying cancellations or other schedule changes and “because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks” for “distinguishing between departures and arrivals” were all based on the 2 respondents. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

7.9.4 Digital Displays where Difficulties are Encountered

There were 154 respondents who selected a display that they interpreted while travelling, which means that 60.4% of those who travelled selected at least one display. This group consisted of 74.7% males (115) and 25.3% females (39). For the age group, 31.2% were youth (48) and 68.8% were adults (106). There were 138 respondents who ranked the difficulty of tasks which was less than the number of respondents who selected a display. There were 57.8% of males, 69.6% of females, 62.3% of youth, and 59.6% of adults who travel experienced difficulty with a display. Figure 7.59 shows the distributions of the displays based on (A) sex and (B) age group. Although there were some variations in the rankings between sexes, there was no significant association with the three displays for sex ($\chi^2 = 2.0$, $df = 2$, $p = 0.36$) and age group ($\chi^2 = 0.02$, $df = 2$, $p = 0.99$). The “other displays” were not included in the analysis because none were reported by any respondents. Respondents experienced the most difficulty with “monitors displaying maps of different lines or routes” across both sexes and age groups, tied with “monitors displaying arrival and departure times or directions to the correct boarding area” for females.

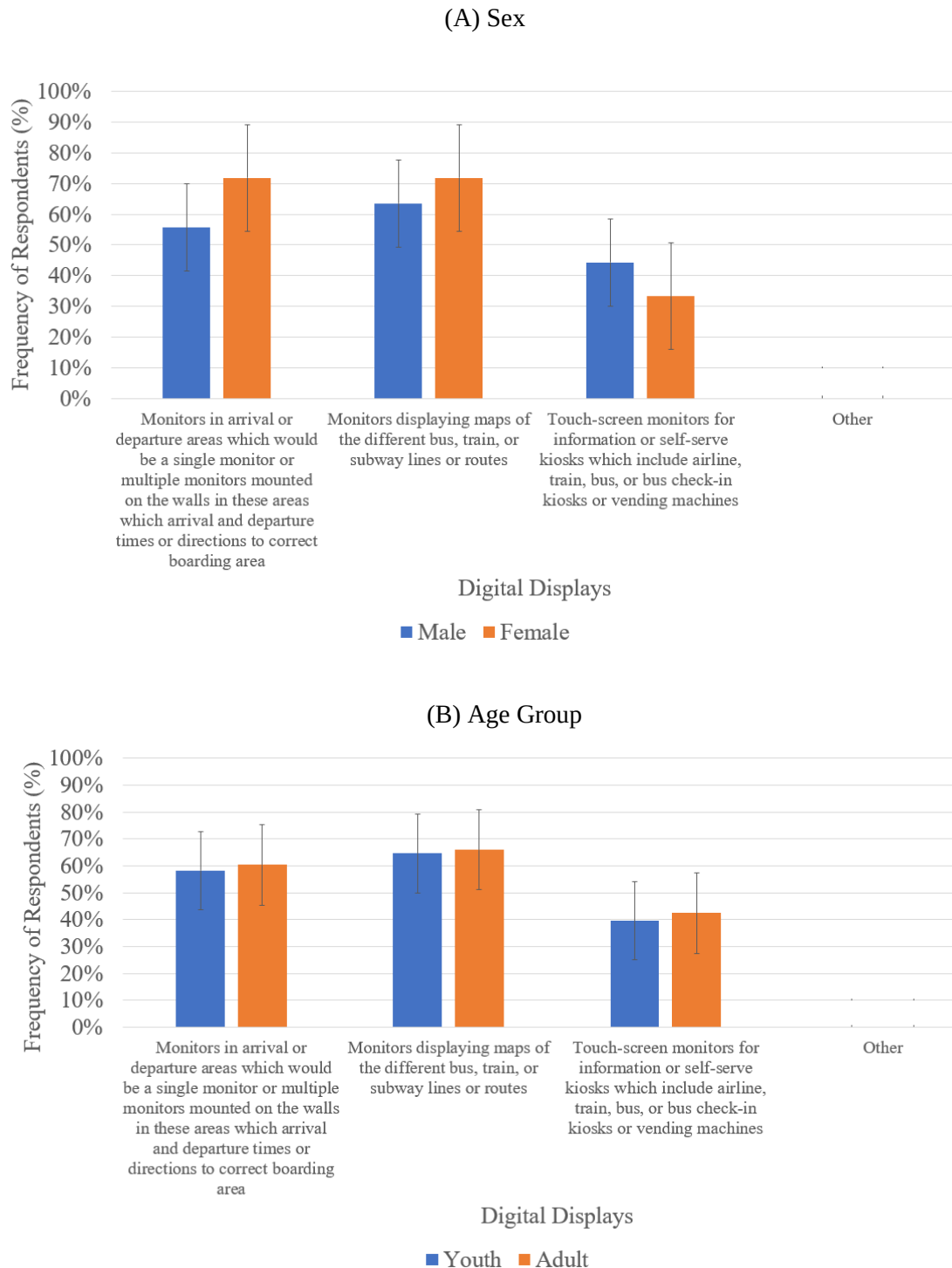


Figure 7.59. The distribution of digital displays that respondents found challenging while travelling based on (A) sex and (B) age group (N=154). There were no respondents who reported difficulty with any “other displays.” The error bars represent standard error.

7.10 Respondents Who Experienced Difficulties with Multiple Displays

Table 7.16 shows the proportions of individuals with CVD who reported having difficulties with two or more displays across the different areas of life. More than half of them selected multiple displays. The one exception was “in-person shopping/banking” where 24.9% reported challenges with more than one display.

Table 7.16. The prevalence of respondents who encountered difficulty with multiple digital displays in a given area of life. The sample size (N) represents the number of respondents who selected at least one display.

Area of Life	Proportion of Respondents Selecting More than One Display
School (N=148)	62.2% (92)
Work/Volunteering (N=182)	64.8% (118)
Recreation/Hobbies (N=184)	75.0% (138)
Social Media (N=298)	72.8% (217)
Gaming & eSports (N=220)	67.7% (149)
Online Shopping/Banking (N=212)	66.0% (140)
In-Person Shopping/Banking (N=281)	24.9% (70)
Driving/Motorized Vehicle (N=142)	64.1% (91)
Travelling (N=154)	51.3% (79)

7.11 Chapter Discussion

7.11.1 Prevalence of Difficulties Experienced by People with CVD Across Various Coloured Tasks

One of the primary objectives of this study was to determine the prevalence of difficulties that individuals with CVD experienced when performing various coloured tasks using digital displays in their daily lives. This was important to explore because if there is a high prevalence of people with CVD who experience

challenges, it further highlights that their interaction with displays is a common obstacle. Numerous studies concluded that individuals with CVD do, in fact, experience some level of difficulty when performing colour-related tasks in various areas of daily life, such as school (Grassivaro Gallo et al., 1998; Mashige, 2019; Stoianov et al., 2019), work (Cumberland et al., 2005), and driving (Steward & Cole, 1989; Tagarelli et al., 2004). Cumberland et al. (2005) followed a cohort of 12,534 11-year-old British children who were born in 1958 consisting of 431 boys with CVD. The study aimed to acquire information about their previous and current occupations at 33 years old (Cumberland et al., 2005). They concluded that males with CVD were under-represented in some “target” occupations (e.g. police officers, firefighters, pilots, and scientists), or lacked presence in others, such as “electrical or electronic engineers.” However, they were employed in many “target occupations” where there was no variation in employment between individuals with CVD and colour normals in the “Armed Forces” (Cumberland et al., 2005). This is further highlighted in Steward and Cole’s study (1989) where almost 25% of people with CVD reported that their condition prevented them from an occupation. Moreover, 75% of the respondents reported problems in making colour judgments in their daily lives. Mashige (2019) explored the challenges students with CVD encountered in their daily lives. Of the 29 students with CVD, 31.0% reported problems watching sports because of colour, 27.6% had problems with colours in fine arts, 17.2% had trouble recognizing traffic signal lights, and 41.4% reported coloured-related issues when working on the computer. These percentages were similar to the ones reported by Steward and Cole for similar tasks, suggesting that these are problems that people with CVD commonly encounter.

Table 7.17 shows the prevalence of respondents who experienced at least a little difficulty with at least one digital display task in different areas of life. Similar to Steward and Cole's results, at least 77% of respondents, overall, reported at least a little difficulty in making colour-related judgments in their daily lives, but this was just for activities where digital displays are used. It is possible that the issues using digital display are in addition to the problems reported in Steward and Cole’s survey, which suggests that navigating through their daily lives has become more challenging. However, when specific areas of life are examined, nearly 100% of individuals with CVD encountered at least a little difficulty using digital displays, which indicates that only a small minority are unaffected by the ubiquitous of the displays and their use of colour. The one exception was travelling, where only 54.1% reported experiencing at least a “little difficulty” with one of the tasks. This decrease could be a result of the designers taking into account consumers with CVD, colour coding is not used as extensively by chance, redundant clues are present, or the use of colour varies across transportation modes and locations. An interesting finding was that less than 50% of travellers experienced difficulty with most colour-related tasks, except for “reading maps to find the correct routes to take” where over 70% of sexes and age

groups reported difficulty with this task. It could be due to the extensive use of colour coding in this task to differentiate routes, reduced contrast sensitivity, or lack of use of secondary cues (e.g. patterns and shapes). It was surprising to find that one of the travelling tasks had a high difficulty prevalence since travelling was an area of life with a lower overall prevalence rate (54.1%). This could just be a result that this particular task was commonly found challenging across most respondents with CVD. Although the prevalence is lower, there was still a majority of individuals with CVD in the group.

Table 7.17. The prevalence of respondents who reported that carrying out a colour-related task on a display in the various aspects of life was at least a little difficult. The sample size (N) represents the number of respondents who reported being present in that area of life.

Area of Life	Proportion of Respondents Ranking At Least a Little Difficulty with One of the Tasks
School (N=151)	96.0% (145)
Work/Volunteering (N=215)	77.2% (166)
Recreation/Hobbies (N=208)	83.2% (173)
Social Media (N=321)	88.2% (283)
Gaming and eSports (N=241)	88.0% (212)
Online Shopping/Banking (N=249)	80.3% (200)
In-Person Shopping/Banking (N=286)	94.1% (269)
Driving/Motorized Vehicles (N=149)	87.9% (131)
Travelling (N=255)	54.1% (138)

The higher percentage of respondents reporting problems using digital devices relative to Mashige's (2019) results could also be due to different sampling techniques and sample sizes. In addition,

the difference could be, the fact, that we asked about specific tasks which was not the case in the earlier study. Questions about specific tasks might be more likely to result in a response. It could also be related to how digital devices are used in the various school systems.

The types of tasks that created challenges were not surprising. Respondents frequently reported difficulties with, such as “colour-coded diagrams” in school, work/volunteering and recreation/hobbies, “colour-coded plans/instructions” at work/volunteering, “reading coloured text” on social media platforms, “matching colours” while gaming or participating in eSports, and “detecting or identifying information from a digital map” while operating a motorized vehicle. The extent of these problems will be explored in the following sections.

7.11.2 The Level of Difficulty Experienced When Performing Coloured Tasks on Digital Displays: Sex and Age Group

Another objective was to determine the level of difficulty that people with CVD experienced when performing these tasks on displays. This was of interest to us because it provided us with a better understanding of the challenges faced by CVDs when interacting with digital displays. Depending on the degree of difficulty of the tasks and displays, it provides a better direction towards where software developers need to focus more of their efforts to ensure optimal experience. In this study, the median ranking for most of the coloured tasks was “some difficulty” regardless of sex or age group, with most respondents ranked as having experienced at least “a little difficulty” for at least one of the tasks included in the survey. Some tasks had median rankings that deviated from the general trend of “some difficulty” (Table 7.18). Table 7.18 also includes tasks where the differences in the difficulty rankings were not statistically significant. The deviation towards higher median rankings was predominately by females and youth. The reason for this is uncertain, but it may be due to differences in task exposure or greater difficulties in performing tasks that require highly complex colour-related judgements are experienced by them as compared to their counterparts. It could also be due to the smaller number of females and youth who did rank, where most of those individuals who experienced greater difficulty with a task could be a result of a bias towards more severe defects by both groups.

Table 7.18. The table includes the median ranking for coloured tasks that deviated from the general trend of the other tasks. The percentages are based on the number of respondents in that particular group who declared themselves present in that area of life and also ranked the task the same as the median difficulty ranking. The asterisks () represent the tasks that were statistically significant based on either sex and/or age group based on the Mann-Whitney test.**

Area of Life	Comparison Factor	Demographic Factor	Task	Median Difficulty Ranking
School	Sex	Female	Colour-coded mathematical or chemical equations	“a lot of difficulty”
	Sex		Editing photos or other coloured images	“a lot of difficulty”
	Age Group	Youth	Colour-coded mathematical or chemical equations	“a lot of difficulty”
Work/Volunteering	Age Group	Youth	Colour-coded diagrams	“a lot of difficulty”
Gaming & eSports	Sex	Male	Difficulty with other colour-related tasks not listed above	“a lot of difficulty”
	Sex	Female	Matching colours	“a lot of difficulty”
	Sex		Perceiving images in 3D	“a lot of difficulty”
	Age Group	Adult	Difficulty with other colour-related tasks not listed above	“a lot of difficulty”
Driving/Motorized Vehicles	Age Group	Youth	Interpreting any navigation information or driver assist systems	“a lot of difficulty”
Travelling	Age Group	Youth	Identifying cancellations or other schedule changes**	“a lot of difficulty”

There were no significant differences in the rankings for most tasks based on sex, except for “reading coloured letters on various backgrounds” while shopping/banking in-person (Mann Whitney, $U = 2994.0$, $p = 0.007$; adjusted p -value for significance = 0.0083). Another possible reason for the differences between sexes could be their level of colour naming vocabulary. Maully (2014) administered a questionnaire to 10 university colour-normal English students (5 males), where females tend to know

~80% of the colour terms as compared to only 20% by males. Females tend to exhibit a more extensive colour naming vocabulary (e.g. “chartreuse, beige, lavender, and azure”) as they tend to be more attentive to colours (Bi, 2010). However, other factors also contribute to colour naming besides sex, such as jobs and hobbies (Ekici et al., 2005). For example, individuals with occupations, such as fashion designers or painters, generally know “more colour terms” (Maully, 2014). Even though these studies explored the colour naming of colour normals, some connections potentially can be made with individuals with CVD. Since this discrepancy already exists between sexes with normal colour vision, CVD can potentially act as an additional barrier in their ability to make colour-related judgments, where an individual's inability to distinguish certain colours along with cultural and social factors affect their description of colours.

There were also certain tasks that one group found more difficult than the other, but the tasks that did reach statistical significance were “interpreting coloured images” while using social media platforms based on age group (Mann Whitney, $U = 177.0$, $p < 0.001$; adjusted p-value for significance = 0.0083), “reading coloured letters on various backgrounds” while shopping or banking in-person based on sex (Mann Whitney, $U = 2994.0$, $p = 0.007$; adjusted p-value for significance = 0.0083), and “identifying cancellations or other schedule changes” while travelling based on age group (Mann Whitney, $U = 144.0$, $p = 0.010$; adjusted p-value for significance = 0.013). This may be due to the difference in exposure to displays. Youth may be more reliant on digital displays when performing tasks in their daily lives. A survey conducted by Common Sense Media highlighted a rapid increase in general electronic media use by 17%, specifically in tweens and teens, from 2019-2021 since the start of the COVID-19 pandemic in March 2020 (Rideout et al., 2022). There are certain areas of life where youth are more present than in others, such as school (74.5%) and driving/motorized vehicles (42.0%), where youth show greater median rankings. This may be a topic to explore further as to why females and youth potentially experience more difficulty in these particular areas of life. This could be due to the complexity of the coloured tasks or the frequency of encountering more colour-related tasks than in other areas.

7.11.2.1 Differences in Difficulty Rankings: Severity

The effect of severity on the difficulty rankings was examined to see if there is any potential relationship between them. It is expected that people with more severe CVD will more frequently encounter challenges, which will be reflected in higher difficulty rankings by individuals with more severe defects. There was no significant difference in the difficulty rankings for most of the tasks. Table 7.19 summarizes the severity results of the tasks that did show significant differences based on severity. These tasks included “colour-coded diagrams” at school, work/volunteering, and recreation/hobbies; “editing coloured images and/or videos” at school, recreation/hobbies, and social media; and “reading coloured letters on various backgrounds” in gaming/eSports, online shopping/banking, and in-person

shopping/banking. The general finding for these tasks was that the rankings were between mild (“less than once per month” and “at least once a month”) and more severe (“more than once a week”) defects were predominately different.

The avoidant group was assumed to consist of individuals with more severe CVD, but our analysis showed that this assumption was not supported. More likely, this group consisted of respondents with different severity levels. Some associations between “more than once a week” and “avoid tasks” groups showed a negative relationship, suggesting that the avoidant group does not consist of those with more severe defects, but of those with more similar severity to “less than once per month.” It could be that people with CVD who are avoiding tasks was not due to difficulties caused by their defect, but more likely due to their perception of challenges imposed by certain tasks, past negative experiences, or coping technique. There were some tasks that were expected to show significant differences in the difficulty rankings if the avoidant group was excluded, we do plan on performing future analyses on severity that exclude respondents who avoid tasks.

Cole’s review (2004) suggested that the majority of individuals with CVD are hindered by their condition when it comes to their ability to make accurate colour matching or discrimination. He reported two surveys (Steward & Cole, 1989; Spalding, 1999) that mentioned that all, except for 7-10% of the people with CVD experience substantial difficulty with daily tasks and occupations. These individuals were more likely to have mild deuteranomaly (Cole, 2004). My results are consistent with this finding and what would be expected, in that individuals with more severe defects are more likely to encounter problems more frequently and have more difficulty making colour-related judgments.

Table 7.19. A summary of the coloured tasks that showed statistically significant differences in the difficulty rankings based on severity (Kruskal-Wallis H test). The p-values in parentheses are statistically significant.

Area of Life	Task	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Adjusted P-Value for Significance	Significant Pairwise Comparisons (the Dunn test with Bonferroni correction)		
						Severity Pair		Adjusted Significance (p-value)
School	Colour-coded diagrams	18.1	4	(0.001)	0.0063	“at least once a month”	“more than once a week”	(0.001)
	Editing photos or other coloured images	16.0	4	(0.003)		“at least once a month”	“more than once a week”	(0.002)
Work/Volunteering	Colour-coded diagrams	24.3	4	(< 0.001)	0.0083	“at least once a month”	“more than once a week”	(0.00)
Recreation/Hobbies	Colour-coded diagrams	26.4	4	(< 0.001)	0.0083	“less than once per month”	“more than once a week”	(0.009)
						“at least once a week”	“more than once a week”	(0.001)
	Colour-coded plans/instructions	18.7	4	(< 0.001)		“at least once a month”	“more than once a week”	(0.002)
						“at least once a week”	“more than once a week”	(0.032)
	Editing coloured images (including photos)	14.9	4	(0.005)		“at least once a month”	“more than once a week”	(0.024)
Social Media	Interpreting coloured images	23.7	4	< 0.001	0.0083	“more than once a week”	“because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks”	(0.003)
						“less than once per month”	“more than once a week”	(0.018)
						“at least once a month”	“more than once a week”	(0.037)

Social Media	Reading coloured text	22.5	4	(< 0.001)	0.0083	“at least once a month”	“more than once a week”	(0.002)
						“less than once per month”	“more than once a week”	(0.021)
						“at least once a week”	“more than once a week”	(0.036)
	Editing images and videos using various filters and effects to create content	16.5	4	(0.002)		“less than once per month”	“more than once a week”	(0.010)
Gaming & eSports	Matching colours	19.9	4	(< 0.001)	0.0083	“at least once a month”	“more than once a week”	(0.002)
						“at least once a week”	“more than once a week”	(0.027)
	Experiencing objects disappearing or having difficulty seeing as the background/scene colours change	19.5	4	(< 0.001)		“at least once a month”	“more than once a week”	(0.006)
						“less than once per month”	“more than once a week”	(0.010)
	Reading coloured letters on various backgrounds	20.2	4	(< 0.001)		“less than once per month”	“more than once a week	(0.003)
						“at least once a month”	“more than once a week”	(0.013)
Online Shopping/Banking	Reading coloured letters on various backgrounds	19.5	4	(< 0.001)	0.0063	“at least once a week”	“more than once a week”	(0.022)
						“less than once per month”	“more than once a week”	(0.026)
						“at least once a month”	“more than once a week”	(0.050)
In-Person Shopping/Banking	Identifying colours	29.9	4	(< 0.001)	0.0083	“at least once a month”	“more than once a week”	(0.00)
						“less than once per month”	“more than once a week”	(0.013)
						“more than once a week”	“because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks”	(0.016)
						“at least once a month”	“at least once a week”	(0.023)

In-Person Shopping/Banking	Experiencing objects disappearing or have difficulty seeing these objects as the background/scene colours change	21.0	4	(< 0.001)	0.0083	“more than once a week”	“because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks”	(0.010)
						“at least once a week”	“more than once a week”	(0.042)
	Reading coloured letters on various backgrounds	21.2	4	(< 0.001)		“at least once a month”	“more than once a week”	(0.004)
						“less than once per month”	“more than once a week”	(0.042)
						“more than once a week”	“because I avoid colour related tasks, I rarely or never encounter difficulty doing colour-related tasks”	(0.048)
Travelling	Identifying cancellations or other schedule changes	17.2	4	(0.002)	0.013	“at least once a month”	“more than once a week”	(0.013)
						“less than once per month”	“at least once a month”	(0.028)

7.11.3 Specifics Areas

7.11.3.1 School Subjects that Students with CVD Encountered the Most Difficulties with Performing Tasks on Displays

We were interested to see if there were certain school subjects with which students with CVD tend to experience more difficulties due to their condition. If this was the case, then it may suggest a more targeted approach for software designers to improve accessibility, and it would make instructors and course designers aware of the problem so that they could reduce their reliance on colour coding without redundant clues. Several studies have suggested that CVD influences students' academic performance in school, specifically in certain subjects, such as sciences (Grassivaro Gallo, 1998; Sullivan, 2011; Mashige, 2019). One study by Grassivaro Gallo et al. (1998) assessed the academic achievement (grades) of 3124 10-15-year-old boys (152 students with CVD) from Liguria, Italy in 1993-1994. Overall, they found that there was a significant reduction in the grades of students with CVD relative to colour normals in subjects, such as “natural sciences,” “mathematics,” “geography,” “history,” “Italian literature,” and “foreign language” (Grassivaro Gallo, 1998). Surprisingly, art grades did not differ, which they attributed to the fact that the grading weighed heavier on originality (Grassivaro Gallo, 1998). Although we did not ask about grades and academic performance, problems in performing colour-related tasks in “general sciences” and “geography” have been carried over to digital displays. The other subject in this study that most students frequently encountered problems with was “graphic design/art” which was not the case in Grassivaro Gallo et al.’s study (1998). This may reflect different grading criteria, but also the expectation that colour should be liberally used in digital displays.

7.11.3.2 Games Using Digital Displays

An additional question that was included in the “gaming/eSports” section listed up to five games that the colour detectives had difficulty playing using any digital display. Colours are used in games to convey information in various tasks, such as identifying opponents and distinguishing obstacles, so a gamer with a CVD could be hindered by their condition in their performance and experience (Tillem & Gün, 2023). Napoli and Chiasson (2018) performed the study on 12 gamers (1 gamer with “slight deuteranomaly”) by comparing their gaming performance in normal settings and a stimulated colour-blindness mode of an online puzzle game. There was no drastic decrease in their performance in the colour blindness mode, but the gamers did find it to be more difficult that they even felt that it impeded their performance (Napoli & Chiasson, 2018). Although we cannot always distinguish between finding a game challenging and having a performance decrement versus finding the game challenging but no performance decrement. Some of the comments suggest that there is a performance decrement for some individuals with CVD. Both, ours and theirs, studies supported that there are some shortcomings in the design of the games which impede

their performance. Approximately 83.4% of individuals with CVD who reported using displays for gaming listed at least one game, which reiterates that the majority of gamers with CVD do encounter challenges when performing tasks.

We were surprised by the number of games listed, which indicates that there are very few games that are accessible to people with CVD, and more consideration of the problems they face is required for nearly all games. Despite the long list of games, a few games were listed frequently by the respondents as problematic. These were “Candy Crush,” “Super Mario Bros,” “FortNite,” and “Solitaire” with the most reported game being “Call of Duty.” We are uncertain whether the relatively high frequencies are due to their popularity or their use of colour. This survey was administered in July-September 2022, and the #1 and #12 best-selling games (based on dollar sales) in the USA were from the “Call of Duty” saga, with “Call of Duty: Modern Warfare 2 (2022) (Activision Blizzard)” in the top spot (NPD Group, 2023), so it is not surprising that Call of Duty was frequently mentioned. Nevertheless, the finding that other first-person shooter games (e.g. “Doom,” “Halo,” and “Borderlands”) were also listed suggests that there is an accessibility issue with the use of colour in identifying friends or foes.

Most games include adjusting colour vision deficiencies by implementing more friendly colour schemes and customizable settings for people with CVD. Napoli and Chiasson’s study (2018) investigated one such game, “Pet Rescue Sage,” and found that the adjustments were inadequate. Based on the survey comments, the adjustments’ success appears to be mixed. Some found them useful, whereas others did not find any difference and it is possible that others were unaware of the adjustments. This indicates that more work is necessary both in the hardware and software (Tillem & Gün, 2023), potentially in the advertising and manuals highlighting the accessibility features.

7.11.3.3 Difficulty Rankings of Colour-Related Tasks in Motorized Vehicles: Background Settings

This section aimed to determine whether there are differences in the difficulty rankings based on differences in the background setting. This is important because background light luminance and colour could affect the ability of the person to use the displays effectively. The results from the survey indicate that the problems encountered by individuals with CVD are often present in both the day and nighttime settings. This result appears to be inconsistent with Tagarelli et al.’s (2004) survey results. They reported that 38.4% of people with CVD preferred driving in “daytime” as opposed to “nighttime” when compared to colour normals with statistical significance ($p < 0.0001$) (Tagarelli et al., 2004). However, we believe this question is related to driving in general and not specifically about interpreting displays, since this

survey was conducted in early 2001 when digital displays were not as common. It was also consistent with the results of the background brightness (chapter 7) where the medium-bright background, presumably, the one with the lowest luminance contrast, had a higher median difficulty ranking in comparison to white and dark backgrounds. But there was a greater frequency of “a lot of difficulty” for dark than white backgrounds, which could suggest a greater preference to “daytime” as opposed to “nighttime” driving found in Tagarelli et al.’s (2004) study.

Unfortunately, our survey did not address the specific reasons why respondents were having difficulty interpreting the displays both during the day and at night. It could be that there are different reasons for different displays. In the daytime, it is possible that the displays are not sufficiently bright and/or the display colour differences are relatively small. At night, the colours may be either too dim for a person with CVD to distinguish easily or too bright so that the glare from individual icons or text reduces the colour difference further. Although, background settings had no significant associations with either demographic factor (sex and age group) or any significant differences in the difficulty rankings of the tasks, but there was a difference in the difficulty ranking for “interpreting any navigation information or driver assist displays” between age groups. The median ranking for this task showed greater difficulty (“a lot of difficulty”) for youth than adults (“some difficulty”). This finding will be discussed in the next section.

7.11.3.4 Difficulty in Interpreting or Identifying the Colours of Text, Symbols or Icons Displayed on the Information Touch Screen GPS Displays that Affect Ability to Operate a Motorized Vehicle

This question asks whether the challenges in interpreting digital displays interfere with people with CVD’s ability to drive the vehicle safely. The concept of safe driving involves identifying exterior signal lights, such as different coloured road signs and traffic lights (Chan et al., 2014), as well as interior coloured signals, such as colour-coded information from vehicle displays. Tagarelli et al.’s study (2004) showed that individuals with CVD regularly use cars significantly less than colour normals. As well as they make more mistakes in identifying the colours of the traffic lights (Nathan et al., 1964; Atchison et al., 2003). However, it is still less challenging for people with CVD in motorized vehicles to interpret traffic signals as compared to rail, maritime, and aviation signals due to the other secondary hues that can assist them (e.g. brightness, direction of traffic flow, and positioning of traffic lights) (Chan et al., 2014).

More than 50% of the male and female adults with CVD did “not have concerns with operating a vehicle because they use other clues (shape, size and sound),” whereas more youth (65.2%) find “it is

challenging because they cannot see or identifying the coloured object(s) on the displays.” Even though the differences in perceived difficulty did show a significant association with age group ($p = 0.0004$), there was no direct relationship with severity in either group. If anything, the youth with the milder defects felt that the colour judgments interfered with their driving. This suggests the difficulties experienced by youth are most likely due to a lack of experience with driving and using the displays. They may not have learned how to use the redundant clues in the environment or even ignore the displays because they are too difficult to interpret. The additional workload would likely be more of a problem for an inexperienced driver who had difficulty distinguishing the street lights to begin with. A good way to limit the workload could be by teaching inexperienced drivers about using secondary clues (e.g. shape, size and sound) when identifying exterior and interior signals. Or having manufacturers incorporate other clues in the design of the vehicle displays to ensure greater accessibility and safety for individuals with CVD.

7.11.4 Digital Displays that Respondents Encountered Difficulties

The next objective was to investigate which types of digital displays are problematic for people with CVD when performing colour-related tasks. This would provide software developers with additional information on which displays to address first for improved accessibility. A limited number of studies have explored the impact of CVD on their interaction with digital displays. Table 7.20 shows the frequency of respondents who selected difficulty with at least one display in this study. More than 85% of the total respondents who reported being present in a particular area of life selected display they frequently encountered challenges. “Travelling” was a slight exception where a lower frequency (approximately 60%) of respondents from each group chose a display.

Table 7.20. The prevalence of respondents who encountered difficulty with at least one digital display in a given area of life. The sample size (N) represents the number of respondents who reported being present in that area of life.

Area of Life	Proportion of Respondents Who Encountered Difficulty with At Least One Digital Display
School (N=151)	98.0% (148)
Work/Volunteering (N=215)	84.7% (182)
Recreation/Hobbies (N=208)	88.5% (184)
Social Media (N=321)	92.8% (298)
Gaming & eSports (N=241)	91.3% (220)
Online Shopping/Banking (N=249)	85.1% (212)
In-Person Shopping/Banking (N=286)	98.3% (281)
Driving/Motorized Vehicles (N=149)	95.3% (142)
Travelling (N=255)	60.4% (154)

“Desktops/laptops” were the most frequently reported digital displays that individuals with CVD frequently encountered difficulties, followed by either “cell phones” or “tablets.” It is uncertain why these displays were most frequently selected; it may be due to the frequency with which they are used in the respondents’ daily lives or availability. This could account for the lower frequency found in the travelling category.

7.11.4.1 Association in Displays Selected and Demographic Factors (Sex and Age Group)

There were generally similar distributions in the displays that were selected with some variations when comparing between sexes and age groups. Table 7.21 shows the areas of life where displays showed significant associations with either demographic factor. Displays showed significant associations with age group, but not sex. This is most likely due to the greater use of displays by youth than adults. The primary difference in displays was that youth reported more problems with tablets, and adults had more problems with cell phones, which could be due to the difference in display exposure.

Table 7.21. The significant associations of the displays selected by respondents with a demographic factor.

Area of Life	Demographic Factor	Pearson's chi-square test of independence (χ^2)		
		Value	Degrees of Freedom (df)	Asymptotic Significance (2-sided)
Work/Volunteering	Age Group	12.3	3	(0.0065)
Recreation/Hobbies	Age Group	18.5	5	(0.0023)
Gaming & eSports	Age Group	29.3	6	(< 0.0001)
Online Shopping/Banking	Age Group	18.7	3	(0.0003)

7.11.4.2 Frequency of Respondents Who Experienced Difficulties with More than One Display

We also wanted to explore whether most people with CVD experience difficulties with multiple digital displays across different areas of life. This is of interest to us because this can show whether the challenges that they face are only encountered when using a particular display or if it is universal across all displays. If the results show that the majority of respondents experience difficulties with more than one display, then this means that their defect affects their interaction with displays, in general. It could also provide information as to how many digital devices are owned or used by individuals with CVD.

More than 50% of the people with CVD who selected a display, reported frequently encountering challenges with two or more displays in most areas of life (Table 7.16). The exception was “in-person shopping/banking” where only 25% had challenges with more than one display. This could be due to the number of different digital displays used for conveying in the brick-and-mortar stores is smaller compared with other areas of life, the colour coding used to convey information in the displays is limited, or there are sufficient non-colour reductant clues. Since more than half of the respondents reported difficulties with multiple displays, this does suggest that software developers need to focus more of their efforts on

enhancing the user interface design across all displays, as it is not an issue that only arises in one individual display.

Chapter 8

Results – Modifications

This chapter describes the changes and modifications that individuals with CVD have implemented to their digital displays to assist them in making colour-related judgments. In addition to the modifications, we also asked them to rate the level of effectiveness and select the displays on which they modified or viewed with coloured filters, tinted spectacles or contact lenses.

8.1 Rankings of Effectiveness of Modifications: Sex Differences

Respondents were initially asked about the types of changes or modifications that they made to their digital displays to assist them with colour-related judgments. Of the 381 respondents who completed the survey, 64.6% of the respondents indicated that they made changes or modifications to their displays (246), 35.2% did not try any modifications (134), and 0.3% did not respond (1). Of the respondents who implemented changes or modifications, 26.4% were male youth (65), 42.3% were male adults (104), 14.6% were female youth (36), and 16.7% were female adults (41). There were 75.6% of male youth, 53.6% of male adults, 83.7% of female youth, and 70.7% of female adults who completed the survey made changes or implemented modifications to their displays.

Of the 246 respondents who selected modifications, 220 ranked at least a little effectiveness with one of these aids. There were 70.5% males (155) males and 29.5% females (65), which means that 91.7% of males and 84.4% of females who implemented a modification ranked at least one of them as effective to some extent. Figure 8.1 shows the distribution of males and females who ranked at least a little across the modifications. The modifications that males most frequently found effective were "adjusting the display's colour settings to enhance colour contrast based on your own experience using a trial-and-error procedure, such as changing to a darker background for enhanced contrast" (51.0%; 79), "using colour contrast enhancing apps, such as Windows Colour Filters that enhances colour contrast for individuals with colour vision deficiencies" (45.2%; 70), and "using cell phone apps that identify the colours of objects on other digital displays" (27.7%; 43). For females, the aids that were most frequently reported as effective were "adjusting the displays' colour settings to enhanced colour contrast based on trial-and-error procedure" (52.3%; 34), "using cell phone apps that identify the colours of objects on other digital displays" (41.5%; 27), and "using colour contrast enhancing apps, such as Windows Colour Filters that enhances colour contrast for individuals with colour vision deficiencies" (38.5%; 25). Although there were some variations in the distribution, there was no significant association between the seven

modifications based on sex ($\chi^2 = 6.3$, $df = 6$, $p = 0.39$). The "other changes or modifications" was omitted from this analysis because it did not meet the inclusion criteria that all expected values must be greater than 1.

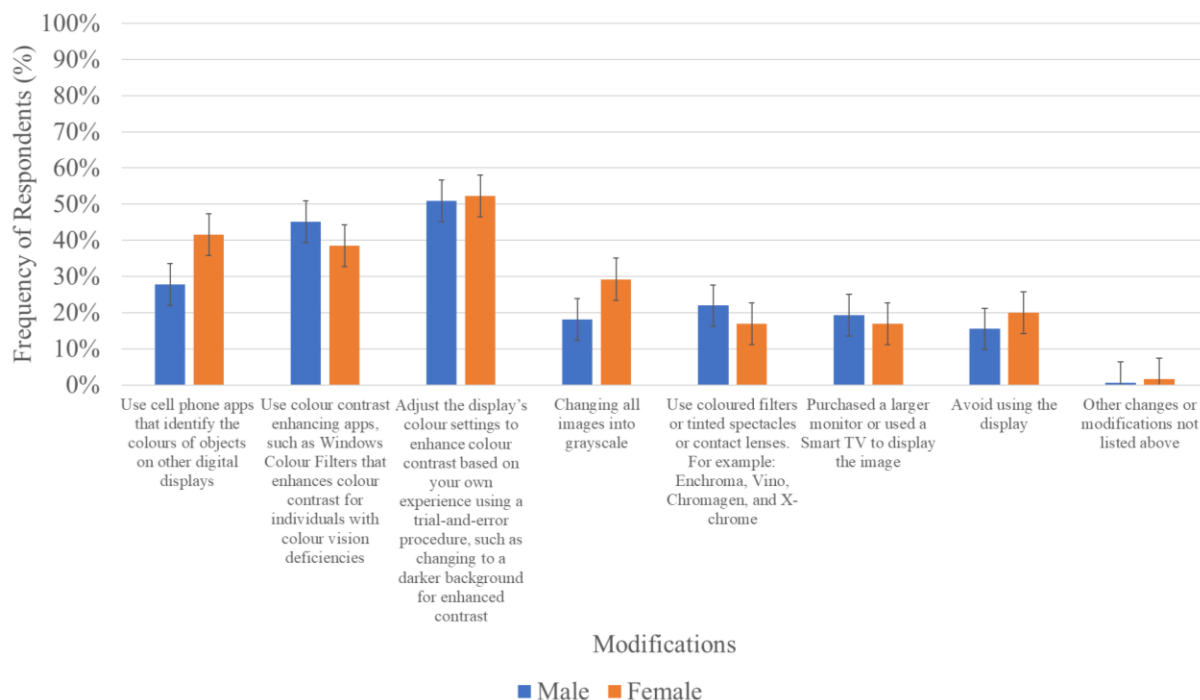
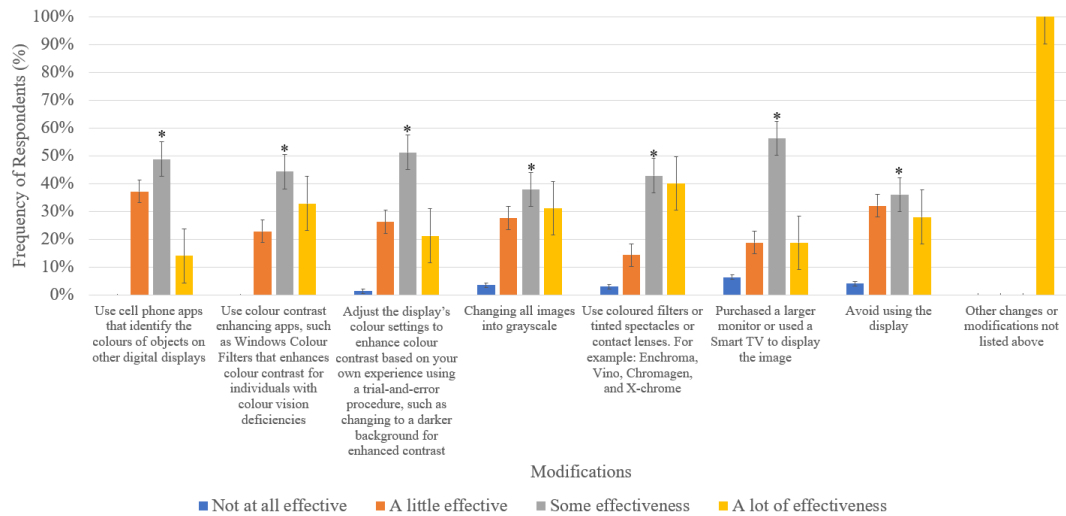


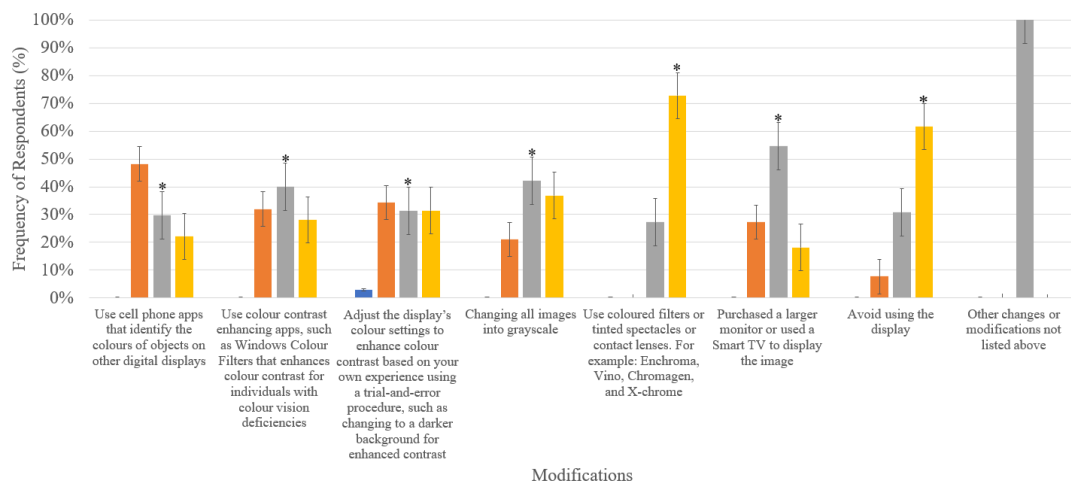
Figure 8.1. The frequency of male and female respondents who ranked at least a little effectiveness in modifications (N=220). The "other modifications" include the responses of one male and one female. The error bars represent standard error.

Figure 8.2 shows the distribution of the rankings, including "not at all effective," of (A) males and (B) females for the different modifications (N=222). There were 7 respondents (5 male adults, 1 male youth and 1 female youth) who ranked a modification as ineffective, which consisted of 2 respondents (1 male youth and 1 male adult) who ranked "not at all effective" for one modification and did not rank any other modifications and 5 respondents who ranked ineffectiveness for one modification but ranked at least a little effectiveness for one or more aids. Most of the aids were ranked as ineffective by at least one respondent except for "using cell phone apps," "using colour contrast enhancing apps," and "other," where no one ranked them as ineffective. "Adjusting the displays" was the only modification that both sexes (1 male and 1 female) reported as ineffective. There were originally 13 respondents included in the "other" category, but after reorganizing because their responses fell into one of the other modifications, these responses were reclassified, and only 2 remained. One was a male adult who wrote, "knowing which colour is wrong and how to interpret it" as having "a lot of effectiveness." The other was a female adult

who "asked friends to read it," which she found had "some effectiveness." Because there were only 2 respondents, no median ranking was determined. The median ranking for males was "some effectiveness" for all modifications. There was also a similar distribution across most modifications for females ("some effectiveness"), except for "use coloured filters or tinted spectacles or contact lenses" and "avoid using the display," which had a median ranking of "a lot of effectiveness." These differences were insignificant across the seven aids based on the Mann-Whitney for each task ($p \geq 0.035$; adjusted p-value for significance = 0.0071).



(A) Male



(B) Female

Figure 8.2. The distribution of effectiveness of modifications ranked by (A) male (N=157) and (B) female (N=65) when helping with making colour-related judgments. The percentages are based on respondents who ranked the difficulty of each particular modification. One male and one female listed "other" modifications, which account for 100% of the effectiveness ranking. The asterisks (*) identify the median ranking for each modification. The error bars represent standard error.

8.2 Rankings of Effectiveness of Modifications: Differences in Age Group

Of the 220 respondents who ranked the effectiveness of the modification, 41.4% were youth (91) and 58.6% were adults (129). There were 90.1% of youth and 89.0% of adults who modified their display and ranked an aid as at least a little effective. Figure 8.3 shows the distributions of the youth and adult respondents that experienced at least a little effectiveness across the aids. Both age groups most frequently "adjusted the display's colour settings to enhanced colour contrast based on your own

experience using a trial-and-error procedure" (youth: 49.5%; 45; adult: 52.7%; 68), "used colour contrast enhancing apps" (youth: 48.4%; 44; adult: 39.5%; 51), and "used cell phone apps that identify the colours of objects on other digital displays" (youth: 36.3%, 33; adult: 28.7%, 37). There were relatively similar distributions between both age groups. There was no significant association between the seven aids and age groups ($\chi^2 = 4.5$, $df = 6$, $p = 0.61$). The "other" category was removed from this analysis for reasons similar to those mentioned for sex.

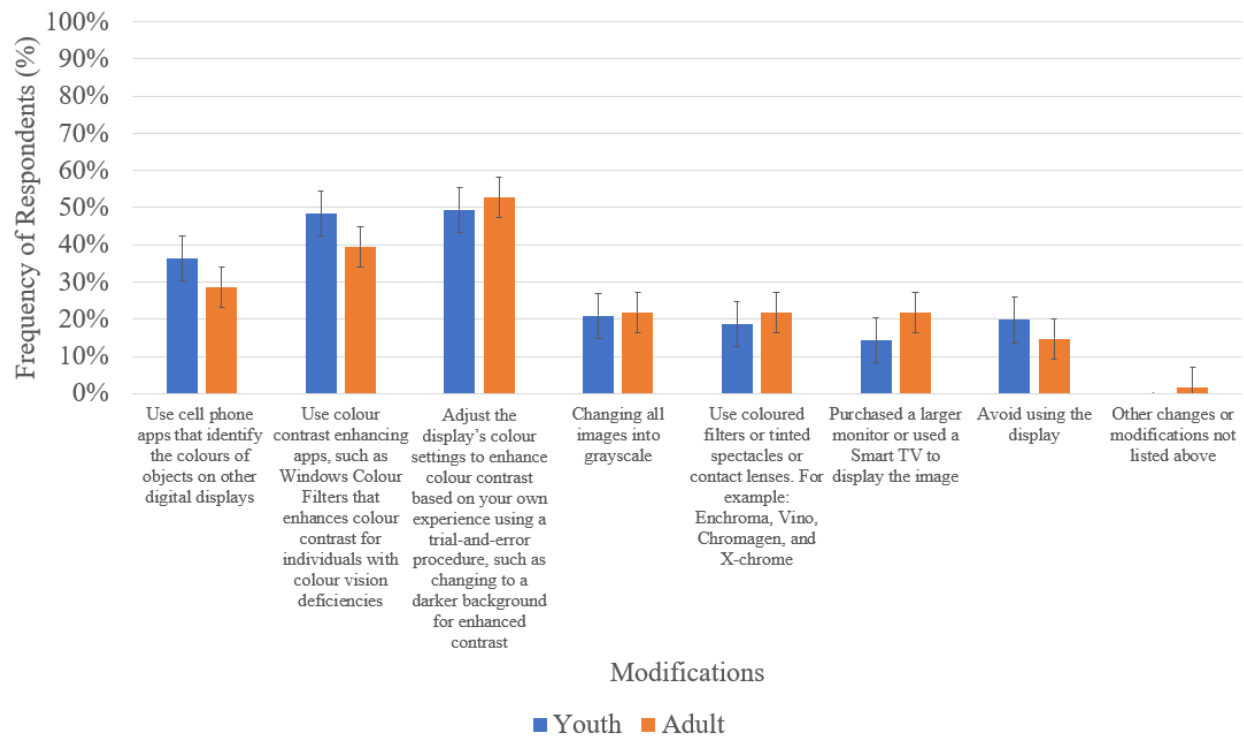


Figure 8.3. The frequency of youth and adult respondents who ranked at least a little effectiveness in modifications (N=220). The "other modifications" include the responses of no youth and 2 adults. The error bars represent standard error.

Figure 8.4 shows the distribution of the rankings (including "not at all effective") of (A) youth and (B) adults. For youth, the median ranking for most modifications was "some effectiveness," except for "use coloured filters or tinted spectacles or contact lenses," which had a median ranking of "a lot of effectiveness." There were no youth respondents who implemented any "other modifications." For the adults, there was a similar distribution in the rankings as the youth ("some effectiveness"). No median ranking is shown because only two adults were in the "other" category. A relatively similar trend was found by 7 respondents who ranked ineffectiveness for a modification as mentioned in sex, except for "adjusting the display" which was found to be ineffective by 2 youth respondents and no adults. The "other" category responses are the two previously mentioned adults. Because there are only 2 subjects, it

was not included in this analysis. There was a significant difference in the rankings for "use coloured filters or tinted spectacles or contact lenses" ($U = 102.5$, $p < 0.001$) based on age groups but not for the other aids ($p \geq 0.18$; adjusted p-value for significance = 0.0071).

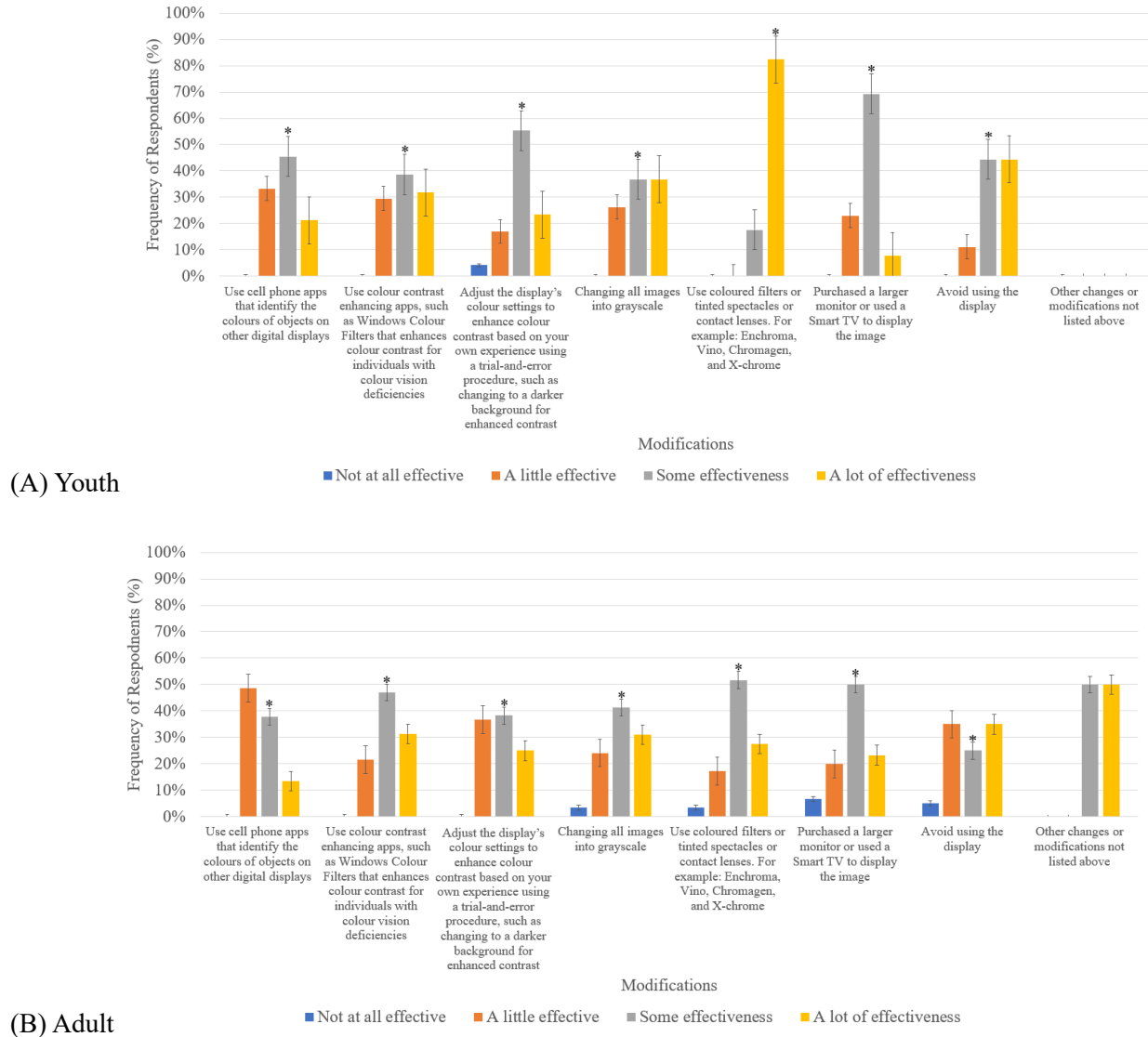


Figure 8.4. The distribution of effectiveness of modifications ranked by (A) youth (N=92) and (B) adult (N=130) respondents when helping with making colour-related judgments. The percentages are based on respondents who ranked the difficulty of each particular modification. No youth respondents reported implementing any "other modifications." The asterisks (*) identify the median ranking for each modification. The error bars represent standard error.

8.3 Rankings of Effectiveness of Modifications: Differences in Severity

Respondents were pooled together to examine the effect of severity on the effectiveness rankings, including those who ranked ineffectiveness. Table 8.1 shows the results from the Kruskal-Wallis test for the rankings of the seven modifications based on severity. None of the seven modifications showed significant differences in the rankings as a function of severity within an aid ($p \geq 0.039$; adjusted p-value for significance = 0.0071). The "other" category was excluded from this analysis since it was omitted in the Mann-Whitney analyses for sex and age group.

Table 8.1. The results of the Kruskal-Wallis H test of the effectiveness rankings of modifications based on severity. The p-values in parentheses are significantly different based on the adjusted p-value with the Bonferroni correction of $p = 0.0071$ for significance for asymptotic significance and $p = 0.05$ for pairwise comparisons.

Modification	Total N	Test Statistics	Degrees of Freedom (df)	Asymptotic Significance	Pairwise Comparisons (the Dunn test with Bonferroni correction)	
					Severity Pair	Adjusted Significance
Use cell phone apps that identify the colours of objects on other digital displays	70	10.1	4	0.039	N/A	
Use coloured filters or tinted spectacles, or contact lenses. For example, EnChroma, Vino, Chromagen, and X-chrome	46	6.2	4	0.19	N/A	
Use colour contrast-enhancing apps, such as Windows Colour Filters, to enhance colour contrast for individuals with colour vision deficiencies	95	6.2	4	0.19	N/A	
Adjust the display's colour settings to enhance colour contrast based on your own experience using a trial-and-error procedure, such as changing to a darker background for enhanced contrast	115	5.0	4	0.28	N/A	
Changing all images into grayscale	48	4.4	4	0.35	N/A	
Avoid using the display	38	4.0	4	0.41	N/A	
Purchased a larger monitor or used a Smart TV to display the image	43	1.3	4	0.86	N/A	

Figure 8.5 shows the distribution of rankings as a function of severity for adjusting the display's colour settings to enhance colour contrast based on your experience using a trial-and-error procedure ($p = 0.28$) as an example. The median ranking of most severity levels was "some effectiveness," except for "less than once per month," which had a median ranking of "a lot of effectiveness," and "I avoid colour-related tasks," which had a median ranking of "a little effective."

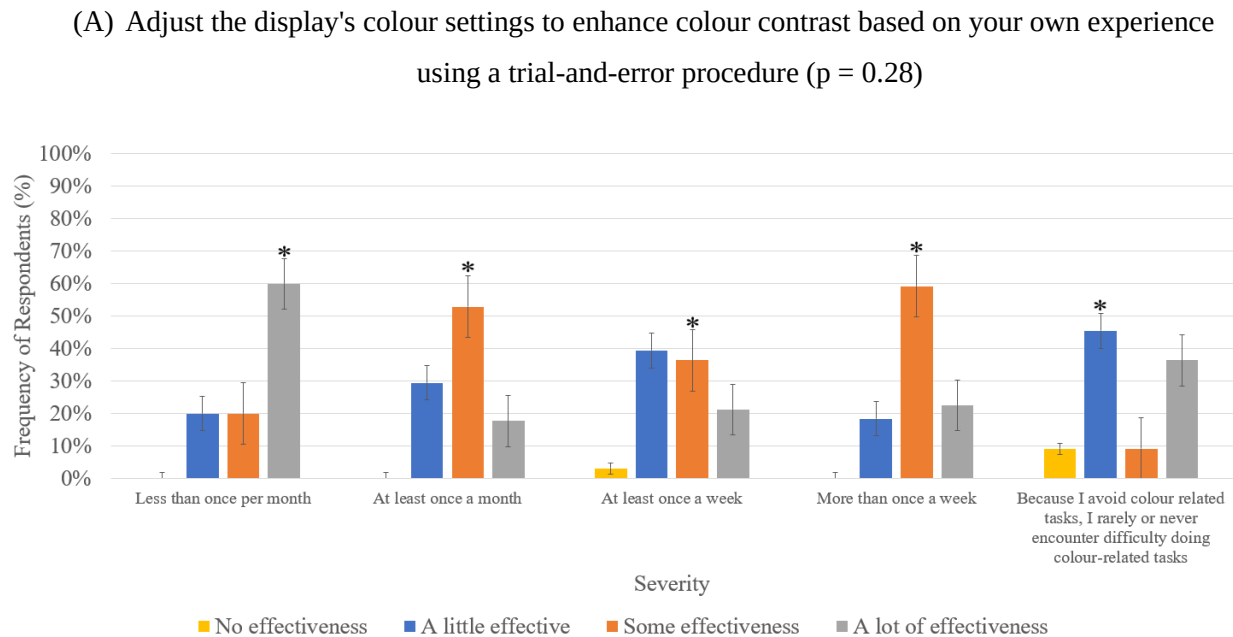


Figure 8.5. The distribution of ranked effectiveness by all respondents with (A) adjust the display's colour settings to enhance colour contrast based on your experience using a trial-and-error procedure. The percentages are based on respondents who ranked the difficulty for each severity level. The asterisks (*) identify the median ranking for each coloured task. The error bars represent standard error.

8.4 Digital Displays that Respondents Modified or Viewed with Coloured Filters, Tinted Spectacles or Contact Lenses

Of the 241 respondents who reported modifying a digital display, 68.9% were males (166) and 31.1% were females (75). For age groups, 41.5% were youth (100) and 58.5% were adults (141). There were 220 respondents who ranked the effectiveness of an aid, which was less than the number of respondents who selected a display. This means that 98.2% of males, 97.4% of females, 99.0% of youth, and 97.2% of adults selected at least one display that they modified or viewed with coloured filters. Figure 8.6 shows

the distribution of the devices selected based on (A) sex and (B) age group. There were originally 14 respondents who selected "other" displays, but only 11 respondents remained after reclassifying their responses to previously listed devices. All of these respondents (10 male adults and 1 female adult) reported implementing aids onto their "television/video gaming consoles." No youth respondent implemented modifications onto "other digital displays." There were relatively similar distributions in the displays selected by both sexes. However, the youth were more likely to modify tablets than adults, and adults were more likely to modify cell phones than the youth. The distributions for males and females were not significantly different ($\chi^2 = 6.0$, $df = 6$, $p = 0.42$), but the difference in the youth and adult distributions was significant ($\chi^2 = 24.6$, $df = 6$, $p = 0.004$).

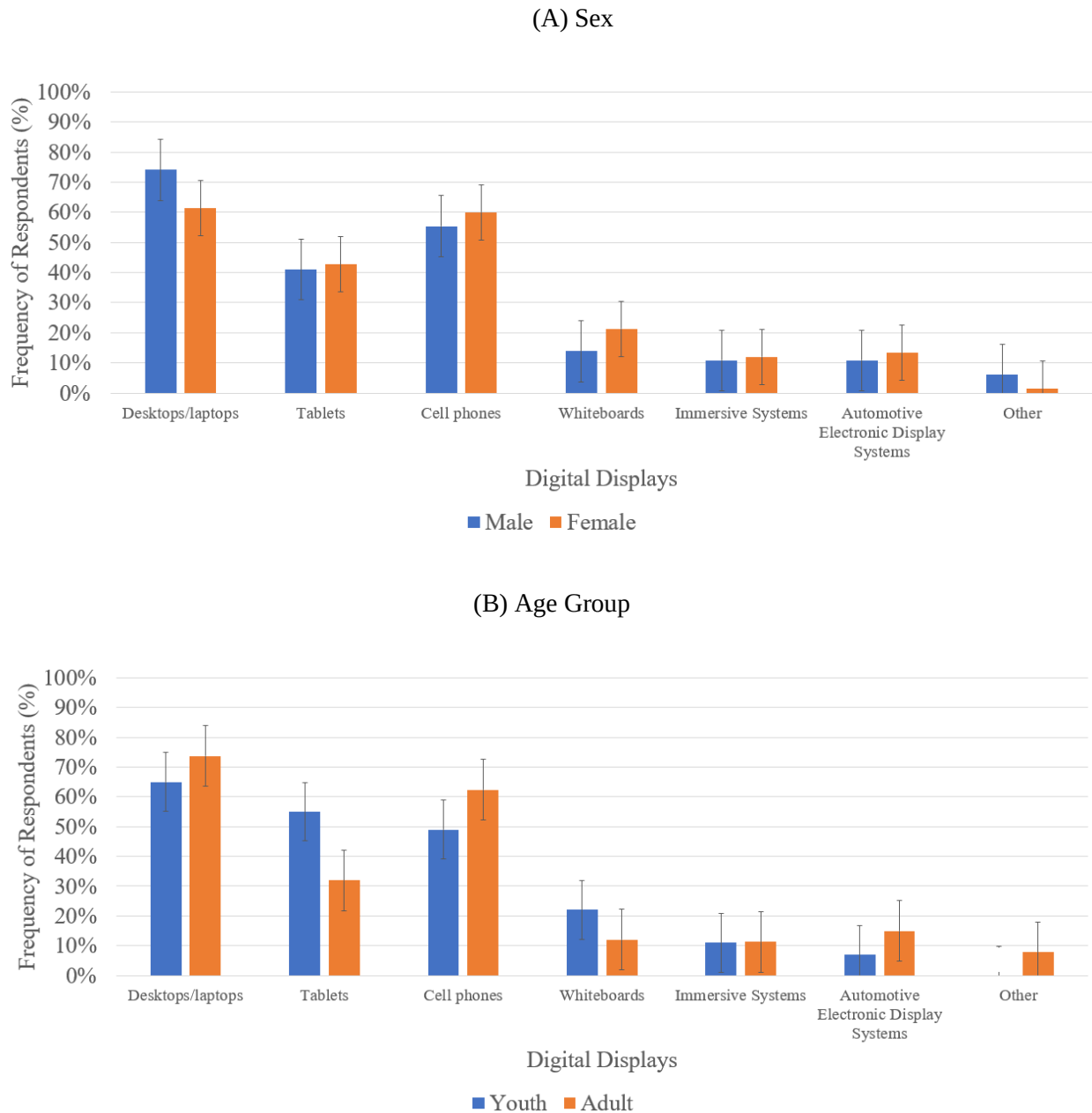


Figure 8.6. The distribution of digital displays that respondents modified or viewed with coloured filters, tinted spectacles or contact lenses based on (A) sex and (B) age group (N=241). The "other displays" included the responses of 10 male adults and one female adult. The error bars represent standard error.

8.5 Chapter Discussion

8.5.1 Prevalence of Effectiveness Experienced by People with CVD Across Various Modifications

Another major objective of this study was to analyze any modifications that individuals with CVD implemented to their displays to help with their colour discrimination. This section began by examining the prevalence of the types of modifications by people with CVD and their effectiveness. This interested us because it could give a better idea of whether it is worth exploring modifications to enhance their digital experiences. If it is found that the majority of individuals with CVD do not find these aids to be at least a little effective, then it shows software developers that other approaches are required. The data also indicates whether available aids have even been used. Low frequency of use could suggest that the users were unaware of the modifications or that they heard from other sources that modifications do not work. As mentioned in the Introduction (section 1.5), there are two types of assistive technologies: active (e.g. recolouring, edge enhancement, and pattern superposition) and passive (e.g. coloured filters, tinted glasses and contact lenses).

In this study, 64.6% of the respondents reported making changes or modifying their displays. Both active and passive techniques were tried, but the active modifications were tried more often. The three most frequently tried modifications were trial-and-error adjustments, colour enhancing applications or programs that came with the operating system or could be installed, and cell phones that take a picture of an object and identify the colours. The interesting finding was that despite the availability of colour-enhancing programs and applications, "the trial-and-error procedure" was the most popular. We are uncertain as to the reason for this result, but possible explanations include low cost, the ability to adjust displays to their preferred settings, and limited knowledge of the other aids that are available in the market. The frequency of use did not vary with either sex or age. Although 65% of the 381 respondents tried at least one aid, 35% did not. We are uncertain as to why they did not try a modification. In the past 10 years, there have been some new advancements in the development of assistive technologies, such as Google Glasses and optical see-through head-mounted displays. These aids have shown promise in assisting CVD users with colour-related tasks (Melillo et al., 2017), but they did not appear to be in use at the time of the survey.

8.5.2 Effectiveness of Modifications on Digital Displays

Of the individuals who tried a modification, approximately 90% reported that they were at least a little effective. However, less than 3% reported that at least one modification was ineffective and only 25% rated the modifications highly, with most of the median rankings in between. Although the number of respondents who thought at least one of the aids was ineffective was small, their ratings may be useful to software developers in helping to improve existing techniques or develop new ones.

The finding that highly effective ratings were uncommon suggests that there is more work to do to improve accessibility for individuals with CVD; however, the result could also indicate that the users' expectations are unrealistic. That is, the users may expect to perceive colours they have never perceived before, whereas the software improves discrimination by moving the colours off the lines of confusion, which helps the visibility of colour differences but distorts the colours within the scene (Hung et al., 2020). The finding that most respondents found the modifications to be no more than "somewhat effective" is consistent with Chaparro & Chaparro's conclusion that people with CVD still experience challenges even with the presence of these tools, and their needs should be accounted for in the design of software so that it is accessible to all users (Chaparro & Chaparro, 2017). Although it is likely a combination of these two factors, one of the results in our study that reinforces the idea that more work is required for the most frequent modification, "trial-and-error," where slightly over half of those respondents who tried modifications answered this question and used that technique. This result also suggests that any new enhancement technique may require some flexibility for the individual to adjust the settings to their preference.

There was no statistical difference between sex or age group regarding the frequencies of using each modification. Nevertheless, there was a difference in the effectiveness rating for the passive devices. Although the difference did not reach statistical significance using a conservative decision approach, females rated filters more effective than males. When examining these devices by age group, the youth found the passive devices more effective than adults, which did reach statistical significance. The main contributor to this difference was the young females, where 100% of those who ranked the effectiveness of the "coloured filters" ranked them as highly effective, as opposed to 72.7% of young males who did. Compared to the adults, 25% of male adults and 40% of adult females ranked them highly effective. The difference in ranking between age groups provides software developers with more information on the variation in experience in the use of coloured filters between youth and adults. The difference in ranking the effectiveness of coloured filters could reflect the larger debate on whether passive solutions are effective in enhancing overall colour vision. However, there are still some studies that suggest that

coloured filters do have some advantages (Salih et al., 2020; Bardeci & Lagori, 2021; Alkhudairy & Al Shalman, 2022). Salih et al. (2020) showed that both tinted contact lenses (X-Chrom and ChromaGen) and tinted glasses improved the observation and discrimination of colours under some conditions, but it was not comparable to colour normals. I am uncertain why the youth found the passive solutions more effective than adults. Part of the explanation could be an interaction between the youth's use of the displays and filters. A study by Twenge & Martin (2020) found that boys tend to spend more of their time gaming and on electronics overall, whereas girls spend the majority of their time on computers, smartphones, texting, social media, and online browsing (Twenge & Martin, 2020). The colours used in these activities may be limited in number, consistently displayed and more likely to be distinguished when wearing coloured filters.

Based on severity, there was no statistical difference in the effectiveness rankings of any of the modifications, which suggests that the effectiveness is more impacted by the user interface design than the severity of the defect. This can give software developers a better direction of where to focus more of their efforts when designing aids for individuals with CVD, such as colour contrast of backgrounds (chapter 4), colour schemes, and accessibility.

8.5.3 Digital Displays that Respondents Modified or Viewed with Coloured Filters

The modifications were applied to all devices listed in the survey. Desktops/laptops, tablets and cell phones were the most frequently listed devices. This is likely a result of these devices being ubiquitous in society. The frequencies were similar for males and females. However, the youth group was less likely to modify desktops/laptops and cell phones, whereas adults were less likely to modify tablets. These differences in displays were significant between age groups. Whether this is due to differences in usage of these devices or the content on these devices is different for youth and adults is uncertain.

This study shows that modifications are being implemented to a variety of different digital displays. Regardless of which displays are being modified, the results show that more work needs to be done to enhance the accessibility, adaptability, and satisfaction of people with CVD as digital users. Software developers need to focus more on consulting with their digital users regarding their needs and wants to ensure optimal experience.

Chapter 9

Results - Additional Information

This chapter discusses the results of two open-ended questions where respondents were asked to list the most frustrating/difficult, along with any additional comments they would like to make regarding their experiences with digital displays and modifications.

9.1 Most Frustrating or Difficult Colour-Related Tasks to Carry Out When Using Digital Displays

Respondents were asked to list up to 5 colour-related tasks that they found most frustrating or difficult when using digital displays. There was a total of 745 entries submitted. Out of the 381 respondents who completed the survey, 87.4% listed at least one task as frustrating/difficult (333), 8.7% left the question blank (33), and 3.9% provided unapplicable/invalid responses (15), such as "none," "a," "don't know," "cannot recall," "no comment," "N/A," and "I don't know as I never really thought about it." The respondents consisted of 72.1% males (240) and 27.9% females (93). The breakdown for age was 34.8% youth (116) and 65.2% adults (217). Tasks were classified into four categories:

1. "previously mentioned" includes tasks that were previously mentioned in the survey and respondents are re-emphasizing their frustrations (e.g. "reading coloured text on different coloured backgrounds due to low contrast," "colour-coded maps," "editing photos," and "playing games");
2. "other digital tasks" where respondents referred to a task being performed on digital displays, online agencies, or the assumption that the task can only be performed using digital displays (e.g. "determining if a button is clickable," "making PowerPoint presentations," and "viewing weather reports");
3. "non-digital tasks" include tasks where there was no specification or the assumption cannot be made on whether the task is performed using digital displays (e.g. "reading restaurant menus," "enjoying nature," and "asking for assistance"); and
4. "vague/uninterruptable" was where there was uncertainty as to the task being referred, so we could not make any inferences on their behalf (e.g., "seeing certain things," "understanding," and "all/everything").

There were several "vague/uninterruptable" responses that were not further analyzed. These responses made up 10.8% of males and 15.1% of females who reported a frustrating task. Whereas for age group, it consisted of 15.5% of youth and 10.1% of adults. Some respondents included answers that could be applied to multiple categories, such as "multi-coloured active action games and fast-moving flashing ads," which were categorized into "games" and "advertisements." There were also respondents who included several responses that referred to one similar task, so their responses were counted only once. For example, "video games" and "computer games" were both referencing "gaming."

Table 9.1 shows the distribution of the five most frequently reported "previously mentioned," "other digital," and "non-digital" tasks based on sex and age group. The tasks that respondents re-emphasized as having the most frustrations/difficulties were "reading coloured text/numbers on different coloured backgrounds due to low contrast" and "identifying, distinguishing, or differentiating colours." Contrast refers to differences in both colour and luminance between target and background. For the "other digital" tasks, respondents experienced the most difficulty with "determining whether buttons are clickable/known where to tap." Meanwhile, for "non-digital" tasks, the most frequently reported tasks were "enjoying nature" by males and adults and "identifying and finding colour-coded items" by females and youth. Since there were no major differences in the distribution of the tasks listed between sexes and age groups, there was no need to break the data down further. The majority of the respondents just re-emphasized their frustrations/difficulties with tasks that were already mentioned in the survey. This included the responses of 220 (91.7%) males who listed at least one task in the 25 "previously mentioned" categories, 83 (89.2%) females in 23 categories, 103 (88.8%) youth in 22 major categories, and 200 (92.2%) adults in 21 categories.

Table 9.1. The most frustrating or difficult tasks that respondents reported performing based on sex and age group. Tasks were categorized into "previously mentioned" referring to tasks that have been already mentioned in the survey, "other digital" referring to tasks using digital displays or online agencies, and "non-digital" tasks. The percentages were based on the number of respondents in each demographic.

Demographic Factor	Previously Mentioned Tasks	Other Digital Tasks	Non-Digital Tasks
Male (N=240)	1. <u>Reading coloured text/numbers on different coloured backgrounds due to low contrast</u> (45.4%; 109) 2. <u>Identifying, differentiating or distinguishing colours</u> (30.0%; 72) 3. <u>Gaming</u> (16.7%; 40) 4. <u>Maps</u> (16.3%; 39) 5. <u>Graphs/Shopping online</u> (7.9%; 19)	1. <u>Buttons</u> – pressing a display button based on colour description or finding where to click/tap (2.1%; 5) 2. <u>Links</u> – cannot see HTML links (0.8%; 2) 3. <u>PowerPoint presentations</u> (0.8%; 2) 4. <u>LEDs</u> – identifying colours and reading LED signs (0.8%; 2) 5. <u>Weather reports</u> (0.8%; 2)	1. <u>Nature</u> (2.1%; 5) 2. <u>Items</u> (1.3%; 3) 3. <u>Assistance</u> – having to confirm with another person (0.8%; 2) 4. <u>Colour blind tests</u> – passing the Ishihara plate tests (0.8%; 2) 5. <u>Focusing</u> (0.8%; 2)
Female (N=93)	1. <u>Reading coloured text/numbers on different coloured backgrounds due to low contrast</u> (46.2%; 43) 2. <u>Identifying, differentiating or distinguishing colours</u> (25.8%; 24) 3. <u>Maps</u> (16.1%; 15) 4. <u>Difficulties with adjusting and interacting with certain components of displays</u> (e.g. monitors, screen, glare/colour, and adjusting brightness) (9.7%; 9) 5. <u>Photos</u> (8.6%; 8)	1. <u>Buttons</u> – determining which is the right button and where to tap (3.2%; 3) Remaining tasks have one respondent (1.1%) each: • Calendar • Dashboards • Flashing words • LEDs – digit LED • Posts – informational posts with bad colour combinations • PowerPoint presentations • Texting • Typing	1. <u>Items</u> (4.3%; 4) 2. <u>Menus</u> (3.2%; 3) 3. <u>Blurriness</u> (2.2%; 2) 4. <u>Roads</u> (2.2%; 2) Remaining tasks have one respondent (1.1%) each: • Assistance – unable to ask if no one is around • Billboards • Colouring • Correlation between things • Eyes – seeing what eye colour people have • Focusing • Line – if there's a line behind me, I get anxious • Moving objects • Playing with friends • Produce – colour of produce • Rainbow – making a rainbow • Want – not being able to do what I want

Youth (N=116)	1. <u>Reading coloured text/numbers on different coloured backgrounds due to low contrast</u> (44.0%; 51) 2. <u>Identifying, differentiating or distinguishing colours</u> (21.6%; 25) 3. <u>Maps</u> (14.7%; 17) 4. <u>Gaming</u> (12.1%; 14) 5. <u>Images and graphics/Photos/School</u> (6.9%; 8)	1. <u>Buttons</u> – determining the correct button to click (2.6%; 3) 2. <u>Typing</u> (1.7%; 2) Remaining tasks have one respondent (0.9%) each: • Calendar • Coding • Dashboards • Emails • Flashing words • Infographics • LEDs – digit LED • Links • PowerPoint presentations • Printing – identifying colour on colour printing • Texting • Websites – creating a website layout	1. <u>Items</u> (2.6%; 3) 2. <u>Colouring</u> (1.7%; 2) 3. <u>Focusing</u> (1.7%; 2) 4. <u>Menus</u> (1.7%; 2) Remaining tasks have one respondent (0.9%) each: • Billboards • Blurriness • Characters • Cook • Eyes – my eyes both me with the colours • In-store – looking at non-digital logos, charts or discount diagrams in stores • Moving objects • People • Playing with friends • Produce • Products
Adult (N=217)	1. <u>Reading coloured text/numbers on different coloured backgrounds due to low contrast</u> (49.8%; 108) 2. <u>Identifying, differentiating or distinguishing colours</u> (29.0%; 63) 3. <u>Maps</u> (16.6%; 36) 4. <u>Gaming</u> (14.7%; 32) 5. <u>Shopping Online</u> (8.3%; 18)	1. <u>Buttons</u> – pressing a display button based on colour description or finding where to click (2.3%; 5) 2. <u>PowerPoint presentations</u> (0.9%; 2) 3. <u>LEDs</u> – identifying colours and reading LED signs (0.9%; 2) 4. <u>Weather reports</u> (0.9%; 2) Remaining responses have one respondent (0.5%) each: • Icon • Links – cannot see HTML links • Moving objects • Painting • Pop-up banners • Posts – informational posts with bad colour combinations	1. <u>Nature</u> (2.3%; 5) 2. <u>Items</u> (1.8%; 4) 3. <u>Assistance</u> – having to confirm with another person (1.4%; 3) 4. <u>Blurriness/Colour blind tests</u> – passing the Ishihara plate test (0.9%; 2)

9.2 Additional Digital Display Challenges and Modifications

In this section, respondents were given the opportunity to include anything else that they would like us to know regarding their challenges and modifications with digital displays. There were 180 entries. Of 381 respondents, 25.7% responded to this question (98), 1.0% provided more of a feedback response (4), 52.8% left the question blank (201), and 20.5% provided unapplicable/invalid responses (78). The unapplicable/invalid responses included "none," "nothing," "I don't have any other comments to add," "N/A," "all good," "there is nothing I can think of right now," "ok," "no comments," and highlighted difficulties with "breathing due to their nostrils." Of the 98 respondents remaining, 67.3% were males (66), 32.7% were females (32), 36.7% were youth (36), and 63.3% were adults (62).

9.2.1 Digital Display Challenges

Responses regarding their experiences with digital displays and modifications were categorized into "challenges" and "modifications." The difference between "challenges" and "frustrations" is that "challenges" focus more on difficulties involving the skillset needed to perform a task, whereas "frustrations" focus more on obstacles that prevent a task from being performed. However, both discuss the experiences of people with CVD with using or gathering information on digital displays. "Modifications" refer to aids that assist them with their colour discrimination. The responses were further classified into "previously mentioned," "other digital," "non-digital," and "vague/uninterruptable" as was previously done in the above section. A similar approach was also taken regarding responses including multiple tasks, multiple tasks referring to one similar task, and vague responses that were interruptible. There was a total of 64 respondents who were included in the "challenges" section, which consisted of 64.1% males (41), 35.9% females (23), 39.1% youth (25), and 60.9% adults (39). There were four "vague/uninterruptable" responses that were not further analyzed. These responses included 3.0% of males, 6.3% of females, and 6.5% of adults who reported at least one challenge. There were no "vague/uninterruptable" responses in the youth respondents.

Table 9.2 shows the distribution of the "previously mentioned," "other digital," and "non-digital" challenges based on sex and age group. The "previously mentioned tasks" that were most frequently reported were "reading letters/numbers on different coloured backgrounds due to low contrast," "identifying colours," and "troubles in identifying colours and finding targets/teammates in video games, such as Wordle, PubG, and Call of Duty." The primary "other digital" challenge was "accessibility of websites and apps" for males and adults, and "accommodation for disabilities" (e.g. "more variety of screens/electronic devices" and "more enhancements") for youth. Several "other digital" challenges were reported by one female each, which included "accommodations for disabilities," "emails," and "variability

in colours among displays." For "non-digital" challenges, "coping - just living with it and getting to know your colours" was the most frequently reported task by all males. The most frequent non-digital challenge for females was "curability – talk about defect being cured by ancient medicine in India." Since there were relatively similar challenges experienced between both sexes and age groups, no further analysis was needed.

Table 9.2. The challenges that respondents encountered when gathering information based on sex and age group. "Previously mentioned" means that their responses refer to challenges already mentioned in the survey. Challenges were categorized as "digital" when they used digital displays or online agencies or "non-digital" challenges. The percentages were based on the number of respondents in each demographic.

Demographic Factor	Previously Mentioned Challenges	Other Digital Challenges	Non-Digital Challenges
Male (N=41)	1. <u>Gaming</u> - troubles in identifying colours and finding targets/teammates in video games, such as Wordle, PubG, and Call of Duty (12.2%; 5) 2. <u>Reading coloured letters/numbers on different coloured backgrounds due to low contrast</u> (12.2%; 5) 3. <u>Identifying colours</u> (9.8%; 4) 4. <u>Work</u> – (e.g. Naval Rescue and IT) (7.3%; 3) 5. <u>Maps</u> (4.9%; 2)	1. <u>Accessibility of websites and apps</u> (4.9%; 2) 2. <u>Variability in colours among displays</u> – every display is different with colours, so it is hard to clarify with others that the actual colour is (4.9%; 2) Remaining challenges have 1 respondent (2.4%) each: • Accommodation for disabilities – more variety of screen/electronic devices • Clarity of monitor • Coping – issues with digital displays - I am trying to work with it • Lack of awareness – did not think to look for aids in electronics as I was unaware • Non-specific interface design • Variability in modifications – all use different technology, but would prefer a universal way to modify displays	1. <u>Coping</u> – just living with it and getting to know your colours (9.8%; 4) 2. <u>Difficult</u> (7.3%; 3) Remaining challenges have 1 respondent (2.4%) each: • Art • Assistance – have to ask for help with someone with normal colour vision • Confusion - when looking at things quickly • Consideration for disability – interest of people should be considered • Headaches • Light – the amount of ambient light affects my vision • Living in black and white - would be less complicated • Microwaves • Viewing – looking to get better viewing again

Female (N=23)	1. <u>Reading coloured letters/numbers on different coloured backgrounds due to low contrast</u> (21.7%; 5) 2. <u>Identifying colours</u> (8.7%; 2) 3. <u>Driving</u> (8.7%; 2) 4. <u>Photos</u> (4.3%; 1) 5. <u>Videos</u> (4.3%; 1)	1. <u>Accommodation for disabilities</u> - more enhancements (4.3%; 1) 2. <u>Emails</u> (4.3%; 1) 3. <u>Eyes</u> - hurts the eyes trying to figure out what is on the screen (4.3%; 1) 4. <u>Variability in colours among displays</u> - all displays are different and offer different colour spectrum (4.3%; 1)	1. <u>Curability</u> - talk about defect being cured by ancient medicine in India (13.0%; 3) 2. <u>Coping</u> - just living with it (8.7%; 2) 3. <u>Consideration for disabilities</u> - manufacturers keep colour issues in mind when making products (4.3%; 1) 4. <u>Cooking</u> (4.3%; 1) 5. <u>Hospitals</u> (4.3%; 1)
Youth (N=25)	1. <u>Reading coloured letters/numbers on different coloured backgrounds due to low contrast</u> (16.0%; 4) 2. <u>Identifying colours</u> (8.0%; 2) Remaining challenges have 1 respondent (4.0%) each: • Clothing • Colour matching tests • Graphs • Maps • Videos • Visibility of digital displays	1. <u>Accommodation for disabilities</u> - more variety of screens/electronic devices and more enhancements (8.0%; 2) 2. <u>Accessibility of websites</u> (4.0%; 1) 3. <u>Coping</u> - having issues with displays and trying to work with it (4.0%; 1) 4. <u>Variability in colours among displays</u> - all displays are different and offer different colour spectrum (4.0%; 1)	1. <u>Coping</u> - just living with it and getting to know your colours (12.0%; 3) 2. <u>Curability</u>- talk about defect being cured by ancient medicine in India (12.0%; 3) 3. <u>Consideration for disabilities</u> - consider people's interest, and manufacturers keep colour issues in mind when making products (8.0%; 2) 4. <u>Difficult</u> (8.0%; 2) 5. <u>Art/Cooking/Headaches</u> (4.0%; 1)
Adult (N=39)	1. <u>Reading coloured letters/numbers on different coloured backgrounds due to low contrast</u> (17.9%; 7) 2. <u>Gaming</u> - troubles in identifying colours and finding targets/teammates in video games, such as Wordle, PubG, and Call of Duty (12.8%; 5) 3. <u>Identifying colours</u> (10.3%; 4) 4. <u>Work</u> (e.g. Naval Rescue and IT) (7.7%; 3) 5. <u>Driving</u> (5.1%; 2)	1. <u>Accessibility of websites and apps</u> (5.1%; 2) 2. <u>Variability in colours among displays</u> - every display is different with colours, so it is hard to clarify with others that the actual colour is (5.1%; 2) Remaining challenges have 1 respondent (2.6%) each: • Clarity of monitor • Emails • Eyes - hurts the eyes trying to figure out what is on the screen • Lack of awareness - did not think to look for aids in electronics as I was unaware • Microwaves • Variability in modifications - all use different technology, but would prefer a universal way to modify displays • Non-specific interface design	1. <u>Coping</u> - just living with it (7.7%; 3) Remaining challenges have 1 respondent (2.6%) each: • Assistance - have to ask for assistance with someone with normal colour vision • Confusion - when looking at things quickly • Difficult • Hospitals • Light - the amount of ambient light affects my vision • Living in black and white - would be less complicated • Viewing - looking to get better viewing again

9.2.2 Digital Display Modifications

A total of 34 respondents submitted additional comments about modifications that they implemented to help them interpret the digital displays that were not addressed previously. This group consisted of 73.5% males (25), 26.5% females (9), 32.4% youth (11), and 67.6% adult (23). The aids were categorized as "previously mentioned," "other digital," and "non-digital" as listed in Table 9.3. There were no "vague/uninterruptable" modifications. "Adjust display's settings" was the most frequently reported "previously mentioned" modification, followed by "colour contrast enhancing apps" for males and adults and "avoid using displays" for females and youth. "Adjust display's settings" and "avoid using displays" were tied in terms of the frequency of being reported among youth. For "other digital" modifications, "asking for assistance in the understanding of digital displays" was reported by one male adult, "making aids better than currently available by adding some features for CVD" by a male youth, and "adjusting the angle and distance of displays" by one female adult. For "non-digital" modifications, "adjusting the distance by moving it closer, further or at an angle" was most frequently reported response by 2 male adults and 1 female youth, "coping" (e.g. "just living with it") reported by one female youth, and "making sure to take breaks every 15 minutes or so" by a male adult. As both sexes and age groups reported similar modifications, there was no need to perform further analysis. The results from this question further confirmed findings in previous survey sections. For instance, in both this and the other "modifications" section (chapter 8), "adjusting the display's settings" was the most frequently reported modification by most respondents.

Table 9.3. The modifications implemented that help interpret or gather information. "Previously mentioned" means that their responses refer to tasks that have been already mentioned in the survey. Modifications were categorized as "digital" modifications referring to their use of digital displays or online agencies, or "non-digital" modifications. The percentages were based on the number of respondents in each demographic.

Demographic Factor	Previously Mentioned Modifications	Other Digital Modifications	Non-Digital Modifications
Male (N=25)	1. <u>Adjust display's settings</u> – adjusting brightness and contrast (36.0%; 9) 2. <u>Colour contrast enhancing apps</u> – colourblind mode on sites, programs, apps, games, and devices (computers and cell phones) (28.0%; 7) 3. <u>Coloured filters</u> – e.g. EnChroma (16.0%; 4) 4. <u>Avoid using displays</u> (8.0%; 2) 5. <u>Vehicle dashboard displays</u> (4.0%; 1)	1. <u>Assistance</u> - asking others to assist me in understanding of digital displays (4.0%; 1) 2. <u>Better than currently available</u> – adding features for CVD (4.0%; 1)	1. <u>Distance</u> - moving it closer or further (8.0%; 2) 2. <u>Breaks</u> -make sure to take a break every 15 minutes or so (4.0%; 1)
Female (N=9)	1. <u>Adjust display's settings</u> – adjusting brightness and contrast (33.3%; 3) 2. <u>Avoid using displays</u> (22.2%; 2) 3. <u>Colour contrast enhancing apps</u> – e.g. Wordle (11.1%; 1) 4. <u>Grayscale images</u> (11.1%; 1)	1. <u>Distance</u> – adjusting the angle and distance of displays (11.1%; 1)	1. <u>Coping</u> – live with it (11.1%; 1) 2. <u>Distance</u> – moving it further or at an angle (11.1%; 1)
Youth (N=11)	1. <u>Adjust display's settings</u> – adjusting brightness and contrast (27.3%; 3) 2. <u>Avoid using displays</u> (27.3%; 3) Remaining modifications are 1 respondent (9.1%) each: • Changing displays • Colour contrast apps – colourblind mode on sites • Coloured filters • Grayscale images	1. <u>Better than currently available</u>– adding features for CVD (9.1%; 1)	1. <u>Coping</u> – live with it (9.1%; 1) 2. <u>Distance</u> - moving it further or at an angle (9.1%; 1)

Adult (N=23)	1. <u>Adjust display's settings</u> – adjusting brightness and contrast (39.1%; 9) 2. <u>Colour contrast enhancing apps</u> – colourblind mode on programs, apps, video games and devices (computers and cell phones) (30.4%; 7) 3. <u>Coloured filters</u> – e.g. EnChroma (13.0%; 3) 4. <u>Avoid using displays</u> (4.3%; 1) 5. <u>Vehicle dashboard displays</u> (4.3%; 1)	1. <u>Assistance</u> – asking others to assist me in understanding of digital displays (4.3%; 1) 2. <u>Distance</u> – adjusting the angle and distance of displays (4.3%; 1)	1. <u>Distance</u> - moving it closer (8.7%; 2) 2. <u>Breaks</u> - make sure to take a break every 15 minutes or so (4.3%; 1)
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9.3 Chapter Discussion

9.3.1 Most Frustrating/Difficult Tasks and Challenges on Digital Displays

Both open-ended questions aimed to explore whether any other major problems were missed in the survey. Over 89% of respondents from each sex and age group re-emphasized their frustrations/difficulties with tasks already covered. Some examples included "identifying colours," "reading coloured letters on various backgrounds," "playing games," "colour-coded maps," "colour-coded photos," and "reading advertisements." Although respondents reported new "other digital" and "non-digital" tasks, there were generally no more than 5 respondents who reported challenges with one particular task. Some examples included "determining if buttons were clickable," "creating PowerPoint presentations," "reading weather reports," "enjoying nature," "finding colour-coded items," "reading restaurant menus," and "asking for assistance." This finding has been supported by several other studies, where they also suggest that colour vision deficiencies do impose difficulties/challenges on an individual's ability to perform tasks. Steward and Cole's study (1989) reported that, in general, 75% of individuals with CVD admitted to experiencing difficulties with daily colour-related tasks, regardless of severity. Another study by Mashige (2019) suggested that CVD does impact their ability to use computers. From the schoolchildren who reported some difficulty with this task, over 60% of them had a colour vision defect, and their condition's effect was significant (Mashige, 2019).

As with the frustrating tasks, the responses for the additional challenges re-emphasized previously mentioned tasks. Most of the challenges that respondents encountered when using digital displays can be labelled as issues in the interface designs and lack of accessibility for people with CVD. In contrast, the "non-digital" challenges highlighted their lack of adaptability to the condition and questions about its curability through ancient medicine from India. It was interesting to observe that most respondents re-emphasized similar challenges that were already mentioned in the survey and the "frustrating tasks" section. Other examples include "watching videos," "matching colours," "difficulties in science (e.g. chemistry and microbiology," "interpreting caution signs," and "editing photos." This finding could be due to the respondents having similar definitions for frustrations and challenges, or their view that frustrating tasks present challenges.

9.3.2 Modifications Implemented onto Digital Displays

For the modifications, respondents also reiterated aids that were already mentioned in the survey, such as "adjusting display's colour settings," "using colour contrast enhancing apps," "using coloured filters" (e.g. EnChroma glasses), and "avoiding the use of displays." There were only a few "other digital" and "non-digital" modifications that were listed by respondents, such as "asking others for assistance," "holding the

display at certain angles or distances," "taking 15-minute breaks," and "learning to live with it." These results suggest that although there is a range of aids available, there does seem to be one or two aids that consistently work. This brings up a debate on how useful these current modifications are in improving colour perception. A systematic review by Male et al. (2022) concluded that there was no clinical significance in the enhancement of colour perception for aids, such as "EnChroma Glasses, Chromagen filters, and EnChroma Cx-14." Allen et al. (2021) reported that although most respondents (58.8%) felt significant changes in their perception of colours, there was still some variability in the conditions where they were effective.

Overall, the additional comments by individuals with CVD displayed mixed opinions about the challenges and modifications available. Some respondents expressed "frustrations" with their inability to make colour-related judgments and feelings of discouragement in the "lack of enhancements available" to them. While others expressed more "acceptance" where they have learned "to live with it" or "avoid displays that impose difficulties." Taken together, the comments re-emphasize the need for further research in developing customizable aids or modifications for digital displays.

Chapter 10

Discussion and Conclusion

10.1 General Discussion

This survey examined how a colour vision deficiency (CVD) affects an individual's ability to perform tasks using digital displays. The first objective of this study was to determine the prevalence of difficulties that people with CVD experience when performing several colour-related tasks. Table 10.1 lists the top three tasks that respondents most frequently ranked as difficult across the different areas of life. People living with CVD had the most challenges with "reading coloured text" while using displays on social media platforms (204), "identifying colours" while shopping or banking in-person (179), and "interpreting coloured images" while using social media platforms (177). However, if school, work/volunteering, and recreation/hobbies are combined because of their similarity of the tasks, then "colour-coded diagrams" (325) and "colour-coded plans/instructions" (280) become the top two tasks that are most frequently listed as problematic by people with CVD. Table 10.2 shows the results based on sex and age group. The frequencies of the most difficult tasks were similar across most areas of life. However, a greater proportion of females had trouble with "colour-coded diagrams" at school than males (male: 61.7%; female: 81.3%). Whereas for age group, a larger proportion of youth had problems with "maps" while working/volunteering (youth: 66.7%; adult: 48.3%), whereas more adults struggled with "colour-coded diagrams" (youth: 42.9%; adult: 77.2%), "colour-coded plans/instructions" while working/volunteering (youth: 42.9%; adult: 61.4%), and "interpreting coloured images" while using social media platforms (youth: 50.0%; adult: 69.4%). This is most likely due to differences in task exposure and a larger proportion of adults than youth respondents who completed the survey. Regardless of the types of tasks that individuals with CVD found challenging, nearly 100% of them reported at least a little difficulty with displays when examining the areas of life individually, except for travelling where only 54.1% reported difficulty interacting with digital displays. This result demonstrates that the defect does affect the life of most individuals with CVD when using displays.

Table 10.1. The top three tasks that respondents most frequently ranked as having at least a little difficulty in different areas of life. The number in brackets "()" represents the number of respondents who selected having difficulty with the task.

Area of Life	Tasks that Respondents Frequently Reported as Challenging
School	1. Colour-coded diagrams (99) 2. Colour-coded instructions (80) 3. Maps (79)
Work/Volunteering	1. Colour-coded diagrams (121) 2. Colour-coded plans/instructions (98) 3. Maps (84)
Recreation/Hobbies	1. Colour-coded diagrams (105) 2. Colour-coded plans/instructions (102) 3. Maps (94)
Social Media	1. Reading coloured text (204) 2. Interpreting coloured images (177) 3. Editing images and videos using various filters and effects to create content (109)
Gaming & eSports	1. Reading coloured letters on various backgrounds (136) 2. Matching colours (132) 3. Identifying targets/objects (117)
Online Shopping or Banking	1. Identifying colours without labels (114) 2. Reading colour letters on various backgrounds (106) 3. Selecting colours that match without labels (105)
In-Person Shopping or Banking	1. Identifying colours (179) 2. Reading coloured letters on various backgrounds (152) 3. Experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours change (106)
Driving/Motorized Vehicles	1. Reading coloured text about the status of the vehicle or operating systems (70) 2. Detecting or identifying information from a digital map (65) 3. Detecting, identifying, or interpreting non-warning or caution information icons about the vehicle operating or driver assist systems (63)
Travelling	1. Reading the bus, train, or subway maps to find the correct route to take (100) 2. Distinguishing between departures and arrivals (54) 3. Identifying cancellations or other schedule changes (51)

Table 10.2. The top three tasks that respondents most frequently ranked as having at least a little difficulty in different areas of life. The number in brackets "()" represents the percentages of respondents in a particular area of life who ranked at least a little difficulty with a task.

Areas of Life	Tasks that Respondents Frequently Reported as Challenging			
	Sex		Age Group	
	Male	Female	Youth	Adult
School	1. Colour-coded diagrams (61.7%) 2. Colour-coded instructions (57.7%) 3. Graphs (56.7%)	1. Colour-coded diagrams (81.3%) 2. Maps (52.1%) 3. Colour-coded instructions/colour-coded mathematical or chemical equations/editing photos or other coloured images (50.0%)	1. Colour-coded diagrams (67.6%) 2. Colour-coded instructions (54.6%) 3. Maps (54.6%)	1. Colour-coded diagrams (70.3%) 2. Colour-coded instructions (56.8%) 3. Maps (54.1%)
Work/Volunteering	1. Colour-coded diagrams (70.5%) 2. Colour-coded plans/instructions (58.9%) 3. Maps (55.0%)	1. Colour-coded diagrams (81.1%) 2. Colour-coded plans/instructions (59.5%) 3. Graphs (43.2%)	1. Maps (66.7%) 2. Colour-coded diagrams (42.9%) 3. Colour-coded plans/instructions (42.9%)	1. Colour-coded diagrams (77.2%) 2. Colour-coded plans/instructions (61.4%) 3. Maps (48.3%)
Recreation/Hobbies	1. Colour-coded diagrams (61.9%) 2. Colour-coded plans/instructions (57.9%) 3. Maps (55.6%)	1. Colour-coded plans/instructions (61.7%) 2. Editing coloured images (including photos) (59.6%) 3. Colour-coded diagrams (57.4%)	1. Colour-coded diagrams (64.2%) 2. Maps (59.7%) 3. Colour-coded plans/instructions (58.2%)	1. Colour-coded plans/instructions (59.4%) 2. Colour-coded diagrams (58.5%) 3. Editing coloured images (including photos) (52.8%)
Social Media	1. Reading coloured text (71.1%) 2. Interpreting coloured images (64.9%) 3. Editing images and videos using various filters and effects to create content (36.0%)	1. Reading coloured text (75.0%) 2. Interpreting coloured images (55.6%) 3. Editing images and videos using various filters and effects to create content (45.8%)	1. Reading coloured text (71.0%) 2. Interpreting coloured images (50.0%) 3. Editing images and videos using various filters and effects to create content (44.0%)	1. Reading coloured text (72.7%) 2. Interpreting coloured images (69.4%) 3. Editing images and videos using various filters and effects to create content (35.5%)
Gaming & eSports	1. Reading coloured letters on various backgrounds (63.7%) 2. Matching colours (60.2%) 3. Identifying targets/objects (57.9%)	1. Matching colours (70.7%) 2. Experiencing objects disappearing or having difficulty seeing as the background/scene colours change (70.7%)	1. Reading colours letters on various backgrounds (56.9%) 2. Matching colours (56.9%) 3. Experiencing objects disappearing or having difficulty	1. Reading colours letters on various backgrounds (67.9%) 2. Matching colours (65.0%) 3. Identifying targets/objects (60.0%)

		3. Reading coloured letters on various backgrounds (65.9%)	seeing as the background/scene colours change (56.9%)	
Online Shopping or Banking	1. Identifying colours without labels (61.0%) 2. Selecting colours that match without labels (50.0%) 3. Reading coloured letters on various backgrounds (49.4%)	1. Reading coloured letters on various backgrounds (65.2%) 2. Selecting colours that match without labels (60.9%) 3. Detecting patterns in items (52.2%)	1. Identifying colours without labels (53.3%) 2. Detecting patterns in items (48.9%) 3. Selecting colours that match without labels (44.4%)	1. Identifying colours without labels (58.1%) 2. Reading coloured letters on various backgrounds (58.1%) 3. Selecting colours that match without labels (54.8%)
In-Person Shopping or Banking	1. Identifying colours (68.8%) 2. Reading coloured letters on various backgrounds (56.3%) 3. Experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours change (39.1%)	1. Identifying colours (61.0%) 2. Reading coloured letters on various backgrounds (57.1%) 3. Experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours change (40.3%)	1. Identifying colours (64.6%) 2. Reading coloured letters on various backgrounds (53.1%) 3. Experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours change (38.5%)	1. Identifying colours (67.6%) 2. Reading coloured letters on various backgrounds (58.4%) 3. Experiencing objects disappearing or having difficulty seeing these objects as the background/scene colours change (39.9%)
Driving/Motorized Vehicles	1. Reading coloured text about the status of the vehicle or operating systems (53.7%) 2. Detecting, identifying, or interpreting non-warning or caution information icons about the vehicle operating or driver assist system (49.5%) 3. Detecting, identifying, or interpreting warning or caution information icons about the vehicle operating or driver assist systems/detecting of identifying information from a digital map (45.3%)	1. Detecting or interpreting information from a digital map (61.1%) 2. Reading coloured text about the status of the vehicle or operating systems (52.8%) 3. Detecting, identifying, or interpreting non-warning or caution information icons about the vehicle operating or driver assist system (44.4%)	1. Reading coloured text about the status of the vehicle or operating systems (54.6%) 2. Detecting, identifying or interpreting non-warning or caution information icons about the vehicle operating or driver assist systems (52.7%) 3. Detecting or identifying information from a digital map (47.3%)	1. Reading coloured text about the status of the vehicle or operating systems (52.6%) 2. Detecting or identifying information from a digital map (51.3%) 3. Detecting, identifying or interpreting warning and caution information icons about the vehicle operating or driver assist systems (47.4%)
Travelling	1. Reading the bus, train, or subway maps to find the correct route to take (70.4%) 2. Distinguishing between departures and arrivals (36.1%) 3. Identifying cancellations or other schedule changes (34.3%)	1. Reading the bus, train, or subway maps to find the correct route to take (80.0%) 2. Distinguishing between departures and arrivals (50.0%) 3. Identifying cancellations or other schedule changes (46.7%)	1. Reading the bus, train, or subway maps to find the correct route to take (69.1%) 2. Distinguishing between departures and arrivals (47.6%) 3. Reading warning or other critical information (42.9%)	1. Reading the bus, train, or subway maps to find the correct route to take (74.0%) 2. Identifying cancellations or other schedule changes (38.5%) 3. Distinguishing between departures and arrivals (35.4%)

The second objective was to determine the extent of difficulties that they experience when performing these tasks on digital displays. The respondents were asked to subjectively rank the level of difficulty of several tasks from "no difficulty" to "a lot of difficulty." The median rankings for most coloured tasks by respondents who ranked the difficulty were "some difficulty" for both sexes and age groups. However, some tasks within the groups had higher median rankings ("a lot of difficulty"). Females ranked "reading coloured letters on various backgrounds" while shopping/banking in-person as more difficult than males. Youth ranked greater difficulty with "interpreting coloured images" when using social media platforms, whereas adults ranked less difficulty. Youth also ranked greater difficulty with "identifying cancellations or other schedule changes" while travelling with a median ranking of "a lot of difficulty," whereas adults had a median ranking of "some difficulty." These differences in rankings may be due to task exposure or adults had learned to use the non-colour information more effectively.

The majority of tasks did not show significant differences in the difficulty rankings based on severity, but for the ones that did, these differences were primarily between mild ("less than once per month" and "at least once a month") and more severe ("more than once a week") defects. Some examples included "colour-coded diagrams" at school, work/volunteering, and recreation/hobbies; "editing photos or other coloured images" at school, recreation/hobbies, and social media; and "reading coloured letters on various backgrounds" while gaming/eSports, online shopping/banking, and in-person shopping/banking. These results were expected since people with CVD with more severe defects are more likely to encounter difficulties more frequently.

The third objective was to determine the types of digital displays which individuals with CVD most frequently encountered challenges. Over 85% of respondents who were present in an area of life reported having difficulty with at least one display, and more than 50% reported problems with more than one display. The exceptions were travelling where only 60% selected a device, and in-person shopping/banking where only 25% reported using multiple displays. These lower percentages in these environments could be due to fewer displays being present, limited use of colour-coded information, or the presence of sufficient non-colour clues.

"Desktops/laptops," "cell phones," and "tablets" were the displays that most respondents reported as encountering difficulties. This result could be due to the fact that these displays are used frequently in most people's daily lives. There was generally no significant association between displays and demographic factors (sex and age group), except for work/volunteering, recreation/hobbies, gaming/eSports, and online shopping/banking based on age group. The primary difference for these exceptions was that youth reported more problems with tablets in comparison to adults who reported

more problems with cell phones. This is probably due to the differences in the use or exposure of these displays by the two age groups.

The final objective was to determine the types of modifications being implemented to displays to assist them in carrying out the colour-related tasks. In this study, 64.6% of respondents implemented some type of modification to their displays, with "trial-and-error adjustments" being the most popular aid, followed by "using cell phone apps to help identify colours of objects" and "colour contrast enhancing apps." This was a similar trend found in both sexes and age groups. The popularity of the "trial-and-error adjustments" may be due to a number of reasons, such as low cost, customization to preferred settings, and lack of awareness of other aids available. However, 35.2% did not try any aids for reasons unknown. Approximately 90% of respondents who implemented a modification reported that they were at least a little effective, but only 25% found them highly effective and less than 3% found at least one aid ineffective. These numbers suggest more work needs to be done to enhance the accessibility for people with CVD. For most of the modifications, there were no significant differences in the rankings based on sex and age group. The exception was "coloured filters," which youth found more effective than adults. The higher rating was primarily a result of the female youth ranking the devices highly effective. This may be due to differences in colours used in tasks encountered by younger users, particularly females. There was also no significant difference in the rankings based on severity, which suggests that the effectiveness of the modifications may be more based on user interface design than on the severity of the defect. As in the areas of life section, "desktops/laptops," "cell phones," and "tablets" were the displays that respondents most frequently reported modifying. There was a significant association with age group, which may be due to differences in display usage, where more youth modified tablets and more adults modified cell phones.

The purpose of this study was to provide a better understanding of the needs and difficulties that individuals with CVD encounter in terms of their ability to perform colour-related tasks on displays, in hopes that it can provide software and hardware developers with more information that can guide them in making displays more accessible to them.

10.2 Limitations of this Study

Even though the survey gathered additional information on the experiences of people with CVD as digital users, there were some limitations. One of the limitations was rating the severity of the defect. Ideally, it would be better to classify the type and severity of the defect based on the anomaloscope as was done in Steward and Cole's study, or using the Farnworth 100 Hue as an index of their general colour

discrimination. Because we only used a short screening test, it is possible that respondents with mild defects may have been overlooked. Others could have been excluded because of different display settings that could invalidate the screening test, although we instructed the respondents to set their display back to the standard colour settings and remove any tinted lenses before viewing the screening test. Most studies do conclude that online colour vision tests are comparable for screening to those administered in a clinic, but they can underestimate the severity of the defect (Ozgur et al., 2018; Zhao et al., 2019). However, some studies do acknowledge the convenience of screening for colour vision deficiencies, such as van Staden et al.'s study (2018) which showed that the online ColBlinder Ishihara test was valid in screening for the condition but not for determining severity. We relied on the Waggoner Diagnostics in-house research to determine whether the screening plates were valid, so we are uncertain as to which individuals were disqualified or improperly included in the survey.

Nevertheless, using a subjective scale based on the individual's perception of how frequently they encounter colour-related performance issues does indicate the severity to some degree in that individuals who experience problems frequently are more likely to have a severe defect. The assumption that respondents in the avoidant severity group consist of those with more severe defects imposed limitations in our study, in terms of our understanding of why they avoid colour-coded tasks. Since the avoidant group primarily consisted of individuals with different severity levels, some possible reasons could be due to their choice of coping, negative past experiences, or a lack of aids being readily available. It can suggest that software developers need to focus less on meeting the needs of digital users with CVD based on severity, but more on user interface design.

Another limitation was the discrepancy in the subjective ranking system of difficulty used by respondents based on personal opinions (e.g. "no," "a little," "some," or "a lot"). The extent of difficulty can vary between individuals with CVD as there is no objective way of ensuring that the level is similar across all respondents, similar to the effectiveness of the modifications. There needs to be more research in developing an objective measuring system that clinicians can use to measure the impediments of their defect in performing colour-related tasks. This could provide clinicians with a better understanding of their challenges so that they can offer better accommodations. Since the focus of this study was more on understanding the difficulties from the perspective of the people with CVD rather than the severity obtained from a professional diagnosis, this rating system for the degree of difficulty was sufficient in providing a good overall understanding of their challenges.

There were also some restrictions in the data obtained about the types of digital displays that respondents experienced challenging or modified. Based on the phrasing of these questions, no definitive

conclusions could be made regarding the reasons why particular displays were chosen. It can be that it was because these displays were the most challenging to operate, more colours were used on a given display or simply that it was used more frequently in their daily activities. Additional questions asked respondents about the prevalence of the different displays and identifying what specifically about these devices imposed the greatest challenges in their use to get a better idea of the potential causes of the difficulty or the effectiveness of any modifications.

Colour normals were unnecessary in our study because they would likely complain about the level of difficulty encountered in using digital displays, and the problem would be addressed because of the large number of potential users. Also it is likely that the majority of developers and graphic designers likely have normal colour vision, so it is unlikely that they would create a display that they could not use because they could not distinguish between colours.

10.3 Conclusion

Nearly everyone with CVD encounters difficulties in their interactions with digital displays, ranging from mild inconvenience to substantial difficulty with obtaining necessary information. Clearly, developers have not appropriately accommodated this population by adapting a design that incorporates cues that do not depend on colour discrimination for frequently encountered challenges, such as "reading coloured text," "interpreting coloured images" while using displays on social media platforms, and "identifying colours" while shopping or banking in-person. The current accommodations are probably insufficiently promoted and inadequate to meet the needs of those with CVD, since only 25% ranked a modification as highly effective. Congenital red-green CVDs affect a substantial segment of digital users and it is not well understood. There are no barriers to making digital platforms more accessible to those with CVD as they are to those with normal colour vision, but it could involve using colours that are further apart from each other on the lines of confusion which may not be acceptable to the users with normal colour vision. An understanding of the challenges highlighted directly from the user's perspective is highly beneficial in reducing the gap between the developer's and user's expectations of user-friendly colour schemes that can enhance their experiences.

10.3.1 Future Recommendations

There is still more research that needs to be done on this topic. One area can be exploring the variability of task difficulty on a particular display or display difficulty when performing a particular task to understand the potential causes of the challenges. More research needs to be done to establish a universal

design or general guidance principles for using non-chromatic cues and other enhancements that would provide a systematic method for determining which modifications are effective for those with CVD, and whether these modifications degrade the experience for individuals with normal colour vision. It could also help in providing more information as to why "desktops/laptops," "cell phones," and "tablets" were the most selected displays. It would also be interesting to perform this same study on a sample of colour normals (as a control group) to compare whether there are significant differences with individuals with CVD. Steward and Cole (1989) performed a similar study where they explored the effect of CVD on the performance of tasks on 102 colour normals and 102 people with CVD. Since their study was published 35 years ago and did not specifically focus on digital tasks, it would be interesting to see whether there are changes in the perceived difficulty of similar tasks between people with CVD and normals. Also, the percentage of students who reported difficulty with displays at school was higher than 63.2% of students who reported problems with working with computers having CVD in Mashige's study (2019). Additional research could determine whether this difference is still true approximately 5 years after his study and perhaps answer the question as to why there is a difference. More importantly, it would be useful to determine whether the use of digital displays affects the academic performance of students with CVD. Our study may provide future studies with a better direction in where to focus more of their efforts to ensure an optimal experience for all digital users, including individuals with CVD.

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Appendix

Appendix A Survey Questionnaire

Color Vision Deficiencies in the Digital Age: A survey of user experiences

Programmer, it is important that the survey is programmed using colors that people who are color blind can see. Avoid the use of red, green and yellow for buttons and copy.

SCREENER

S1

Are you 18 years of age or older?

Yes

No (Terminate)

Terminate

Thank you for your time but for this survey, we are currently collecting responses from people aged 18 or older.

This survey is being conducted by the University of Waterloo Survey Research Centre (SRC) on behalf of researchers at the University of Waterloo who are conducting research about individuals who have color vision deficiencies (also called color blindness) and are 10 yrs or older. Color vision deficiency often happens when someone cannot distinguish between certain colors. The colors that are usually mixed up or confused by individuals with a red-green color vision deficiency are greens, yellows, reds, and occasionally blues and purples and blue-greens and blues.

S2

Do you have a color vision deficiency (color blindness) or do you have a child between the ages of 10 and 17 with a color vision deficiency? (mandatory)

1. I have a color vision deficiency (**go to For Participants Age 18 and Older section**)
2. I have a child between the ages of 10-17 with a color vision deficiency (**Go to PARENT_PREAMBLE**)
3. I have a child age 18 or older with a color vision deficiency (**Go to AM**)
4. I do not have a color vision deficiency nor do I have a child between the ages of 10-17 with a color vision deficiency (**Go to Screen Out**)

Screen Out

Thank you for your time but for this survey, we are currently collecting responses from people who have a color vision deficiency.

(If not terminated then the following is displayed)

FOR PARTICIPANTS UNDER AGE 18

PARENT_PREAMBLE

You indicated that you have a child between the ages of 10-17 with a color vision deficiency. We would like to conduct a survey with this child. If you have more than one child between the ages of 10-17 with a color vision deficiency, please choose the oldest child who is willing to participate. Please read the information on the following page and, at the end, indicate if you are willing to let your child participate in this survey. To thank you for your child's participation, you will be rewarded with Leo points in accordance with Leo's user agreement. We encourage you to share this with your child. Before we start, we will provide you with information about what this research study is about, the possible risks and benefits, and then ask whether you consent to have your child participate.

PARENT_CONSENT

Before we start, we require your consent for your child to participate:

Researchers at the University of Waterloo are conducting research about individuals who have color vision deficiencies and how it impacts their use of several different digital displays in various aspects of their daily life. We are interested in feedback on experiences with these various digital displays (e.g., computers, smartphones, tablets), which will help us to improve our understanding of how color vision deficiencies impact their ability to use digital displays effectively and apply this information to develop algorithms to improve the ability to interpret the color-coded information.

The survey will begin by asking a few demographic questions so that we can make sure our participants represent the overall population in terms of their age and region. Your child will first be asked to view two to five test pictures to help us determine if they are eligible to complete this survey about color vision deficiency. Please note that the purpose of this test is to determine only if they are eligible for the survey. It does not provide a diagnosis of colour vision deficiency. If you need help understanding or answering any questions then they should ask your parent for help. We do not anticipate any negative impacts of your child participating in this survey.

The survey is part of a research study being conducted by Professor Jeff Hovis at the University of Waterloo, Canada (School of Optometry). The research results will be disseminated for a Master's thesis project, publication, and conference presentation. The study is funded by Qualcomm and there will be no data sharing. They will only have copies of the final report and pre-publications. There may be sharing of the anonymized data with other researchers interested in the same topic or be stored in a repository for future publications. The survey will take about 15-30 minutes to complete.

We take your child's privacy very seriously and will keep their identity confidential. We will

never share their personal information with any company or marketing firm. All of the information your child provides will be grouped with responses from other participants, which means that there will be no way to identify participants individually from the reports we create. Your child will not be asked to provide their name, address, or telephone number. The data will be stored for a minimum of 7 years on a secure University of Waterloo server in Canada. Once the study is complete, general anonymized findings will be combined and reported in summary research reports and publications. However, when information is transmitted over the internet, as is the case with an online survey, privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). The SRC temporarily collects your computer IP address to avoid duplicate responses in the dataset. Although the SRC temporarily collects your computer IP address to avoid duplicate responses in the database, the investigators won't be able to access the IP address information. You can withdraw your participation at any time by not submitting your responses. It is not possible to withdraw your responses after they are submitted as there is no way of knowing which response is yours. By providing your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

This study has been reviewed and received ethics clearance through the University of Waterloo Research Ethics Board (REB #43990). If you have questions for the researcher or the ethics board, please click on the Help Box button for the contact information.

Would you be willing to allow your child to participate in this survey? By clicking “Yes” below, you confirm that you are the parent/legal guardian of the child participating in this study and agree to allow them to participate.

1. Yes
2. No

PARENT_CONFIRM

Programmer: Display message if “No” is ticked: “To confirm, you do not consent to participate in this survey?” Please add the options: “No, I do not consent” and “Yes, I do consent to participate”. If no, go to message “Thank you for your time.” If yes, continue.

If left blank, display message “Your consent is required in order to proceed with the survey.”

If no consent is provided: “Thank you for your time. You will now be redirected back to the survey company.”

PARENT_PREAMBLE2

Thank you. We have two questions for you before your child completes the survey.

LOCATION (mandatory)

Where do you and your child currently live?

1. Canada
2. The United States
3. Outside of Canada or the United States (go to NE)

Programmer: if left blank, the following message should pop up “This is a required question that will help us identify whether your child can participate. Please do your best to answer. If you can’t or don’t wish to answer this question, unfortunately you will not be able to continue”

AGE (mandatory)

Thinking about your child aged 10-17 ...

What is their age group?

1. 9 years old or younger (go to NE)
2. 10-13 years old
3. 14-17 years old
4. 18 years or older (go to AM)

Programmer: if left blank, the following message should pop up “This is a required question that will help us identify whether your child can participate. Please do your best to answer. If you can’t or don’t wish to answer this question, unfortunately, you will not be able to continue”

PROGRAMMER, PLEASE PROVIDE LOGIC TO DETERMINE IF QUOTA FOR AGE GROUP AND REGION IS FULL. IF FULL, GO TO QUOTA FULL.

QUOTA_FULL

Thank you for your time but we have now completed the number of surveys we need for this age group and region.

NE

Thank you for your time but for this survey, we are currently collecting responses from people aged 10-17 who live in Canada or the United States.

AM

You have indicated that you have child aged 18 or older who has a color vision deficiency. This child is eligible to complete the survey. Please pass the survey to your child age 18 years or older. **GO to For Participants Age 18 and Older section**

CHILD_PREAMBLE

Thank you. Please now ask your child aged 10-17 to complete the survey.

CHILD_CONSENT

Hello! This is a survey about how you see in color and how this affects your ability to use digital

displays like computers, smartphones and tablets. We plan to use this information to help improve how color is seen by people like you! Participation in this study is voluntary. If you do not want to respond to a particular question, you can leave it blank except for the first two questions that are needed to make sure that you qualify for the survey. If you are not eligible, we will thank you for your time. As far as we know, completing this survey will not hurt you or make you feel bad.

The research results will be disseminated for a Master's thesis project, publication, and conference presentation. The study is funded by Qualcomm and there will be no data sharing. They will only have copies of the final report and pre-publications. There may be sharing of the anonymized data with other researchers interested in the same topic or be stored in a repository for future publications. The survey will take about 15-30 minutes to complete. We appreciate you taking the time to complete our survey.

If you decide to participate in this study, you will first be asked to view up to five test pictures to help us determine if you are eligible to complete this survey about seeing color. Please note that the purpose of this test is to determine only if you are eligible for the survey. You will then be asked questions about how you use various digital displays. There are no right or wrong answers, so please answer as honestly as possible. If you need help understanding or answering any questions then they should ask your parent for help. We do not anticipate any negative impacts of your child participating in this survey.

We take your privacy very seriously and will keep your identity confidential. The survey will not require your name, so no one will know these are your answers. Only the study researchers will see your answers. Your information will be kept for at least 7 years in a secure location at the University of Waterloo in Canada. Once the study is complete, general anonymized findings will be combined and reported in summary research reports and publications. However, when information is transmitted over the internet, we cannot promise privacy. There is always a risk your responses may be found by a third party (e.g., hackers). You can withdraw your participation at any time by not submitting your responses. It is not possible to withdraw your responses after they are submitted as there is no way of knowing which response is yours. By providing your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

This study has been reviewed and received ethics clearance through the University of Waterloo Research Ethics Board (REB #43990). If you have questions for the researcher or the ethics board, please click on the Help Box button for the contact information.

Do you agree to participate in this survey?

1. Yes
2. No

CHILD_CONFIRM

Programmer: Display message if “No” is ticked: “To confirm, you do not consent to participate in this survey?” Please add the options: “No, I do not consent” and “Yes, I do consent to participate”. If no, go to message “Thank you for your time.” If yes, go to the VISION_SCREENING section.

If left blank, display message “Your consent is required in order to proceed with the survey.”

If no consent is provided: “Thank you for your time. You will now be redirected back to the survey company.”

FOR PARTICIPANTS AGE 18 AND OLDER (Panel and Social Media)

INTRODUCTION

Researchers at the University of Waterloo are conducting research about individuals who have color vision deficiencies and how it impacts their use of several different digital displays in various aspects of their daily life. We are interested in feedback on experiences with these various digital displays (e.g., computers, smartphones, tablets), which will help us to improve our understanding of how color vision deficiencies impact their ability to use digital displays effectively and apply this information to develop algorithms to improve the ability to interpret the color-coded information.

The survey is part of a research study being conducted by Professor Jeff Hovis at the University of Waterloo, Canada (School of Optometry). The research results will be disseminated for a Master's thesis project, publication, and conference presentation. The study is funded by Qualcomm and there will be no data sharing. They will only have copies of the final report and pre-publications. There may be sharing of the anonymized data with other researchers interested in the same topic or be stored in a repository for future publications. The survey will take about 15-30 minutes to complete.

CONSENT SECTION

The survey will begin by asking a few demographic questions so that we can make sure our participants represent the overall population in terms of your age and region. You will first be asked to view two to five test pictures to help us determine if they are eligible to complete this survey about color vision deficiency. Please note that the purpose of this test is to determine only if you are eligible for the survey. We do not anticipate any negative impacts your participation in this survey.

We are conducting research on individuals in who have color vision deficiencies and how it impacts their use of different digital displays in various aspects of their daily life, such as school, work, recreation, and driving. This information to develop algorithms to improve your ability to interpret the color-coded information. The survey will begin with questions regarding your age, gender, and some general questions about your color vision deficiency.

We take your privacy very seriously and will keep their identity confidential. We will never share their personal information with any company or marketing firm. All of the information your child provides will be grouped with responses from other participants, which means that there will be no way to identify participants individually from the reports we create. Your child will not be asked to provide their name, address, or telephone number. The data will be stored for a minimum of 7 years on a secure University of Waterloo server in Canada. However, when information is transmitted over the internet, as is the case with an online survey, privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). The SRC temporarily collects your computer IP address to avoid duplicate responses in the dataset. Although the SRC temporarily collects your computer IP address to avoid duplicate responses in the database, the investigators won't be able to access

the IP address information. You can withdraw your participation at any time by not submitting your responses. It is not possible to withdraw your responses after they are submitted as there is no way of knowing which response is yours. By providing your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

This study has been reviewed and received ethics clearance through the University of Waterloo Research Ethics Board (REB #43990). If you have questions for the researcher or the ethics board, please click on the Help Box button for the contact information.

I consent to participate in this survey

Programmer: Please add an error message if box not ticked and respondent tries to continue with the survey: “Your consent is required in order to proceed with the survey”

Help Box

If you require technical help with the survey, please contact the Survey Research Centre at srccinb@uwaterloo.ca.

For any questions about the study itself, contact the researcher:

Dr. Jeff Hovis

University of Waterloo

Phone: 519-888-4567 (x46768)

Email: jhovis@uwaterloo.ca

If you have questions or concerns about research ethics related to this study, please contact the research ethics committee:

University of Waterloo:

Office of Research Ethics

Phone: 519-888-4567 (x36005)

Email: reb@uwaterloo.ca

The ethics reference number is REB #43990

About this study

We are conducting research on individuals in who have color vision deficiencies and how it impacts their use of different digital displays in various aspects of their daily life, such as:

- school
- work/volunteering
- recreation/hobbies
- gaming
- driving/motorized vehicles

- online shopping
- in-person shopping/traveling

We would like to receive feedback on your experiences with these various digital displays (e.g., computers, smartphones, tablets), which will help us to improve our understanding of how color vision deficiencies impact your ability to use digital displays effectively and apply this information to develop algorithms to improve your ability to interpret the color-coded information. The survey will begin with questions regarding your age, gender, and some general questions about your color vision deficiency.

[End of help box]

SCREENING QUESTIONS (mandatory)

LOCATION

Where do you currently live?

1. Canada
2. United States
- 03 Outside of Canada or the United States (go to INELIGIBLE)

Programmer: if left blank, the following message should pop up “This is a required question that will help us identify whether you can participate. Please do your best to answer. If you can’t or don’t wish to answer this question, unfortunately you will not be able to continue”

AGE

What is your age group?

1. Under 18 (go to INELIGIBLE)
2. 18-22 years old
3. 23-29 years old
4. 30-39 years old
5. 40-49 years old
6. 50-59 years old
7. 60+ years old

Programmer: if left blank, the following message should pop up “This is a required question that will help us identify whether you can participate. Please do your best to answer. If you can’t or don’t wish to answer this question, unfortunately you will not be able to continue”

INELIGIBLE

Thank you for your time but for this survey, we are interested in currently collecting responses from adults age 18 and older who live in Canada or the United States. **CODE DISPOSITION AS “IN” SURVEY TO BE REDIRECTED TO PANEL FIRM URL (TO BE PROVIDED)**

PROGRAMMER, PLEASE PROVIDE LOGIC TO DETERMINE IF QUOTA FOR AGE GROUP AND REGION IS FULL. IF FULL, GO TO QUOTA FULL.

QUOTA_FULL

Thank you for your time but we have now completed the number of surveys we need for this age group and region.

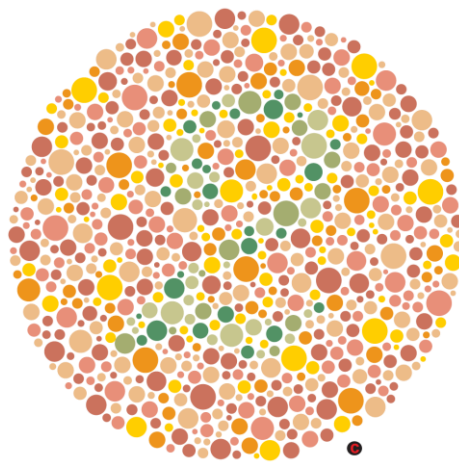
VISION SCREENING QUESTIONS (mandatory) Child participants start survey here.

VISION_PREAMBLE

To start, we are going to show you a series of pictures to help us determine if you are eligible to complete this survey about color vision deficiency. Please note that the purpose of this test is to determine only if you are eligible for the survey. It does not provide a diagnosis of any colour vision deficiency. First, please:

1. Remove any glasses with colored lenses
2. Sit so that you are about 20 inches (50 cm) from your computer monitor
3. If you have made any adjustments to your computer display to help you with color discrimination, please reset the color management back to the original settings

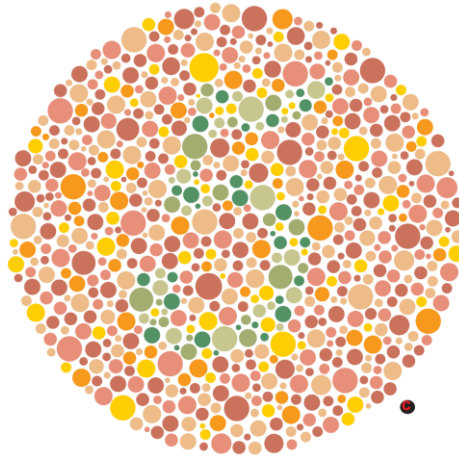
Programmer: Continue with survey with respondents who 1) do not choose the correct response TWO times during the following 5 tests or 2) chooses 10 or 11 TWO times during the following 5 tests. All others continue with test questions until end, then go to SO.



TEST 1

Please indicate what number, if any, that you see in the picture:

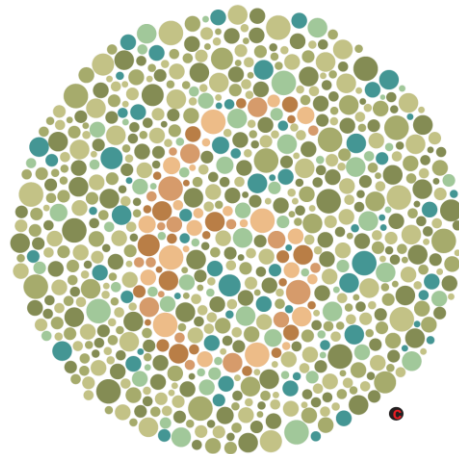
1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. 9
10. I don't see a number
11. I can't determine which number I see



TEST 2

Please indicate what number, if any, that you see in the picture:

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. 8
9. 9
10. I don't see a number
11. I can't determine which number I see

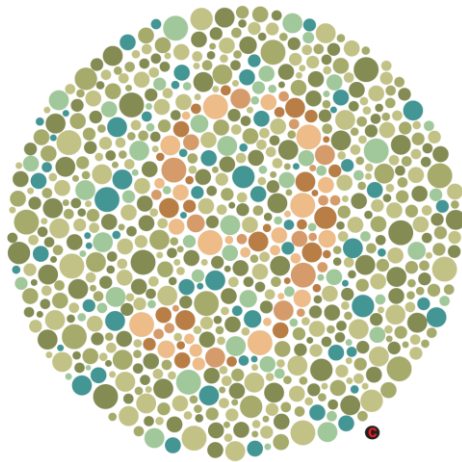


TEST 3

Please indicate what number, if any, that you see in the picture:

1. 1
2. 2
3. 3
4. 4
5. 5

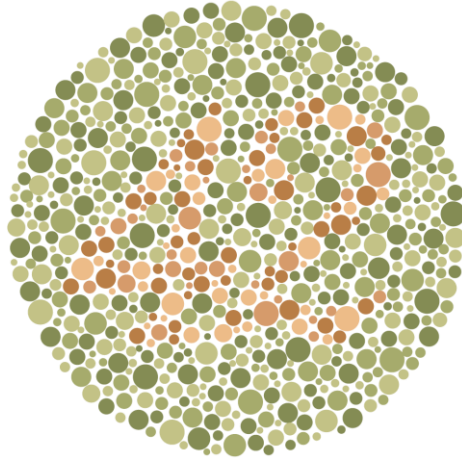
- 6. 6
- 7. 7
- 8. 8
- 9. 9
- 10. I don't see a number
- 11. I can't determine which number I see



TEST 4

Please indicate what number, if any, that you see in the picture:

- 1. 1
- 2. 2
- 3. 3
- 4. 4
- 5. 5
- 6. 6
- 7. 7
- 8. 8
- 9. 9
- 10. I don't see a number
- 11. I can't determine which number I see



TEST 5

Please indicate what number, if any, that you see in the picture:

1. 4
2. 11
3. 21
4. 36
5. 42
6. 60
7. 73
8. 85
9. 98
10. I don't see a number
11. I can't determine which number I see

SO

Thank you for your time but we are interested in currently collecting responses from people who have a color vision deficiency and cannot see the previous set of numbers correctly. This result does not necessarily mean that you have normal color vision. If you think that you do have difficulty with colors, please consult your eye care professional.

SURVEY QUESTIONS

Programmer: Error prompt to appear on all the following questions if response not provided (response not mandatory) “There is an unanswered question on this page. Would you like to continue? If so, please click “Next” again. Otherwise, please answer the question above.”

SEX

What was your sex at birth?

1. Male
2. Female

Q1

When did you become aware that you have a color vision deficiency?

1. Preschool
2. Elementary school
3. Junior high
4. High school
5. Post-high school
6. I was not aware that I had a color vision deficiency, but I was curious (or suspicious) and started the survey, or a family member or friend recommended that I take this survey **(go to NotAware)**

Programmer display the next message if Q1=06. All others continue with Q2a.

NotAware

Although you meet the criteria to continue in the study, we would recommend that you visit your eye care professional for additional testing regarding your color vision deficiency.

(Skip to Q3)

Q2a

Has a health care professional ever diagnosed you with a color vision deficiency?

1. No **(skip to Q3)**
2. Yes

Q2b

How much time was there between when you were aware of your color vision deficiency and your diagnosis of color vision deficiency by a health care professional?

1. Less than 6 months
2. 6 months to 1 year
3. 1 year to 5 years
4. More than 5 years
5. I am not sure

Q3

In general, how often do you encounter difficulty with color-related tasks?

1. Less than once per month
2. At least once a month
3. At least once a week
4. More than once a week
5. Because I avoid color related tasks, I rarely, or never, encounter difficulty doing color-related tasks
6. Never (**Go to SO_2**)

SO_2

Thank you for your time but we are interested in currently collecting responses from people who encounter difficulty with color-related tasks.

We would like to know if the brightness of any digital displays' background makes color related tasks more, or less difficult. The displays could be any computer, tablet or cell phones, touch screen, immersive system (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz), gaming device or other digital device.

Q4a

To what extent, if at all, do you have difficulty reading colored letters, numbers or icons on digital displays using a white background?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

To what extent, if at all, do you have difficulty reading colored letters, numbers or icons on digital displays using a medium bright background (grey or light blue)?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q4c

To what extent, if at all, do you have difficulty reading colored letters, numbers or icons on digital displays with a dark background?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

School

Q5a

Are you currently enrolled in either a full-time or part-time educational program (school, college, university etc.) ?

01 No **(skip to Q7)**

02 Yes

Q5b

In what level of the educational program are you currently enrolled?

1. Elementary school
2. Junior high or middle school
3. High school
4. Community college or technical school
5. University/college

05 Other educational program, please specify: _____

School PREAMBLE

You may be using digital displays for a variety of different reasons or in different environments. However, for this section, please answer the questions as they relate to your school or school-related environment.

Q6a

Which of the following types of colored images, if any, do you have difficulty reading, interpreting, reviewing, creating or editing colored images and other content on digital displays at school? Please select all that apply.

1. Maps
2. Color-coded diagrams
3. Color-coded instructions
4. Graphs
5. Spreadsheets
6. Photos
7. Color-coded mathematical or chemical equations
8. Editing photos or other colored images
9. Other tasks or images, please specify: _____
10. None of the above **(skip to Q7)**
11. I don't read, interpret, review, create or edit colored images on digital displays at school **(skip to Q7)**

Display the following rating scale question for each 01 to 09 response selected in Q6a. Use dynamic programming to insert open-ended text from 09 as applicable.

Q6b

To what extent, if at all, do you have difficulty reading, interpreting, reviewing, creating or editing these colored images or other content on digital displays at school?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q6c

In which school subjects do you experience difficulty with color-related tasks on digital displays? Please select all that apply.

1. Geography
2. History
3. Political Science
4. Social Science
5. Math
6. Science (Geology/Earth Science, Chemistry, Biology and Physics)
7. Electrical and Computer Engineering
8. Graphic Design/Art
9. Other subjects, please specify: _____
10. None of the above

Q6d

Which digital displays are you using at school or while doing homework when you experience difficulty in distinguishing colors ? Please select all that apply.

1. Desktops/Laptops
2. Tablets (such as iPad, Samsung Galaxy Tablet, Microsoft Surface, Kindle and Smart Phone Displays)
3. Cell Phones
4. Touch Screen Digital Whiteboard & Whiteboard Computers (such as SMARTBoards, Microsoft Surface Hub 2 and OneScreen Store Touchscreen)
5. Immersive Systems (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz)
6. Other digital displays, please specify: _____

Work/Volunteering

Q7

Are you currently employed or working as a volunteer?

1. No **(skip to Q9)**
2. Yes, full time
3. Yes, part-time
4. Yes, volunteering only

WORK/VOLUNTEERING_PREAMBLE

For those of you who have answered questions about digital displays in school, several of the following questions are similar. However, please answer these questions as they relate to your work/volunteering environment independent from answers in your school environment.

Q8a

Which of the following types of colored images, if any, do you have difficulty reading, interpreting, reviewing, creating or editing on digital displays in just your work or volunteering environment? Please select all that apply.

1. Maps
2. Color-coded diagrams
3. Color-coded plans/instructions
4. Graphs
5. Spreadsheets
6. Photos
7. Other tasks or images, please specify: _____
8. None of the above **(skip to Q9)**
9. I don't read, interpret, review, create or edit colored images on digital displays at work or during volunteering **(skip to Q9)**

Display the following rating scale question for each 01 to 07 response selected in Q8a. Use dynamic programming to insert open-ended text from 07 as applicable.

Q8b

To what extent, if at all, do you have difficulty reading, interpreting, reviewing, creating or editing these colored images or seeing details on digital displays in just your work or volunteering environment?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q8c

Which digital displays are you using at work or volunteering when you experience difficulty in distinguishing colors? Please select all that apply.

1. Desktops/Laptops
2. Tablets (such as iPad, Samsung Galaxy Tablet, Microsoft Surface, Kindle and Smart Phone Displays)
3. Cell Phones
4. Touch Screen Digital Whiteboard & Whiteboard Computers (such as SMARTBoards, Microsoft Surface Hub 2 and OneScreen Store Touchscreen)
5. Immersive Systems (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz)
6. Other digital displays, please specify: _____

Recreation/Hobbies

Q9

Do you use any digital device for hobbies or recreational activities besides social media, gaming or esports? (The next set of questions will address these activities).

1. No (skip to Q11)

02 Yes

RECREATION/HOBBIES_PREAMBLE

For those of you who have answered questions about digital displays in school and/or work/volunteering, several questions in the next section are similar. However, please answer these questions as they related to your recreation/hobbies environment independent from answers in your school and/or work/volunteering environments. **Social Media and Gaming will be covered in the next sections.**

Q10a

Which of the following types of colored images, if any, do you have difficulty with when making color-related judgments using digital displays for your hobbies or recreational activities? Please select all that apply.

1. Maps
2. Color-coded diagrams
3. Color-coded plans/instructions
4. Graphs
5. Spreadsheets
6. Editing colored images (including photos)
7. Other tasks or images, please specify: _____
8. None of the above (skip to Q11)
9. I don't make any color-related judgements for my recreation activities (skip to Q11)

Display the following rating scale question for each 01 to 07 response selected in Q10a. Use dynamic programming to insert open-ended text from 07 as applicable.

Q10b

To what extent, if at all, do you have difficulty reading, interpreting, reviewing, creating or editing these colored images or seeing details on digital displays in your hobbies or recreational activities?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q10c

Which digital displays are you using for hobbies or recreational activities when you experience difficulty in distinguishing colors? Please select all that apply.

1. Desktop/Laptops
2. Tablets (such as iPad, Samsung Galaxy Tablet, Microsoft Surface, Kindle and Smart Phone Displays)
3. Cell Phones
4. Touch Screen Digital Whiteboard & Whiteboard Computers (such as SMARTBoards, Microsoft Surface Hub 2 and OneScreen Store Touchscreen)
5. Immersive Systems (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz)
6. Other digital displays, please specify: _____

Q11

To ensure we are capturing your answers correctly, please select all the fruits from the following list:

01	Strawberry
02	Horse
03	Apple
04	Squirrel
05	Banana

Social Media

Q12

Do you use any digital device for social media activities, such as Facebook, Instagram, Snapchat, TikTok, Twitter or YouTube?

1. No **(skip to Q14)**
2. Yes
3. Yes, another social media App that is not listed, Please specific _____

Q13a

Which of the following types of colored images, if any, do you have difficulty with when making color-related judgments using digital displays for interacting with social media platforms. Please select all that apply.

1. Interpreting colored images
2. Reading advertisements
3. Reading color test
4. Viewing videos
5. Editing images and videos using various filters and effects to create content
6. Other tasks or images, please specify: _____
7. None of the above **(skip to Q14)**
8. I don't have difficulty with colored images when making color-related judgments using digital displays for interacting with social media platforms **(skip to Q14)**

Display the following rating scale question for each 01 to 06 response selected in Q13a. Use dynamic programming to insert open-ended text from 06 as applicable.

Q13b

To what extent, if at all, do you have difficulty reading, interpreting, reviewing, creating or editing these colored images or seeing details on digital displays in your hobbies or recreational activities?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q13c

Which digital displays are you using for hobbies or recreational activities when you experience difficulty in distinguishing colors? Please select all that apply.

1. Desktop/Laptops
2. Tablets (such as iPad, Samsung Galaxy Tablet, Microsoft Surface, Kindle and Smart Phone Displays)
3. Cell Phones
4. Touch Screen Digital Whiteboard & Whiteboard Computers (such as SMARTBoards, Microsoft Surface Hub 2 and OneScreen Store Touchscreen)
5. Immersive Systems (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz)
6. Other digital displays, please specify: _____

Gaming and eSports

Q14

Do you play games (e.g., Solitaire, Wordle, Call of Duty) or participate in eSports (multi player competitive gaming with an audience) on any digital devices?

1. No **(skip to Q16)**
2. Yes

Q15a

Which of the following types of tasks, if any, do you have difficulty with when reading, identifying or interpreting information on digital displays while playing games or participating in eSports? Please select all that apply.

1. Matching colors
2. Identifying targets/objects
3. Experiencing objects disappearing or having difficulty seeing as the background/scene colors change
4. Perceiving images Difficulty perceiving in 3D
5. Reading colored letters on various backgrounds
6. Difficulty with other color-related tasks not listed above, please specify:

7. None of the above **(skip to Q16)**
8. I don't read, identify or interpret information on digital displays while participating in online gaming or esports **(skip to Q16)**

Display the following rating scale question for each 01 to 06 response selected in Q15a. Use dynamic programming to insert open-ended text from 06 as applicable.

Q15b

To what extent, if at all, do you have difficulty with the following tasks when reading, identifying or interpreting information on digital displays while playing games or participating in eSports?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q15c

Which digital displays are you using for playing games or participating in eSports when you experience difficulty in distinguishing colors? Please select all that apply.

1. Desktops/Laptops
2. Tablets (such as iPad, Samsung Galaxy Tablet, Microsoft Surface, Kindle and Smart Phone Displays)
3. Cell Phones
4. Touch Screen Digital Whiteboard & Whiteboard Computers (such as SMARTBoards, Microsoft Surface Hub 2 and OneScreen Store Touchscreen)
5. Immersive Systems (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz)
6. Monitors used with gaming devices, such as Xbox, Wii and PlayStation.
7. Other digital displays, please specify: _____

Q15d

List up to 5 games that you have difficulty playing using any digital display.

1. _____
2. _____
3. _____
4. _____
5. _____

Driving/Motorized Vehicles

Q16

Do you have difficulty detecting, identifying, or interpreting information on digital displays in motorized vehicles as a driver, passenger, or both?

1. No **(skip to Q18)**
2. Yes as a driver
3. Yes as a passenger
4. Yes as both a driver and passenger
5. I don't interact with the digital displays in any of the vehicles that I use **(skip to Q18)**
6. None of the vehicles that I use have digital displays **(skip to Q18)**

Q17a

Which of the following types of tasks, if any, do you have difficulty with when using digital displays in motorized vehicles? Please select all that apply.

1. Detecting, identifying, or interpreting non-warning or caution information icons about the vehicle operating or driver assist systems.
2. Detecting, identifying, or interpreting warning and caution icons about the vehicle operating or driver assist systems
3. Reading colored text about the status of the vehicle or operating systems
4. Interpreting any navigation information or driver assist displays
5. Detecting or identifying information from a digital map
6. Difficulty with other color-related tasks not listed above, please specify:

7. None of the above **(skip to Q18)**

Display the following rating scale question for each 01 to 06 response selected in Q17a. Use dynamic programming to insert open-ended text from 06 as applicable.

Q17b

For which background setting(s) do you experience difficulty using digital displays in motorized vehicles?

1. Daytime
2. Nighttime
3. Both

Q17c

To what extent, if at all, do you have difficulty with the following tasks when using digital displays in motorized vehicles?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q17d

Which digital displays are you using while driving or riding in a motorized vehicle when you experience difficulty in distinguishing colors?

1. Digital dashboard displays
2. Heads-up displays
3. Touch screen information displays
4. Global Positioning System (GPS) or cell phone in GPS mode
5. Other digital displays, please specify: _____

Programmer, display Q17d if Q16=02 or 04 all others skip to Q18

Q17e

Which of the following statements best applies regarding how your difficulty in interpreting or identifying the color of text, symbols or icons displayed in the information touch screen or GPS display affects your ability to operate a motorized vehicle?

- 01 It is challenging to operate the vehicle or navigate to my destination because I cannot see or identify the colored object(s) on the displays
- 02 It is challenging to identify or detect the colored object(s), but there are other clues (shape, size, sound) so operating the vehicle is not a concern

Online Shopping or Banking

Q18

Do you use any digital devices for online shopping or banking?

1. No **(skip to Q20)**
2. Yes

Online Shopping/Banking_PREAMBLE

Please answer these questions as they related to your online shopping or banking tasks independent from answers in your school and/or work/volunteering and/or recreation/hobbies environments.

Q19a

Which of the following types of tasks, if any, do you have difficulty with when using digital displays while online shopping or banking? Please select all that apply.

1. Identifying colors without labels
2. Selecting colors that match without labels
3. Detecting patterns in items
4. Reading colored letters on various backgrounds
5. Perceiving the color that is described on any labels
6. Coordinating color selection
7. Reading text or numbers
8. Reading charts
9. Difficulty with other color-related tasks not listed above, please specify:

10. None of the above **(skip to Q20)**

Display the following rating scale question for each 01 to 09 response selected in Q19a. Use dynamic programming to insert open-ended text from 09 as applicable.

Q19b

To what extent, if at all, do you have difficulty with the following tasks when using digital displays while online shopping or banking?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q19c

Which digital displays are you using for online shopping or banking when you experience difficulty in distinguishing colors? Please select all that apply.

1. Desktops/Laptops
2. Tablets (such as iPad, Samsung Galaxy Tablet, Microsoft Surface, Kindle and Smart Phone Displays)
3. Cell Phones
4. Touch Screen Digital Whiteboard & Whiteboard Computers (such as SMARTBoards, Microsoft Surface Hub 2 and OneScreen Store Touchscreen)
5. Immersive Systems (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz)
6. Other digital displays, please specify: _____

Information Displays While Shopping In-Person or Traveling by Means other than a Personal Vehicle

Q20a

Which of the following types of tasks, if any, do you have difficulty reading, identifying or interpreting information on digital displays such as touch screen monitors for ATMs, retail checkouts, mall directories or in-store digital advertisements, while shopping/banking in-person? Please select all that apply.

1. Identifying colors
2. Identifying targets/objects
3. Experiencing objects disappearing or have difficulty seeing these objects as the background/scene colors change
4. Reading colored letters on various backgrounds
5. Identifying maps and diagrams such as store directory, store logos and inventory
6. Difficulties with completing transactions, such as processing payments on PIN pads and/or navigating touch screen monitor
7. Difficulty with other color-related tasks not listed above, please specify:

8. None of the above **(skip to Q21)**
9. I don't use digital displays while shopping/banking in person **(skip to Q21)**

Display the following rating scale question for each 01 to 07 response selected in Q20a. Use dynamic programming to insert open-ended text from 07 as applicable.

Q20b

To what extent, if at all, do you have difficulty with the following tasks when reading, identifying or interpreting information on digital displays such as touch screen monitors for ATMs, retail checkouts, mall directories or in-store digital advertisements, while shopping/banking in-person?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q20c

Which digital displays do you experience these difficulties with while shopping/banking in-person? Please select all that apply.

1. In-store digital advertisements which would be a single monitor or multiple monitors mounted on the walls in shopping areas that advertise in-store items, pricing or other in-store information
2. Touch-screen monitors for information or self-serve kiosks which includes retail checkout, bank ATMs and vending machines
3. Other digital displays, please specify: _____

Q21a

To ensure we are capturing your answers correctly, please select all the animals from the following list:

01	Dog
02	Blue
03	Tiger
04	Monkey
05	Orange

Q21b

Have you travelled by plane, bus or subway in the past 5 years?

- 01 No **(skip to Q23)**
02 Yes

Q22a

Which of the following types of tasks, if any, do you have difficulty when reading, identifying or interpreting information on digital displays such as monitors used for arrival/departure times or directions, touch-screen monitors, self-serve kiosks, check-in kiosks or vending machines while traveling by plane, train, bus, or subway? Please select all that apply.

1. Reading warning or other critical information
2. Distinguishing between departures and arrivals
3. Identifying cancellations or other schedule changes
4. Reading the bus, train, or subway maps to find the correct route to take
5. Difficulty with other color-related tasks not listed above, please specify:

6. None of the above **(skip to Q23)**
7. I don't use digital displays while travelling by plane, train, bus, or subway **(skip to Q23)**

Display the following rating scale question for each 01 to 05 response selected in Q22a. Use dynamic programming to insert open-ended text from 05 as applicable.

Q22b

To what extent, if at all, do you have difficulty with the following tasks when reading, identifying or interpreting information on digital displays such as monitors used for arrival/departure times or directions, touch-screen monitors, self-serve kiosks, check-in kiosks or vending machines while traveling by plane, train, bus, or subway?

1. No difficulty
2. A little difficulty
3. Some difficulty
4. A lot of difficulty

Q22c

Which digital displays do you experience difficulty with while travelling by plane, train, bus, or subway? Please select all that apply.

1. Monitors in arrival or departure areas which would be a single monitor or multiple monitors mounted on the walls in these areas which arrival and departure times or directions to the correct boarding area
2. Monitors displaying maps of the different bus, train, or subway lines or routes
3. Touch-screen monitors for information or self-serve kiosks which includes airline, train, bus, or bus check-in kiosks or vending machines
4. Other, digital displays please specify: _____

Q23

Overall, what do you find to be the most frustrating or difficult color-related tasks to carry out when using digital displays? List up to 5 tasks.

1. _____
2. _____
3. _____
4. _____
5. _____

Modifications

Q24a

Have you made any changes or modifications to your digital display(s) to assist with color-related judgments? Please select all that apply.

1. Use cell phone apps that identify the colors of objects on other digital displays
1. Use color contrast enhancing apps, such as Windows Color Filters that enhances color contrast for individuals with color vision deficiencies
2. Adjust the display's color settings to enhance color contrast based on your own experience using a trial-and-error procedure, such as changing to a darker background for enhanced contrast
3. Changing all images into grayscale
4. Use colored filters or tinted spectacles or contact lenses. For example Enchroma, Vino, Chromagen, and X-chrome
5. Purchased a larger monitor or used a Smart TV to display the image
6. Avoid using the display
7. Other changes or modifications not listed above, please specify:

8. I have not made any changes to my digital display to assist with color-related judgements (**skip to Q25**)

Programmer, display Q24b for each response selected in Q24a

Q24b

To what extent, do these modifications help with your color-related judgments?

- 01 Not at all
- 02 A little
- 03 Some
- 04 A lot

Q24c

Which digital displays did you modify or view with colored filters, tinted spectacles or contact lenses ? Please select all that apply.

1. Desktops/Laptops
2. Tablets (such as iPad, Samsung Galaxy Tablet, Microsoft Surface, Kindle and Smart Phone Displays)
3. Cell Phones
4. Touch Screen Digital Whiteboard & Whiteboard Computers (such as SMARTBoards, Microsoft Surface Hub 2 and OneScreen Store Touchscreen)
5. Immersive Systems (head-mounted displays, such as an Oculus, HTC Vive, Magic Leap and WorldViz)
6. Automotive Electronic Display Systems (touch screens, dashboard displays heads-up displays, and GPS systems such as standard or after-market)
7. Other digital displays, please specify: _____

Q25

Please add any additional comments that you would like us to know regarding your experiences with digital displays, your experiences on gathering information from digital displays or modifications you have done to help interpret the digital displays.

THANK YOU

You have reached the end of the survey. On behalf of the researchers, we would like to thank you very much for your time.

Once the study is complete, general anonymized findings will be combined and reported in summary research reports and publications. If you wish to obtain a summary report of the study, please contact Dr. Jeff Hovis at jhovis@uwaterloo.ca.