Computer-based solutions to support those with Colour Vision Deficiency to access day-to-day information

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DECLARATION

I certify that the work submitted is my own and that any material derived or quoted from the published or unpublished work of other persons has been duly acknowledged.

Signed: Majed Abdullah Alsafyani

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Date: November 2019

ABSTRACT

In modern-day society, we are bombarded with vast amounts of electronic information which we may be expected to make decisions from. Many people have difficulties in interpreting such information due to either physical or cognitive difficulties in using electronic devices, or an inability to identify information as intended by the author.

Colour Vision Deficiency (CVD) is one such problem that can cause considerable difficulty in the interpretation of diagrammatical information. This is because a Colour Vision Deficient (CVDt) person has difficulty in seeing: colour boundaries, different shades of colour and different hues. There has been some research to aid the CVDt, where the majority of the research in image processing changes or transforms colours in any given image. Such transformations use a number of different algorithms to create a CVDt friendly post-processed image from the pre-processed image. A major problem of current transformation algorithms is that they are aimed for specific contexts and cannot be used in generic contexts. For example, the transformation algorithm may be aimed at aiding the CVDt to view post-processed images of weather maps only.

The aim of this dissertation is to provide an improved post-processed image algorithm. The algorithm is intended to provide the CVDt with greater benefit by being able to interpret the information in the post-processed image correctly. The algorithm used in this dissertation is not a colour transformation algorithm instead it is a colour separation algorithm. This concept of colour separation is novel.

The colour separation algorithm, which is called the Halo-Effect Algorithm (HEA), parses a given image row-by-row and pixel-by-pixel until the end of file-marker is reached and a CVDt friendly post-processed image is furnished. When there is a colour change between two identified pixels then a colour boundary has been identified within the pre-processed image and a differently coloured pixel is inserted between two, furnishing the post-processed image. As the pre-processed image is parsed row-by-row then the colour the boundary builds up to form a colour boundary interface where the different coloured pixel are inserted in the post-processed image. In this dissertation the separation pixel is always white. The build-up of inserted white pixels at the colour boundary interface of the pre-processed image produces a halo like effect in the post-processed image which is CVDt friendly.

To demonstrate the efficacy of the colour separation concept, the HEA has been developed and implemented. A number of surveys have been conducted using participant responses to questions within each survey. The responses that each participant gave were then collated and analysed statistically. Two statistical techniques were used to test a number of hypotheses around the mean of a sample drawn from a normally distributed population. In this dissertation the normally distributed populations were the survey participants. From the analyses of the responses, the survey population was divided into two groups. One group was identified to have no problem with identification of pre-processed colour boundaries and were called the non-CVDt. A second group was identified to be those who had some problems with the identification of pre-processed colour boundaries and were called the indicative-CVDt.

Responses from the two groups were collated and statistical analyses were then conducted to test the significance of any results obtained and also to test the validity of the algorithms under investigation. In this dissertation two currently available, but different, colour transformation algorithms were compared with the colour separation algorithm of the HEA. Each of the two transformation algorithms were originally intended for specific use. One was aimed for spectra maps and the other was aimed for background text. Statistical analyses showed that each of the transformation algorithms provided benefit to the indicative-CVDt for their specific context only. However, statistical analyses also showed that HEA fared well in each of the two specific contexts. Thus, hinting that colour separation of HEA could be used in more general contexts.

To confirm that colour separation can provide greater benefit to the indicative-CVDt in more generic contexts than colour transformations further surveys were undertaken. In each survey participants were asked a number of questions about a given image where colour boundaries are expected to occur frequently. One was a map of the provinces of Australia and the other a number of differently coloured geometric shapes. Statistical analyses showed that the colour separation algorithm of HEA provided greater benefit to the indicative-CVDt than the two colour transformation algorithms in both cases. Hence, confirming that colour separation of HEA is beneficial to the indicative-CVDt in generic contexts.

Colour separation of the HEA is still in its infancy and a great deal more research is required to determine how great its efficacy is. For example, clinical studies could be undertaken using two sets from one population. One set of participants who would have been diagnosed

as non-CVDt, which would be identified as a control group, and a second set who would have been diagnosed as CVDt, which would be identified as a test set.

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Presentations

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Colour vision deficiency (CVD) is the inability to differentiate between certain colours. In this dissertation, a person who is Colour Vision Deficient is denoted as CVDt. Albany-Ward's (2015) defined CVD as an inherited condition that influences someone's inability to perceive colours correctly. According to Tanaka et al. (2011), it is one of the most common disorders in humans affecting approximately 8% of males and 0.5% of females worldwide. Pramanik, et al. (2012) estimated that 8.7% Jordanian males, 8% of British males, 6.5% of Japanese males and 4% of Chinese males are CVDt.

The world has evolved into a global village, resulting in quick information transformation being from place-to-place electronically, with information transferred being derived from various forms, with common types including academic research or company statistics, which are collected for analyses or reference. Information and data analyses are commonly represented, such as pie charts, maps and images to ensure the recipient can make an appropriate interpretation from the provided information.

CVD affects human cognition to the general environment as it reduces the colour range of an individual, causing loss of contrast in their level of visual perception. CVDt people overcome the failure to distinguish colours by becoming proficient at identification of reliable cues indicating object colours. According to Kelso and Jenny (2017), a CVDt person can use an inverted triangle or heart as a representative red colour and a banana shape as yellow. In the presence of these cues, CVDt people are able to distinguish colours of objects and images and extract essential information with precise interpretation. These shapes represent common objects in society, making colour interpretation easier for CVDt individuals (Kelso & Jenny 2007). Therefore, use of pie charts, maps and shapes are important in influencing the behaviours of the CVDt in their work environments and CVDt sufferers need to interpret them frequently (Hasrod & Rubin, 2016). In the field of a digital image, contrast is the source of information, including the edges and textures of objects. With these types of images, identification of objects is possible using the textures of surfaces and edges, and also aids CVDt individuals in linking images to the actual physical objects from which the information is extracted. In addition, CVDt people can use them to locate the information displayed on the screen using a combination of pie-charts, maps and shapes by analysing and interpreting their sizes and texture. Optionally, these three elements are used to label the position of colours on objects in a computer-aided graphic, such that any movement of the pointer on the graphic shows the name of the colour. According to Hasrod and Rubin (2016), moving the

colour on top of any triangle shows the text “Red”. Therefore the CVDt mainly rely on the contrast between various colours, not the colour itself. CVDt people can also use patterns on maps and pie charts to interpret data and objects without revealing colour information.

However, CVDt people are still at great risk of missing this information (Wenzel & Samu, 2012). These forms of information do not always achieve the intended purpose. CVDt who use computers will face many problems with information interpretation from colour images in all environments. Conveying any information using colours needs to be done in a form that can be understood by everyone regardless of being CVDt or not. Therefore, it is important to train CVDt people with object recognition using visible objects such as pie charts, maps and geometric shapes is essential for maintaining object recognition regardless of colours, and also colour recognition using texture differentiation.

Because of that, CVDt require a computerised solution to enhance their ability to interpret information. Computerised solutions can offer an opportunity to interpret given pictorial images in their daily working tasks more accurately. Currently, there are two types of post-processing algorithms available which are designed to aid the CVDt in specific contexts. Both of these post-processing algorithms can be considered to be colour transformation algorithms as one changes the colour of adjacent colours of an image and the other adds cross-hatched lines of the same colour. In this dissertation a novel concept is developed in that it is a post-processed colour separation algorithm. In this colour separation algorithm, a space of a different colour (white) is added at the boundaries of different colours.

In the case of CVDt individuals, information provided may be incorrectly interpreted. Assistance can be given electronically by providing post-processed images. Currently, the most successful post-processing algorithms are colour transformations of the original image into a newly post-processed image. The idea is that by transforming colours either by changing them (Culp, 2012) or by marking them with lines of the same colour (hatching) (Hung & Hiramatsu, 2013) offer benefit to the CVDt. Both of these algorithms have limited uses and are only beneficial in specific pictorial image contexts. In this dissertation a completely different post-processing concept is introduced, that of colour separation. With this novel algorithm, a different coloured pixel (white – which has the 8-bit integer value of 255) is added to the boundary or interface of differing colours. These added white pixels build-up at colour boundaries to form a white space or a halo, thereby separating colour mixes (Alsafyani et al., 2016; Egan & Alsafyani, 2018). In this dissertation, it is shown that the

novel Halo-Effect Algorithm (HEA) can be used by the CVDt in multiple pictorial image contexts.

This novel colour separation algorithm, where a differently coloured pixel is inserted in the post-processed image at the interface between two different colour mixes shows that this novel colour separation algorithm provides the greatest benefit to the CVDt. This algorithm may also be used in a number of different contexts and is therefore more generic than currently available colour transformation algorithms. Based on results presented in this thesis, the development of the HEA provides a solution to the problems faced by people with CVDt.

The use of statistical analysis to study the impact of approaches to help with CVDt is under-represented in the background research. As such, two statistical techniques are used to corroborate each other and the analyses of the two techniques are considered in great depth and detail. In future studies corroboration and depth of analyses may not be as necessary as those used in this dissertation.

1.2 RESEARCH MOTIVATION

It is without a doubt that the CVDt are faced with a number of problems when shown images for interpreting information (Hasrod & Rubin, 2016). Currently, there are a number of algorithms available which are designed to aid the CVDt in specific contexts. These algorithms all use colour transformations. One type of colour transformation is to provide a post-processed image to aid the CVDt where adjacent colours are changed. Another colour transformation algorithm is to add cross-hatched lines of the same colour to post-processed images. Both of these techniques can only be used in specific contexts such as, spectrum map and the background of character text.

The motivation for this programme of research is to improve and help CVDt to the interpretation of information for modern-day life, for example with the ever-increasing usage of electronic devices. Therefore, this research is to demonstrate a novel algorithm which is not a transformation algorithm as it is a colour separation algorithm. In this novel colour separation algorithm, a different colour is added at the boundary interfaces between adjacent colours. The ultimate goal is to provide greater benefit to the CVDt in not only specific contexts but also in a generic context.

1.3 THE CAUSES OF CVD

Since CVD is an inherited condition an interesting initial question might be: What is the cause of CVD? The answer to this question is not simple and requires some biological understanding of the eye, but not the brain. CVD is caused by a problem with photoreceptor cells in the eye as seen in Figure 1.1.

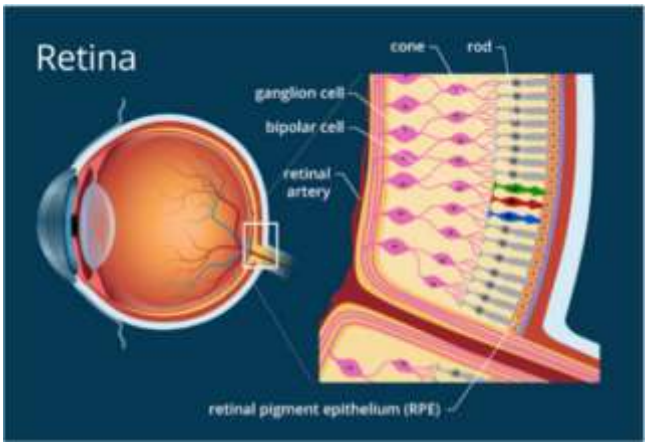

Figure 1.1: Photoreceptor cells (adapted from findlight, 2018)

To further answer this question, it is important to understand how colour vision is correctly perceived. Normal human vision is termed as trichromatic, which means that any colour perceived by humans is reproduced by mixing, in the visual cortex brain, the three primary colours: blue, green and red (Simunovic, 2010). Such mixing or hashing, in the visual cortex, of the three primary colours is used to produce the actual colour, shade and hue seen by humans.

To correctly perceive colours, there are two types of photoreceptor cells in the retina of the eye: cones and rods. Rods are more numerous, about 120 million, and more photosensitive than cones. However, they are not photosensitive to colour. There is about a 17 fold reduction in the number of cones (about 7 million). Unlike rods, cones are photosensitive to colour and they are more concentrated as a yellow spot in the fovea centralis and is commonly termed as the yellow spot or even just the spot (see Figure 1.1). Cone receptor cells are further subdivided into the three primary colours: blue-cone photoreceptor cells, green-cone photoreceptor cells and red-cone photoreceptor cells. Cone photoreceptor cells work at high wavelength levels (between 400 nm and 700 nm), which this is termed as photopic vision. In contrast rod cells work at low wavelength light levels (between 500 nm and 600 nm) which is

termed as scotopic vision. CVD humans mostly suffer from problems with photopic vision, but there may also be problems with scotopic vision.

According to Pramanik, et al., (2012), there are three types of photopic vision cones: short wavelength vision cones (S-cones), medium wavelength vision cones (M-cones) and long wavelength vision cones (L-cones). S-cones tend to be detected mainly at the peak of around 420 nm, M-cones tend to be detected mainly at the peak of around 530 nm, L-cones tend to be detected mainly at the peak of 560 nm and rods tend to mainly be detected at the peak of around 490 nm as seen in Figure 1.2.

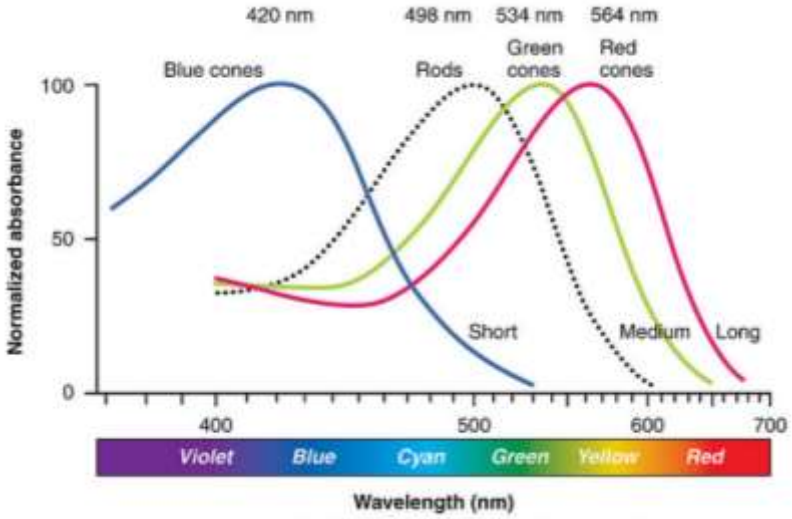

Figure 1.2: The wavelength peaks adapted from (wikipedia, 2013)

These photoreceptors (cones) are the ones responsible for detecting either blue, green or red colours with blue cone responsible for the blue colour, green photoreceptor responsible for detecting green colour, and red photoreceptor responsible for detecting red colour (Albany-Ward, 2015). That is, the blue photoreceptors often respond maximally to short wavelength light (light with 419 nm wavelength which is violet), green photoreceptors respond maximally to medium wavelength light (light with 531 nm wavelength which is green), while red photoreceptors are responded maximally to long wavelength light (light with 538 nm wavelength which is red) (Simunovic, 2010).

CVD occurs when one or more of the cones is unable to respond (or partially responds) to these light wavelengths (colours) (Tanaka, et al., 2010). As a result, the visual cortex of the brain receives wrong information with respect to the perceived colour wavelength mix from the retinal photoreceptor cone cells, resulting into an inability to correctly interpret colours, shades and hues (Pramanik, et al., 2012).

The majority of CVDt sufferers have problems detecting the colour mixes of red and green, or blue and yellow. This creates a problem of colour differentiation between red and green or blue and yellow difficult to perceive. The problem of the two colour mixes is termed as dichromacy. The majority of CVDt sufferers' do see colour but the problem is the differentiation of colour mixes. There are three common types of CVD: Deuteranopia, Protanopia and Tritanopia. Deuteranopia, is sometimes called green dichromacy, as the CVDt suffering from it lack green-cone photoreceptor cells. This means that Deuteranopes lack the ability to distinguish colours in the medium wavelength range of around 530 nm, which are associated with M-cones. For this reason, Deuteranopes have difficulty differentiating red-green colour mixes. Protanopes suffer from the condition known as Protanopia where they lack red photoreceptor cone cells, which is also manifested as a problem with red-green colour mixes. This is frequently termed as red dichromacy. This is around 560 nm and is associated with L-cones. Tritanopes suffer from tritanopia where they lack blue photoreceptor cone cells. This is around 420 nm and is associated with S-cones. This is frequently termed as blue-dichromacy (Albany-Ward, 2015).

There is a minority type of CVD, which is manifested as true colour-blindness and known as Monochromacy. This means that Monochromotes lack the ability to differentiate all colours. That is, Monochromates see the world in black and white, with varying shades and hues of black and white. In the case of monochromacy no photoreceptor cone cells are able to respond to their respective colours (Tanaka, et al., 2010). A complete overview of colour vision deficiency were presented in Appendix A

1.4 RESEARCH AIM AND OBJECTIVES

The main aim of this programme of research is "to provide an improved computerised solution to the problem of how CVDt people read day-to-day information that is presented in a non-monochromatic form, in the form of pie-charts, maps and geometric-shapes."

To achieve the aim, the following objectives are required to be fulfilled.

- **Objective 1):** to develop, implement and test a novel colour separation algorithm that improves information interpretation;
- **Objective 2**): to further develop, implement and test the colour separation novel algorithm such that it can be compared with currently available colour transformation algorithms;

- **Objective 3):** to investigate by use of statistical analyses the extent to which the novel colour separation algorithm provides greater benefit than the already available colour transformation algorithms;

1.5 RESEARCH QUESTION

This thesis aims to provide a suitable answer to the following research question:

- **How to improve CVDt suffers' ability to interpret images with solid colours?**

1.6 STRUCTURE OF THE DISSERTATION

This remainder of the dissertation is organised into six further chapters, where the structure of the chapters is given below:

- **Chapter 2** provides background research on Colour Vision Deficiency (CVD) (previous solutions and present solution).
- **Chapter 3** presents the research methods and the methodology used to investigate and solve the research problem.
- **Chapter 4** explores how the use of the novel HEA provides benefits to the CVDt.
- **Chapter 5** demonstrates the validity of the HEA where survey participants view hard-copy images of pie-charts. The use of surveys to the benefits provided to the CVDt is a novel concept. The data obtained from the surveys are then statistically analysed. Also, further advances in the validity of the HEA by using another survey, but this time using two commonly available electronic devices such as (tablets).
- **Chapter 6** demonstrates the validity of the HEA, Re-colouring Algorithm and Hatching Algorithm, post-processing. The chapter also shows how the three post-processing algorithms aid the CVDt when survey participants view a number of pie-charts, country map and geometric-shapes using the two tablets. Furthermore, this chapter also shows that the novel HEA provides a greater benefit to CVDt than the other two post-processing algorithms.
- **Chapter 7** Presents the conclusions from the work conducted as part of this programme of research. This chapter also presents a discussion of how this work can serve as the basis for future research. Furthermore, this chapter provides detailed considerations for further new work derived from the novel work of this thesis to help those who suffer from colour related conditions.

1.7 LEAD INTO NEXT CHAPTER

The following chapter provides details of the currently available colour transformation algorithms.

CHAPTER 2 BACKGROUND RESEARCH

2.1 INTRODUCTION

This chapter presents a number of background research studies on algorithms have been carried out to help people who are CVDt which provides the rationale of this thesis. It also explores technologies developed to help people who are suffering from colour vision deficiency to distinguish between colours. For example, chroma device technology and Glove device technology. In effect, this chapter provides some of the physical methods and some of the computer methods to help people who are colour vision deficient.

2.2 LMS-RGB TRANSFORMATION MATRIX AND REVERSE TRANSFORMATION MATRIX

The primary problem caused by colour acuity inefficiency in visualisation. Those suffering from deuteranopia are especially not able to develop green, also known as the medium wavelength in the cones of their eye reducing their ability to interpret some images and objects. However, this study suggests the use of LMS daltonization has the ability to enhance contrast and adjust colour to improve perception and interpretation. Vienot, Brettel and Mollon (1999) pointed out that the process of LMS colonisation helps in the modification of the image to fit the colour requirement of colour-blind individuals. The LMS-RGB transformation matrix uses a digital video technology, which constructs LMS specifications based on a standard video monitor consisting of 256 colours. The algorithm specifications are based on the relative extension of long wave sensitivity (L), middle wave sensitivity (M) and short wave sensitivity (S). In the algorithm the stimuli of the confusion line are reduced to a single colour hereby representing the dichromats with a half plane consisting of the neural axis and anchor wavelength hence making the images appear similar to the dichromats and normal colour vision. The advantage of the algorithm is that it takes into account the changed luminosity function of people with dichromancy especially protanopes.

While the LMS-RGB transformation matrix method gives accurate results as suggested by its developers, there are a few deficiencies associated with the method. For example, even though the line of confusion is reduced to a single colour thus providing the dichromats with half-planes consisting of the neural axis and anchor wavelength which makes the images seen by dichromats appear similar to those seen people with normal colour vision, the colour-boundaries may not be clear (Vienot, Brettel, & Mollon, 1999). This may be a problem since some colours may still appear similar after conversion thus making it hard for people with dichromats CVD to distinguish them accurately

Critical Knowledge-Gap Analysis

In this study, LMS-RGB Transformation Matrix and Reverse Transformation Matrix, the active transformation is expected to change the actual physical position of the system. However, it does not make any sense without the coordinate system and further investigation is required to distinguish the active transformation from the passive transformation of a physical system. At the same time, in the reverse transformation, there is a knowledge gap in relating the mathematical matrices to the actual position and dimensions of an object. Another issue that was raised as a point of knowledge gap is in the appearance of the colour. There is a serious problem because some of the colours can still appear similar after they are converted. Therefore, this makes it hard for people having dichromats CVD to be able to distinguish them with high precision. To address and close this gap, there is a need to provide the dichromats with half-planes and neural axis as well as anchor wavelength.

2.3 SELF-ORGANIZING COLOR TRANSFORMATION (SOCT)

Sabudin (2010) explored a colour transformation method for those affected by CVDt when accessing websites. This method focuses on the red-green CVD to increase the ability to access website images. The study, therefore, Self-organizing Colour Transformation, is one of the algorithms that give a positive result, which involve the transformation techniques from the RGB colour spaces to the HSV (hue, saturation and brightness values) colour space and the self-organizing colour conversion technique. Based on the results obtained, the algorithm increases the accuracy, efficiency, and quality of accessibility to websites due to increased colour visibility for those with CVDt. The proposed technique depends on a combination of straight forecasts. At that point, two statistical measurements are processed from the examination of signals obtained. The proportion of these two measurements is a pointer of the nearness/non-appearance of the essential signal (Ruminski et al., 2010). Whereas, the over inspected signal obtained comprises of signal and clamour parts, and the connection between the signal segments in various oversampled channels is high.

Critical Knowledge-Gap Analysis

In this study, Self-organizing Colour Transformation Algorithm, the identified knowledge gap is the unique features and behaviours of the system dynamics, such as automatic change in colours. The gap can be closed by introducing the study of Artificial Intelligence (AL) by engaging research experts with AI system skills. Secondly, in the Self-organizing Colour Transformation Algorithm, there is an over inspection of signal obtained. This comprises signal and clamour parts, and the relationship between the signal segments in the various

oversampled channels is very high. This indicates knowledge gap in the sampling technique of the channels. Another critical gap identified in the "Self-organizing Colour Transformation" method is in the process of creating clear contrasts. It was observed that this algorithm does not give the boundaries clearly for the transformed images. This problem can be solved with dichromats because some of the colours will still be able to appear the same after they are converted, this may be a problem for those with dichromats since some colours may still appear similar after conversion thus making it hard for them to distinguish these colours accurately, as seen in Figure 2.1.

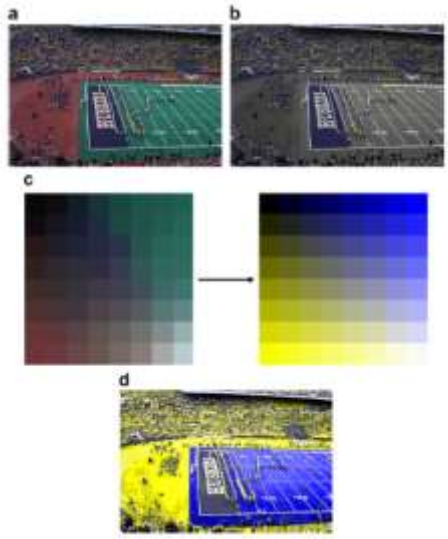

Figure 2.1: The original image, (b) simulation of original image as seen by protanopes, (c) 'original colours' of codebook vectors and their mapped colours (d) image as transformed by "self-organizing colour transformation" adapted from (MA, GU, & WANG, 2009).

2.4 Dichromats Technique (DT)

In another study, Machado and Oliveira (2010), try to refocus on the development of real-time colour contrast enhancement for those with dichromatic vision. The study uses the automatic image re-colouring technique to increase the chances of people with dichromatic vision accessing images and videos on computer systems. The Blind Spectrum Sensing Algorithms provide more quality for this type of vision when accessing computer content by increasing the magnitude of content up to two times more than the current methods used. The study also offers a demonstration of the effectiveness of the technique by developing a visualisation system to show and provide a real-time improved quality re-coloured vision for dichromats. In essence, the introduction of a productive and automatic image re-colouring system for dichromats highlights vital visual points of interest that would in some way or another be unnoticed by these people. While previous methods have approached this issue by changing all the colours of the first image, it creates outcomes that look unnatural to colour

vision inadequate. The approach is around three times quicker than previous ones (Ruminski et al., 2010). The results of a combined correlation assessment with fourteen CVDt demonstrated the effectiveness of their procedure over the previous programmed re-colouring method for dichromats.

Critical Knowledge-Gap Analysis

In this study, Dichromats Technique, there is a challenge in adjusting the visual points in the real-time spectrum. There is no clear way to increase the magnitude of the content up to two times more than the current methods as expected. It was evident that the use of a product and the automatic image re-colouring process in the dichromats exposes significant visual points of interest that may not be noticed at a glance by any observer. Since the past algorithms have used different approaches, this study shows a knowledge deficiency in changing all the colours of the original image. It makes the result look artificial and superficial with the eventual colour vision being scanty. Furthermore, the method does not give clear boundaries on the transformed images. This may be a problem for people with a dichromatic vision since some colours may still appear similar after conversion thus making it hard for them to distinguish these colours accurately. This may affect the quality of interpreting information for them. As seen in Figure 2.2, there is no clear boundary between the enhanced images.

The knowledge gap can be addressed by studying, understanding and integrating the automatic image re-colouring system. Or by providing test environments to increase the opportunities for people with dichromatic vision to access the images and videos on computer systems. Or by the integration of a parallel algorithm; the Blind Spectrum Sensing Algorithms to provide the higher quality vision for this type of image while accessing the computer content.

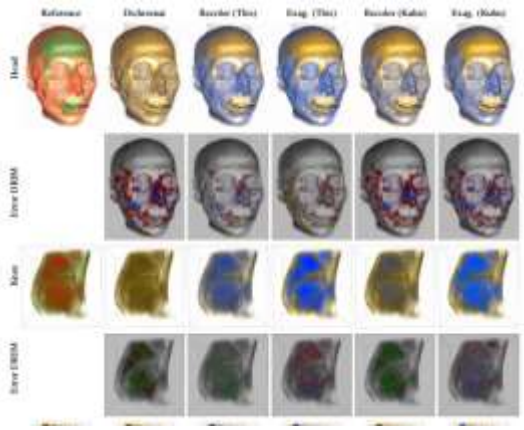

Figure 2.2: Image processing by blind spectrum sensing algorithms adapted from (machado & oliveira 2010)

2.5 AGING PROCESSING TECHNIQUE (APT)

Ruminski et al., (2010) proposed three webs (internet) based image-processing techniques, namely: image simulation technique, "colour transformation-colour difference scaling", and colour transformation-red/green scaling. Image simulation technique uses linear interpolation, which involves the following steps. The first step is gamma correction. The second step is using a scaling factor of 0.992052 to scale colour coordinates to the colour gamut of the same display standard. The third step is the transformation of RGB to XYZ and then to 3D LMS colour spaces. The fourth step is the transformation of 3D LMS to 2D space; the fifth step is an inverse transformation of LiMiSi to XYZ to RGB, and the final step is gamma correction. What this means is that image simulation technique uses linear interpolation to transform original colours to colours that can be viewed by CVDt. The LiMiSi and XYZ are discussed in the glossary section. Figure 2.3 shows original and transformed colours by an image simulation technique.

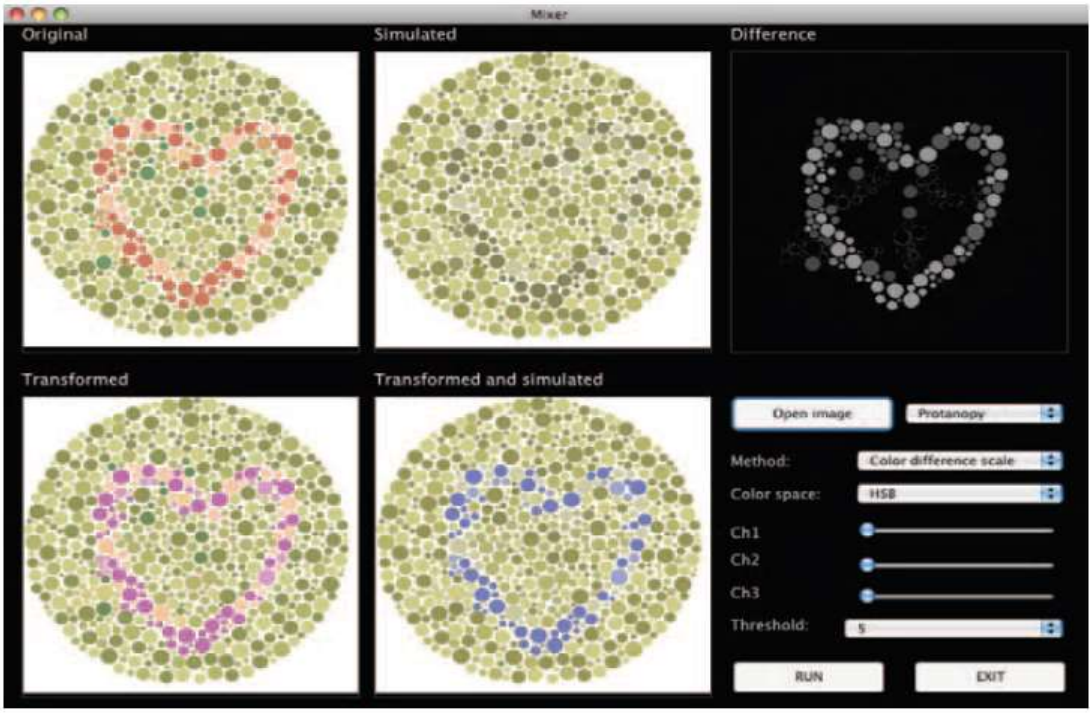

Figure 2.3: Image simulation technique screen shot adapted from (ruminski et al., 2010)

The "colour transformation-colour difference scaling" method uses L*a*b* (discussed in the glossary section) colour space and a number colour difference formulae to transform the image to a grey scale version that can be easily viewed by dichromats. On the other hand, the "Colour transformation-red/green scaling", uses HSB (Hue, Saturation, and Brightness) space for colour simulation. The method generally uses linear scaling parameters to modify saturation and brightness components of an image. Figure 2.4 shows an original image with a simulated one using "Colour transformation-red/green scaling". The top is original colour combination and bottom is the simulated colour combination to enhance the visibility of the colour vision deficiency.

Figure 2.4: Image processing by colour transformation-red/green scaling adapted from (ruminski et al., 2010)

Critical Knowledge-Gap Analysis

In the use of the ageing Processing Technique as an image processing method, there is a deficiency in the expression of the image simulation process and functions. There is no mechanism behind the colour transformation. Again, there is no explanation for the cause of different colour scales between red and green. There is a view that the image simulation method applies linear interpolation to several steps. The six steps are all mentioned but include mechanisms such as gamma correction, use of scaling factor, RGB transformation, the transformation of 3D LMS, inverse transformation and gamma correction. However, these six steps are not explained. It is, therefore, necessary to study and understand the linear interpolation functions and their practical applications in the colour transformation and scaling. In order to modify the saturation scale and brightness of the components in the image, there is a need for understanding of the general application of the linear interpolation in relation to the scaling variables.

2.6 CHARACTERISTICS OF PROTANOPIA AND DEUTERANOPIA (CPD)

The results of the study by Tanaka and Uchino (2010) are consistent with the findings of the previous research in the field. The study recognises that the content in the multimedia platforms has a very significant role in the conveyance of the message from the visual information. The study focused on the characteristics of protanopia and deuteranopia and the need to preserve the original standard colour of the image for easy interpretation. Therefore, the study suggested the need for lightness modification for such issues of colour vision deficiency. The method proposed by Tanaka and Uchino (2010) is based on the conventional un-sharp masking and Ɛ-filtering blending.

Critical Knowledge-Gap Analysis

However, the study leaves a gap in the knowledge of colour differences, recognition and passing of the information. There is difficulty in interpretation; hence, there is a lack of homogeneity of understanding of the colour visualization. This study does not assist the individuals with colour vision problems or those who have difficulty in recognising and differentiating colour mix. There is a need to address this knowledge gap by integrating the Protanopia and Deuteranopia with the RGB for automatic colour changing. At the same time, there is a gap to be bridged in the articulation of the special needs of the individuals with a deficiency in colour vision. The details provided in the multimedia source have to offer significant services in passing on the message from the visual information. However, the colour differences that carry the original information cannot be recognised easily. There is

also a need to address the gap by experimentation of uniform interpretation of colour vision by enough numbers of people in the future.

2.7 COLOUR SIMULATION ALGORITHM (CSA)

Increased research has led to the development of new computer-based techniques, which enhance more colour perception and interpretation by those who are CVDt. According to the study done by Hua Chua et al. (2010), simulations have been used to develop binocular lustres known as Colour-Bless which has led to the improvement of binocular disparity in colour perception. Furthermore, Colour-Bless technology allows the perception and interpretation of the image by using stereoscopic 3D displays. The colour simulation algorithm uses the linear filters, which are fitted to colour outputs systems. The simulator allows changing the colour of an image based on the type of CVD. Once the image is uploaded and the type of CVD is chosen the colour changes immediately to allow the person with colour vision deficiency to make the interpretation.

Critical Knowledge-Gap Analysis

In the study of the Colour Simulation Algorithm, the viewpoint of computer-aided methods is aimed at enhancing vision for the viewers to perceive more colour details. The limitation of this study is that the vision and interpretation of colours are restricted to CVDt users. Another knowledge gap is in the area of simulation. The study does not provide many details about the tools used in the simulation of the binocular. The future improvement of this study has to explain the exact software and hardware systems used in the binocular simulation to detect the difference in the colour vision. As well as, the integration of the Colour-Bless concept to permit the colour perception and analysis of the original image in stereoscope.

2.8 RE-COLOURING ALGORITHM (RCA)

In a study by Culp (2012), he discussed the need to increase map reading with a Re-colouring Algorithm for the maps. There is a deficit in map reading by those with CVDt. Therefore, it is significant to develop techniques to improve the accessibility of maps by people with colour vision deficiency. The algorithm produces the re-coloured images that can be interpreted similarly by the red-green and blue-green colour deficiencies like as with normal vision. The algorithm uses the mass-spring system, which allows the optimisation of colours contained in the input image to enhance the colour contrasts. The algorithm works in three steps, which include image quantisation, mass-spring optimisation and reconstruction of the final colours. The above-described technique produces a single image that can be seen by

red-green deficient individuals and blue-green deficient individuals. In addition, the proposed technique produces multiple images for different types of CVD.

Critical Knowledge-Gap Analysis

In the study of re-colouring algorithm, there is a deficiency in map reading. About 50% of the map is blank, or rather colourless, indicating that the information on these sections is scanty. The knowledge gap can be addressed and closed through increased studies on the level of mapping to read the whole map using the re-colouring algorithm. There is a knowledge gap in map reading since it is enabled only to users with CVDt. In order to fully address the knowledge gap, there is need to study and explain the approaches for developing the systems for improvement of the access to the map by all people including those with a defect in colour vision. There is a significant knowledge gap on the implementation of the algorithm for producing the re-coloured images for uniform interpretation by the RGB mixer for autocorrection of colour. Future studies ought to bridge this gap by stating the algorithm and explaining its implementation in the computer-aided system which allows the actual optimisation of the colours contrast in the input image. As in the previous methods described, this method also does not give clear boundaries between adjacent colours on the transformed images. This may be a problem for those people with dichromats since some colours may still appear similar after conversion thus making it hard for them to distinguish these colours accurately. From Figure 2.5, it is seen that there is no clear boundary between adjacent colours.

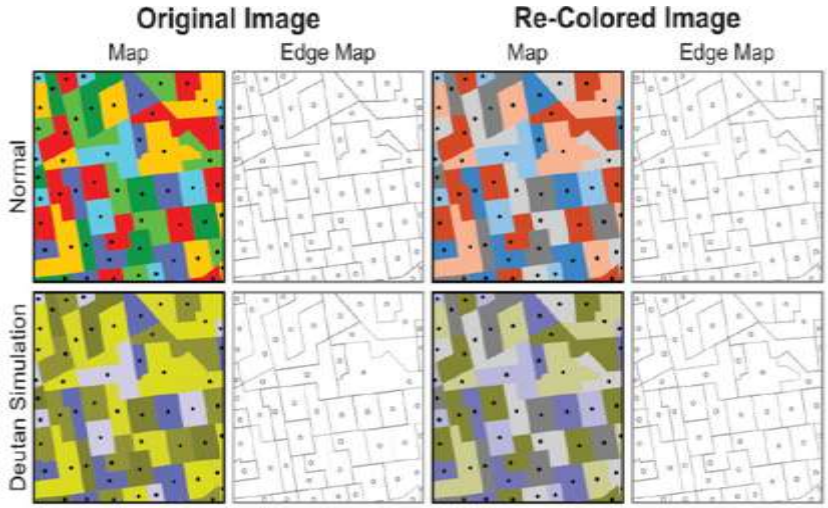

Figure 2.5: Colour transformation by re-colouring algorithm adapted from (CULP, 2012)

2.9 RE-RANKING ALGORITHM (RRA)

Individuals who suffer from colour vision deficiency face a great problem when searching for content online through improper perceptions and interpretation of accessed images. However, the search results of web pages and content on the internet can be optimised to provide accurate results for those who are CVDt.

According to the study by Wang et al. (2014), the accessible image search method is improved through re-ranking of the results based on the relevance of the ranked images in the search account and it improves the accessibility of images for those affected from CVDt. In this method, the image accessibility is quantified based on the degree of the colour information as perceived by the people who are CVDt. The Re-ranking Algorithm is embodied on the computer to be able to generate for CVD while preserving the original image. Estimations are also done to determine the accessibility quantities of the computed images, which enable the re-ranking of images based on quantities increasing the accessibility of web resources by the CVD. The re-ranking algorithm does not transform colours but rather searches online databases for an appropriate image, which it then ranks for accessibility. The problem here is that the displayed image may not be the exact one needed by the web user who affects CVDt.

Critical Knowledge-Gap Analysis

In the study of re-ranking algorithm, there is a show of knowledge deficiency since some images are not accessible for viewing and re-colouring. This algorithm fails to enable the users with vision challenges to search and access the important contents. Just like in the re-colouring algorithm, the re-ranking algorithm does not suggest any software for automation and optimisation of colour vision, but the algorithm indeed includes the aspects of computer-based automation. The solution to this knowledge gap is by conducting further research on the relevant web sources and using them to optimise the accuracy of the results for the CVDt users. The re-ranking method needs to bridge the gap in the accessibility of the images, particularly for CVDt-affected users. In this method, the image accessibility is rated by the perception of the observers on the level of the colour information as seen by CVDt-based users. The re-ranking algorithm has to be clear on the suggested system for automation to simplify the implementation of image processing.

2.10 PATTERN TECHNIQUE TO ENCODE COLOUR TRANSFORMATION (PTECT)

In another study by Sajadi et al., (2013), based on colour transformation in dichromats it recognises the ambiguities in the recognition and interpretation of a large variety of colours. The study, therefore, has developed a pattern encoding technique to improve colour transformation and ensure real colour identification.

The encoding process uses overlaying patterns in the visualised content in which, every colour is provided with a given code. It is directly transformed and detected when the code is read. Specific colours can then be identified while going through an image containing a variety of colours by sensing the encoded pattern. Therefore, the method improves the colour identification mechanism of the dichromats allowing them to perceive colours similar to a person with normal vision.

Critical Knowledge-Gap Analysis

In the Pattern Technique to Encode Colour Transformation, an observer is able to recognise the uncertainties in the colour and image recognition and cannot interpret a wide spectrum of colours. This describes the colour identification in practicality, but addresses the colour transformation only in theory. Apart from colour identification through the dichromats, this study does not express the algorithm for colour transformation and optimization. Therefore, the improvement in colour identification does not have any meaning to ordinary users with no special computerised image processing. Just as in other methods, this method does not give clear boundaries between adjacent colours on the transformed images. This may be a problem since some colours may still appear to be similar after conversion thus making it hard for them to distinguish these colours accurately.

2.11 RE-COLOURING ALGORITHM (RCA)

The most common type of colour vision deficiency involves red-green CVD. Therefore, more research should be concentrated on this form of CVD. However, according to Kim and Ko (2013), the re-colouring algorithm has been developed to enable the adjustment of the red-green CVD through the use of HSV colour space to enable them to improve their perception of red and green colours. The algorithm improves the hue and luminance value of the colours in the image during the conversion to HSV colour space. Therefore, the algorithm improves the hue and luminance value of the colours in the image during the conversion to HSV colour space. Furthermore, the algorithm ensures that the original image during the re-colouring process remains unchanged for people with normal colour vision.

Critical Knowledge-Gap Analysis

In the re-colouring algorithm, there is an ambiguous presentation of colour recognition, visualization and presentation. This is especially true when several colours are involved in the image. The mitigation approach to this issue has been the development of an encoding pattern, for improvement of the recognition and transformation. It is indicated in the algorithm that assigns colour codes for easy reading. The study lacks an illustration of the colour coding and the coding cannot aid an ordinary observer to interpret a wide spectrum of colours. Therefore, there is a need to improve the content of this study by adding the illustration of the colour coding pattern to separate the different colours. The RCA algorithm gives a combinational reconfiguration that is more general, but the combinatorial reconfiguration issues are not addressed in details. For example, there is no clear sequence to find the transformations from one feasible solution to another. In that regard, all the intermediate results are also deemed feasible. The solution to this challenge is by modifying the model to operate in dynamic situations with a predictable sequence of transformation.

2.12 HATCHING ACCUMULATION ALGORITHM (HAA)

People who are CVDt are not capable of sharing documents the same as those who have normal vision because of the difficulty of perception of the colours. However, it is important for them to have equal opportunities when interpreting content such as graphics, letters, and images.

According to Hung and Hiramatsu (2013), the development of a Hatching Accumulation Algorithm makes a significant improvement to the specific angle on the confusion line to improve the perception of images with colour for those with dichromats. The algorithm uses the variation of the position of the confusion line while maintaining the colour of the original image. This means that the algorithm does not change the original colour of the image being interpreted. It instead matches the original image at various angles with each segment having a different hatching angle, as seen in Figure 2.6.

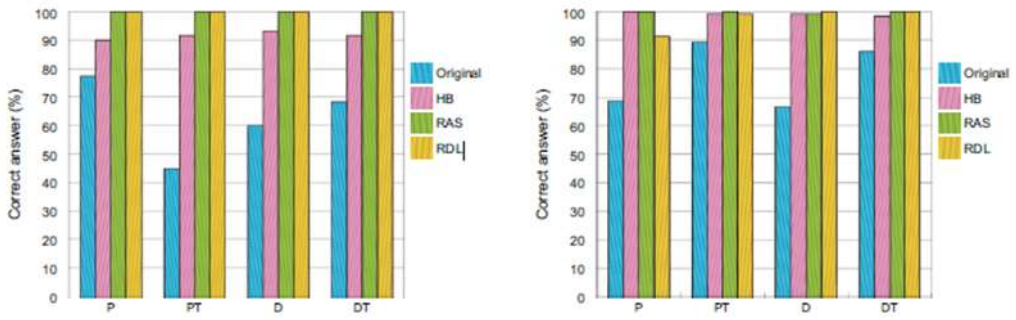

Figure 2.6: Images hatched by hatching accumulation algorithm adapted from (HUNG & HIRAMATSU, 2013)

Additionally, the lightness levels of the image are adjusted through the introduction of the light and dark lines to balance the level of perception. Therefore, through such adjustments using the hatching technique, both Hong and Hiramatsu (2013) expected that the people with normal colour vision, and individuals who are CVDt they can make similar interpretations of images. The hatching accumulation algorithm uses a simple hatching method to enhance the visibility of those who are CVDt. Another difference is that the hatching accumulation algorithm does not change the original colour.

Critical Knowledge-Gap Analysis

In the hatching accumulation algorithm, normal people and those with CVDt do not share information, hence their understandings of colour balancing are different. On the other hand, it is expected that the two parties will have the same opportunities of interpretation of the content of images created by the colour mix. The implementation of this algorithm does not involve the observation of the users with CVDt to confirm the claim. The development of the hatching accumulation algorithm needs to involve these users or observers to create a significant development. To improve the perception of images for people, there is a need to integrate the hatching accumulation algorithm with the colour coding for people with dichromats. Additionally, the variation of the image position is important, but this study has to explain ways of maintaining the colour of the original position of the original image.

2.13 VALIDATING THE TWO COLOUR TRANSFORMATION ALGORITHMS

To ensure that the two transformation algorithms do provide benefits as discussed a validation study was conducted which compared the benefits of each algorithm in their specific contexts. In this validation study the individual types of CVD were considered: Protanopia, Deuteranopia and Tritanopia. The results of the validation study confirmed that each algorithm is only beneficial in the specific contexts for which they were designed. The complete study was presented as Appendix B.

2.14 COLOUR MATCHING ALGORITHM (CMA)

In another study by Kannan and Dakhore (2014), they used a system consisting of a camera, microphone and a computer in assisting people who suffer from colour vision deficiency to choose clothes and read the other factors such as cost, size, material and length. However, there is need to use computer systems in improving the capacity of people who suffer from CVD. This need is not limited to shopping, but it should be exploited for all available opportunities. The study showed that computer technology could be used effectively to improve the abilities of those with red-green colour vision deficiency. The algorithm consists of an integrated system in which the camera that is connected to the computer performs the colour and pattern matching processes. The microphone controls the speech commands and configurations while the audio feedback system provides the results of the matching patterns and colour of the clothes. Therefore, both use mathematical models to transform original images to images with colours can be clearly seen and interpreted by people who are CVDt. However, the Colour Matching Algorithm uses a complex system of the camera, microphone and a computer to enable CVDt to make correct colour choices when purchasing clothes.

Critical Knowledge-Gap Analysis

In the Colour Matching Algorithm, the author expresses the need to apply computer-based systems to improve the ability of people suffering from colour vision deficiency. The study indicates that computer-aided mechanisms technology could be used for efficiency. The knowledge gap in this claim is that the study does not describe the process flow for the red to green colour change and the exact cause of the vision deficiency. Future studies ought to address and solve the deficiency through an integrated system in the algorithm. For example, it has to be connected to a central server since an algorithm has a system that integrates with cameras. This is to link the camera to the computer to perform the colour and pattern matching processes.

2.15 INFORMATION COMMUNICATION TECHNOLOGY BASED ALGORITHM (ICTBA)

According to the findings of (Khan et al. 2014), the techniques and simulations discussed are only meant for the improvement of colour vision to specific colour vision deficiencies. The study, therefore, suggests the need for additional research to ensure the development of Information Communication Technology (ICT) based algorithms to assist people with all CVDt problems in adequately interpreting colours. Therefore, this study focuses on the important features that software developers must use when developing colour vision deficiency applications. These features include colour harmonisers, colour simulators, colour colonisers and colour identifiers. According to the findings of the research, the combination of these features will help alleviate the problem of colour vision deficiency.

The colour identifier automatically identifies the required colour in an image and transfers it to the camera input. The daltoniser enhances the image taken from the input camera to increase colour perception. The image is uploaded to the simulator, which converts the original image to an image that can be perceived correctly by someone who is CVDt. Finally, the harmoniser feature harmonises the colours in the image based on the colour wheel to give the user an appropriate observation. ICT based algorithms use a complex system consisting of a camera, daltoniser and a computer, which consists of the simulator, colour harmonisers, colour identifiers, and colour colonisers to transform original to final image with the colour that can be interpreted by individuals who are CVDt.

Critical Knowledge-Gap Analysis

In the ICT Based Algorithm, the focus is on the improvement of the colour vision since there are noticeable colour vision deficiencies. The clarity of the colour in the hue and the colour luminance value of each distinct colour of an image are expected to assist in the conversion to the HSV colour hue. The connection between the colour encoding and the colour luminance is unclear and any observer applying this algorithm has to understand this from additional literature before the original image is processed in the re-colouring process. Without the illustration of interconnection in the coding and luminance, the image remains unchanged in the eyes of observers with and without colour vision. For people with CVDt challenges, this study suggests a complex system consisting of cameras and daltonisers but ignores the special audio-visual equipment for visually impaired people. This gap has to be solved by analysing all possible CVDt problems in the target area.

2.16 CHROMA TECHNIQUE (CT)

Colour vision deficiency affects the daily activities of people because of the reduction in performance. Several techniques help people with CVDt in their daily tasks thereby improving their performance and efficiency in the process. According to Tanuwidjaja, et al. (2014), one such technique involves the use of Chroma, a wearable augmented reality system employing Google Glass technology. The method has improved the perception of images through filtering to provide a real-time experience. The Chroma Technique automatically adapts to the scene-view using colour saliency dedicated algorithms depending on the type of colour vision deficiency. The technique has been associated with the improvement in real-time perception and recognition of images improving the accuracy of people with CVDt in their daily tasks.

Critical Knowledge-Gap Analysis

In the chroma technique, there is a knowledge gap in relating the colour vision deficiency to the daily activities of people. The impact of impairment is reduced activities. This is a claim that can only be confirmed by practical research with a hypothesis relating the quantitative deficiency to the performance indicators. In solving this deficiency, many techniques help people with CVDt problems to improve their performance and efficiency in the process. Only one technique, the chroma, is explained as an improved reality system that uses Google Glass technology. There is a need for experts to communicate the other mechanisms apart from the chroma. It is risky to depend on one method because there is a possibility of failure. It is important to improve this perception of images by filtering, which provides a real-time experience.

2.17 RGB TO HSV ALGORITHM

A study conducted by Shayeghpour, et al., (2014) indicated that the problem of CVDt results is having a narrow range perception of colours. Therefore, they often face difficulties in recognizing colours and require colour transformation mechanisms to achieve normal perceptions of colour. With, the RGB to HSV Algorithm, the RGB values containing each pixel of a given image are converted to HSV values using pre-defined regulations. During the process of the conversion, the colours that cannot be read are readjusted so they can be easily perceived by an individual with CVDt. Furthermore, the algorithm enables the overall contrast of the visualised image to be constant throughout to prevent the confusion that might arise during the transformation process. RGB to HSV algorithm converts RGB values to HSV.

Critical Knowledge-Gap Analysis

In the RGB to HSV algorithm, the RGB colour values are used with the conversion of each pixel of the image to HSV values. This leads to loss of some image properties and colours details are lost in the conversion process, following the readjustment of the colours that cannot be read by the individual with CVDt. This deficiency in knowledge causes distortion of the image properties and there is a need to manage colours without colour readjustment. As the RGB changes to HSV, the algorithm colour conversion may hinder the overall contrast in the visualisation of the image. Therefore, this confusion needs to be prevented before the transformation process. In this study HSV and RGB are described as the transformation of RGB colours paces. Therefore, (HSV) is necessary to be used in the hue and saturation as opposed to the addition or subtraction of the colour components. Also, this study ought to provide an outline for the colour hue components and colourimetry in relation to the RGB colour space.

2.18 COLOUR OPTIMISATION ALGORITHM (COA)

Colour forms one of the essential visual variable techniques that is used for the grouping of data or encoding information about various features. Therefore, the relationships between the features and the specific groups appear in the form of visual patterns during visualisation. However, biases can occur because of optical illusions resulting from inappropriate perception and analysis of a given image or objects. Mittelstädt, et al. (2014) on the methods for compensating contrast effects suggests the use of colour optimisation algorithm improve colour perception. The algorithm uses perception models and perceptual metrics to reduce the colour effects caused by physiological contrasts.

The perceptual metrics and models help in doubling the accuracy of perception through the comparison and estimation of the encoded colour data values. Therefore, the method helps in the improvement of visualisation of images and objects for individuals who are CVDt. The colour optimisation algorithm uses perception models and perceptual metrics to reduce the colour effects caused by physiological contrasts.

Critical Knowledge-Gap Analysis

In the Colour Optimisation Algorithm, the author expresses the need to use computer-based systems for the creation of visual patterns to eliminate the element of visual illusion. There is a visible knowledge gap, the non-uniform perception of people about the image. This study indicates the use of methods for compensating the contrast but maintaining efficiency. The

knowledge gap in this claim is that the study does not describe the process flow for the actual colour optimisation. Future studies ought to present a common source of information to guide the understanding of different people about the image whether colour changes or not. In addition, colour quantisation or optimisation as described in this study provides a colour palette, which has only a few colours (range from 8 to 255). There is need for more choices of colours to make up the palette and influence the quality of the image with optimal colour.

2.19 COLOUR CAT ALGORITHM (CCA)

Similar, to the findings of this study, Mittelstädt, et al., (2015) propose the use of the Colour Cat Algorithm, which is an improved technique from the ColourBrewer and PRAVADA (Perceptual Rule-Based Architecture for Visualizing Data Accurately) colour techniques to improve map reading. ColourBrewer technique was developed by Brewer C.A., and it is available online to assist people who are CVDt identify the features of maps by selecting the nature of data they want. The PRAVADA colour technique was developed by Bergman, et al., (1995) as a tool for helping persons who are CVDt interpret maps accurately. The colour cat algorithm offers an improved technique that allows a combined analysis of the maps, thereby improving the ability of people with colour vision deficiency to achieve qualitative and sequential data on the maps.

Therefore, the creation of this technique has improved the map analysis for the people with red-green and blue-green colour vision deficiencies. The algorithm uses a manipulation mechanism that transforms any picture to be seen clearly by a CVDt individual. The manipulation was dragging and dropping the picture or map in a CVD simulator and choosing the view suited for an individual (Banic & Loncaric, 2014). The views include trichromatic, dichromatic and monochromatic. The algorithm was developed to enable the CVDt to read and interpret information on a map.

Critical Knowledge-Gap Analysis

In the study of the colour cat algorithm, the main focus is on the map reading by the CVDt people. Since it enables the people to use data to identify the components or sections of the image they require. It describes the algorithm, the computer-aided tool and the process flow for improved map reading. It, therefore, improves the map reading and analysis for people with a deficiency in colour identification, those who confuse red for green and blue for green. The deficiency in this study is that the algorithm must be enabled to manipulate the mechanism for image transformation before observers with CVDt problems view it clearly.

There is a need for further studies to identify ways of simulating the map with a CVD simulator without necessarily manipulating the original image.

2.20 ATOMISATION METHOD (AM)

Apart from the map-reading techniques, more computer-based techniques are important for the improvement of the perception and interpretation of colour related content in the multimedia platforms. Milic, et al., (2015) propose the use of Atomisation Method to achieve re-colouring of the images perceived to be confusing to improve the image quality. The method uses a technique in which the image colour centre is placed on a single confusion centre. Therefore, two colours perceived to be different by a person with CVDt fall in the same confusion line. The conclusion is that colours enhance the interpretation of the individual.

The atomisation method allows the filtering of objects using a device called Chroma to provide the real-time scene of the picture. The Chroma device allows automatic scene view depending on the type of the CVD to improve colour saliency. In addition, the atomisation method was developed to enable people who are CVDt to read and interpret information on a map accurately. Although the two models differ in a number of ways, both use mathematical models and calculations to transform images into what can be seen by CVDt individuals.

Critical Knowledge-Gap Analysis

In the atomisation method, the map reading method is supplemented by more computer-based methods. This is aimed at the improvement of the perception and visualisation of the colour-based content of the multimedia platforms. It is an improved re-colouring of images but it confuses the view of image quality. The Chroma device provides the real-time image scene for improving colour saliency. However, both use mathematical models and calculations to transform images into what can be seen by CVDt individuals. The knowledge gap in this study is that it implements the very idea of the chroma algorithm except for the filtering. More studies are needed to differentiate the atomisation method from the chroma algorithm. The atomisation process needs to be enabled to select the objects with the chroma to give the instant time scene. This study lacks the information about the Chroma device and the mechanisms by which it automates the real-time scene in view of the CVD and for improvement of the colour saliency.

2.21 COLOUR INPUT TO HAPTIC OUTPUT ALGORITHM (CIHOA)

Apart from the chroma technique used for the eyes, there has been a new development, which works for the hands. The Chroma Glove device is worn on the hands to improve the perception of colour through touch. According to Woźniak, et al. (2015) the device uses a colour input to haptic output mechanism in which the colour of the object in touch to the worn devices is detected and transformed to be understood by CVDt people wearing the device. The device performs the role of enhancing the colour-sensing abilities of the users. Therefore, the device uses the variation in pulse widths on the vibration motor to communicate to the user the differences in the hue of the image or object. The data on the colour of the image is then illuminated and interpreted through the colour sensors, which are placed on the palm hence increasing the colour perception of the user. Therefore, the Colour Input to Haptic Output Algorithm uses Chroma Glove device, which helps CVDt detect colour differences by hand.

Critical Knowledge-Gap Analysis

In the colour input to haptic output algorithm, the image transformation is done using the chroma glove device for sensing colour. The concept covers differentiation of the colour texture through a hand. This is a new area of study and has many knowledge gaps. It is not easy for a common person to understand sensing of colours by hand. There is need to provide full details of the algorithm, mechanism and process flow for image colour sensing by hand. This study does not describe the technical functions used by the chroma glove device to process the colour input and give the haptic output.

This deficiency can be mitigated by an additional diagram illustrating the process flow from the input to the transformation algorithm and finally, the output, in which the colour of the object is detected and transformed to be understood by CVDt people wearing the device.

2.22 MULTILAYER NEURAL NETWORK ALGORITHM (MNNA)

Many cases of CVD occur because of the deficiency in the number of cone cells performing colour recognition. Therefore, people who are CVDt face a great problem with discriminating between the combinations of specific colours. Such individuals require help through the conversion of the colours of the primary object to perceptible colour versions. Research conducted by Network (Machado & Menez, 2016) consists of the development of a Multilayer Neural Network Algorithm. Multilayer neural network algorithm uses a number of layers to transform the original image into an image with colours that can be easily seen and interpreted by those who are CVDt. The neural network comprises a set of inputs,

processing unit and output. The processing unit generally consists of three layers, the layer of image colour conversion, the perceptual model for CVD layer and colour discrimination layer. The conversion layer converts the colour combinations to the perceptible forms in the perceptual model, which is transferred to the colour discrimination layer to improve the discrimination performance, hence enabling the appropriate differentiation of colours.

Critical Knowledge-Gap Analysis

In the multilayer neural network algorithm, digital images are converted into improved output for CVDt people to interpret and use. During conversion, this study does not provide the mechanism or the processing of image conversion in the layers and the perceptual model for the CVD layer or the colour discrimination layer. However, it describes the result as the perceptible forms of colour combinations for CVDt people to understand. The MNNA has to provide a process flow and illustration of the colour conversion in the layers as the original image is transformed into the perceptible image with easy-to-interpret colours for CVDt people.

2.23 SUMMARY OF APPROACHES OF SOLCING CVDT PROBLEMS

Table 2.1 illustrates the differences between techniques with regards to aid CVDt individuals to interpret information in their daily working tasks.

Table 2.1: Summary of approaches to solving CVDt people

Studies	Algorithm	Features	Limitations
Vienot, Brettel and Mollon (1999)	LMS-RGB transformation matrix and a reverse transformation matrix	• The original confusing colour shades are transformed into colour shades that CVD can differentiate	Colour-boundaries are not clear making it difficult for the CVDt to accurately differentiate the confusing colours
Sabudin (2010)	Self-organizing Colour Transformation	• Transforms web images to make it easier for the CVDt people to read web pages	• There are no Colour-boundaries. • The transformed may still appear similar for the CVD
Machado and Oliveira (2010)	Dichromats Technique	• The algorithm re-colours or transforms the colours of the original image to help the dichromatic accessing images and videos on computer screens.	• Mainly developed to be used on computer screens. Its performance on paper is therefore not known. • There are no Colour-boundaries. • The transformed may still appear similar for the CVD
Ruminski et al., (2010)	Imaging Processing Technique	• Image simulation technique • Colour transformation	• There are no Colour-boundaries. • The transformed may still appear similar for the CVD
Tanaka and Uchino (2010)	Characteristics of Protanopia and Deuteranopia	• Original colour is preserved • The brightness of the confusing colour shades is alternated	• There are no Colour-boundaries.
Hua Chua et al. (2010)	Colour Simulation Algorithm	• Original colour transformation	• No clear boundary between the adjacent colours
Culp (2012)	Re-colouring Algorithm	• Original colour transformation	• No clear boundary between the adjacent colours

Wang et al. (2014),	Re-ranking Algorithm	• Re-ranks web search results based on the relevance of the ranked images to the CVDt individual	• The displayed image may not be the exact one needed by the CVDt
Sajadi et al., (2013)	Pattern Technique to Encode Colour Transformation	• The original confusing colour shades are transformed	• No clear boundary between the transformed colours
Kim and Ko (2013)	Re-colouring Algorithm	• The original confusing colour shades are transformed	• Colours may still appear to be similar after conversion • No clear boundary between the transformed colours
Hung and Hiramatsu (2013)	Hatching Accumulation Algorithm	• Original colour is maintained • The adjacent colours are hatched using hatching lines running in different directions	• No clear boundary between colours
Kannan and Dakhore (2014)	Colour Matching Algorithm	• An integrated system of the camera, microphone and computer to help CVDt make correct colour choices while buying. • Original images are transformed.	• No boundaries between the transformed colours. • Expensive as many accessories are needed: microphone, camera and computer
Khan et al. (2014)	ICT based algorithm	• Has a camera, daltoniser and a computer which consists of the simulator, colour harmonizers, colour identifiers, and colour colonizers to transform original to the final image	• No boundaries between the transformed colours. • Expensive as many accessories are needed: daltoniser, camera and computer
Tanuwidjaja, et al. (2014)	Chroma Technique	• Uses chroma which is a wearable augmented reality system employing Google Glass technology	• No boundaries between the transformed colours.
Shayeghpour, et al., (2014)	RGB to HSV Algorithm	• The original image colours are transformed into	• No boundaries between the transformed

		colours that can be discriminated by the CVDt •	colours.
Mittelstädt, et al. (2014)	Colour Optimisation Algorithm	• Uses colour contrast and brightness to make confusing colour shades differentiable by the CVDt	• No clear boundaries between the transformed colours.
Mittelstädt, et al., (2015)	Colour Cat Algorithm	• Transforms the colour combination in the maps and internet pages to help CVDt people interpret information portrayed by the maps and internet pages	• Does not include halos at the boundaries of the adjacent colours
Milic, et al., (2015)	Atomisation Method	• The original image is recoloured to colours that be discriminated by the CVDt	• Does not include halos at the boundaries of the adjacent colours
Woźniak, et al. (2015)	Colour Input to Haptic Output Algorithm	• Uses chroma glove device is worn on the hands to improve the perception of colour through touch	• The chroma gloves can be expensive •
Machado & Menez, (2016)	Multilayer Neural Network Algorithm	• Transforms the colours of the original image to colours that can be differentiated by the CVDt	• No clear distinction between the adjacent colours due to lack of halos at the boundaries

2.24 CONCLUSION

Even though a number of research studies on algorithms have been carried out to help people who are CVDt, most of these studies present limitations. They are usually lack in certain aspects. So at times it makes it hard for the person with CVDt to correctly interpret the information being portrayed by colours. For example, most of the algorithms that have been developed do not give a clear boundary between adjacent colours after the transformation. This may be a problem since some colours may still appear to be similar after the conversion thus making it hard for the individuals who are CVDt to interpret them accurately. The newly proposed Halo-Effect Algorithm solves this problem by introducing halos between the colours (Colour-boundaries). These halos (enhanced boundaries) provide a clear boundary

between these confusing colours thus enabling individuals who are CVDt to view contrasting colours accurately. This allows them to make accurate decisions on par with individuals who are non-CVDt.

2.25 LEAD INTO NEXT CHAPTER

The following chapter provides details regarding the used methodology for this thesis.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter provides details regarding the research methods and approaches used in this dissertation. In addition, it also demonstrates the comparison of studies, data collection and sampling methods. Associated ethical considerations and analysis methods are also stated.

3.2 RESEARCH METHOD

Research methods are crucial in research as they are able to be a part of any research methodology, achieving specific aims and objectives. These methods can be divided into three: quantitative methods, qualitative methods and the third type of methods which use a mix from both the quantitative methods and the qualitative methods (Bell, E. et al., 2018). This is frequently abbreviated to the mix methods.

Quantitative methods are ultimately linked with collecting and analysing data in a numerical form, concentrating on sizeable datasets (Bell, E. et al., 2018; Creswell, J. W. and Creswell, J. D., 2017). Whereas, with qualitative methods, there is a build-up of knowledge on specific areas from the users' perspective (Creswell, J. W. et al., 2007).

Quantitative methods can encompass rigorous quantitative analysis in a formal manner, and can be subdivided into inferential, experimental and simulation methods. In this dissertation the inferential method was used to construct databases through which determination of characteristics or relationships of populations can occur. This involves performing survey research where a sample of a defined population is studied. The experimental method has a much more controlled search environment, meaning some variables are treated to monitor their effect on other variables. Simulation methods are used to build an artificial environment through which relevant information and data can be created.

The qualitative method focuses on self-assessment of attitudes, opinions and behaviour, and is essentially based on the researcher's views and impressions. This method can draw on focused group interviews and deep interviews.

To achieve the research objectives of this thesis, a quantitative method was followed. The type of method used was inferential by use of surveys, where participant responses were gathered from a series of questions. The initial survey used paper based images and all other surveys used electronic images shown on two currently and popularly used Personal Digital Assistants (tablets). As part of the inferential method, specific design features were identified. The specificity of the design features was such that they would aid the people who

are CVDt to be able to correctly interpret the information given in the images. A complete overview of the research approach, research strategy, research design and research process for this thesis were presented in Appendix C.

Table 3.1 illustrates the differences between quantitative methods and qualitative methods with regards to the aim, the nature of reality, the relationship of the researcher to the research, the language that is used, the researcher‘s knowledge of the research and research processes.

Table 3.1: Description of the differences between qualitative and quantitative research methods

Questions	Quantitative	Qualitative
What is the aim?	To categorise research features, measure them and then develop statistical models, describing observations.	To provide an in-depth and complete description.
What is the nature of reality?	Objective and individual (excluding researcher). Seeks precise assessment and measurement of the target audience. E.g use of questionnaires, surveys etc.	Subjective and multiple as seen by participants in the study. E.g is employing in-depth interviews of participants, their observations etc.
What is the relationship of the researcher to the research?	Independent of the research.	Interacts with the research.
What language is used?	Formal, based on specific definitions, impersonal voice, and use of accepted quantitative words.	Informal, evolving decisions, personal voice, and accepted qualitative words.
What is the researcher‘s knowledge of the research?	The researcher acknowledges what they are looking for.	The researcher cannot acknowledge what they are looking for.
What is the research process?	All aspects are designed with caution before data	The design appears after the research revealed. The researcher

	collection. The researcher uses tools such as surveys to gather numerical data, which is available in a statistical form. Has the ability to evaluate hypotheses more effectively.	takes on the role of data collection tool. Data are available in the form of pictures, objectives or words. Qualitative data is more time consuming, less capable of generalising.

3.3 APPROACHES TO AIDING THOSE WITH CVD

There are two approaches to aiding the CVD: computerised or physical. Computerised approaches use process imaging where a post-processed image is generated in a manner such that it aids the CVD in a generic manner. Physical approaches use over-layering of spectacles, tailored to a single individual only.

3.3.1 COMPUTERIESED TECHNIQUES

Computer algorithms process colour mixes such that the post-processed colour mixes are changed in a manner that is beneficial to the CVDt. There already exists a number of post-processing techniques that use computer algorithms to modify colours in different ways to aid the CVDt with images from particular contexts. Hence, these algorithms, transform colours in the pre-processed image to furnish a transformed post-processed image such that the CVD can interpret the information provided in the pre-processed image correctly. Currently such transformation post-processing algorithms can only be used for specific contexts and there is no algorithm that aids the CVD with general contexts. The Halo-Effect Algorithm (HEA) is not a colour transformation algorithm as it is a novel colour separation algorithm which has been developed and implemented with the general case in mind. The remainder of this dissertation focuses on this novel colour separation post-processing algorithm to be used in a generic manner unlike those colour transformation algorithms that are currently available. This dissertation also demonstrates statistically that this is so. Statistical analysis of post-processing algorithms is also novel.

3.3.2 THE HALO-EFFECT ALGORITHM (HEA) NOVEL

The HEA is a novel colour separation technique developed by (Alsafyani et al., 2016; Egan & Alsafyani, 2018) with the intent of helping the CVDt to discriminate different colours in a number of given computerised images. The novel concept of the HEA is to insert a white space (the colour separation), to produce a gap, between any given colour boundary interface,

whilst not detracting from the original overall image. As this is colour separation there is no need for any colour transformations of either changing the colour mixes or hatching the colour mixes. Hence, the post processed image does not have any alteration of colours from the original image nor does it add extra shades to the original image. Instead it adds a separation marker (visible boundary interface) at the boundaries between two colour regions.

Figure 3.1 provides the pseudo code of the pixel-by-pixel image processing of the Halo-Effect Algorithm. An image file is inputted into HEA. The image input file is copied to a newly created output file. The input file can now be closed and it remains exactly as the author created it. The output file is viewed as a two dimensional array of rows where each cell in the row is a pixel which has an r.g.b value.

```
c=fgetc (outputfile)
Struct.pixel{
r, g, b unit32;
};
struct pixel candp;
struct pixel nextp;
whitep=0xff;
width=getWidht(putfile);
hight=getHight(putfile);
while (c!=EOF){
    for (!=0; j<width; i++) {
        for (!=0; j<heigh; i++) {
            if((candp. r!=nextp.r) ||
               (candp. g!=nextp.g) ||
               ((candp. b!=nextp.b)) {
                        candp.r=whitep;
                        candp.g=whitep;
                        candp.b=whitep; }
               increment candp to address of nextp;
               increment nextp to address of next pixel address
(nextp+1);
            }
     }
}
fclose (outputfile);
```

Figure 3.1: Shows the pseudo code of pixel-by-pixel image processing of the HEA

The size of the image is computed so that the two dimensional array can be setup and then traversed as (height,width) co-ordinates. The size of the array is determined by the number of rows (height) in the image and the (width) which is the number of pixels in each row. Each pixel in the two dimensional array has an address, and it is this address that the HEA points to. The HEA loops through the two dimensional array addresses, row-by-row and pixel-by-pixel.

As the HEA loops, it compares for inequality the r.g.b value from the address of a candidate pixel with the r.g.b values of the next address pixel in the array. In the case that inequality is found then the two pixels are of different colour and a boundary interface has been detected. In which case the r.g.b value of the candidate-pixel is altered to white (r=0xff, g=0xff and b=0xff).

Irrespective of the outcome of the inequality comparison the current candidate-pixel array address is incremented to the next-pixel array address and the next-pixel array address is incremented to subsequent-pixel array address. This procedure continues until the end of the row, and then the next rows' pixels are compared for inequality pixel-by-pixel. After parsing through several rows of the two dimensional array a collection of boundary interfaces will have been built up into a Region of Concern. The loop continues this row by row and pixel-by-pixel interrogation until the EOF (end of file) marker is encountered. At which point the output file is closed and an accessible CVD file should have been created.

Figure 3.2 is a pictorial representation of the HEA. Having copied the original file 1), by creating and then opening for amendment a new output file 2), the HEA compares the image file pixel-by-pixel (candidate-pixel with next-pixel). When there is a colour change a boundary interface is detected in 2). In this example a boundary interface is detected when the candidate-pixel is red and the next-pixel is green. The candidate-pixel is then changed to the colour white in 3).

As the image file is parsed row-by-row a region, of boundary interface changes, is identified which builds up to the Region of Concern in 2) and in 3) (shown as an oval). An additional pixel cannot be inserted between the two pixels at a boundary interface as this would increase the overall size of the image by adding extra columns. Also, it is highly likely that the resultant image might be too large for the page size. Furthermore, the addition of pixels may distort the shape of the image. For these reasons at a boundary interface in 2), the candidate

pixel is changed to the colour, white in 3). The result is that there is no addition of pixels and so the overall output image size in 4) remains the same as the original input image in 1).

The downside is that it means the number of pixels of the same colour before the boundary interface is decremented by one, which could have a knock-on effect as it might result in a marginal change in the shape of the accessible CVD image in 4). Since, the change is marginal it is considered that the viewer of the image will not notice any difference in the shape of the image, but will be able to differentiate the more important boundary interface colour change. Therefore, this is an acceptable trade-off. Also, it should be borne in mind that the HEA furnishes as 4) a different file to the original file 1), which means the original file 1) can be viewed whenever necessary and any differences between the two files noted.

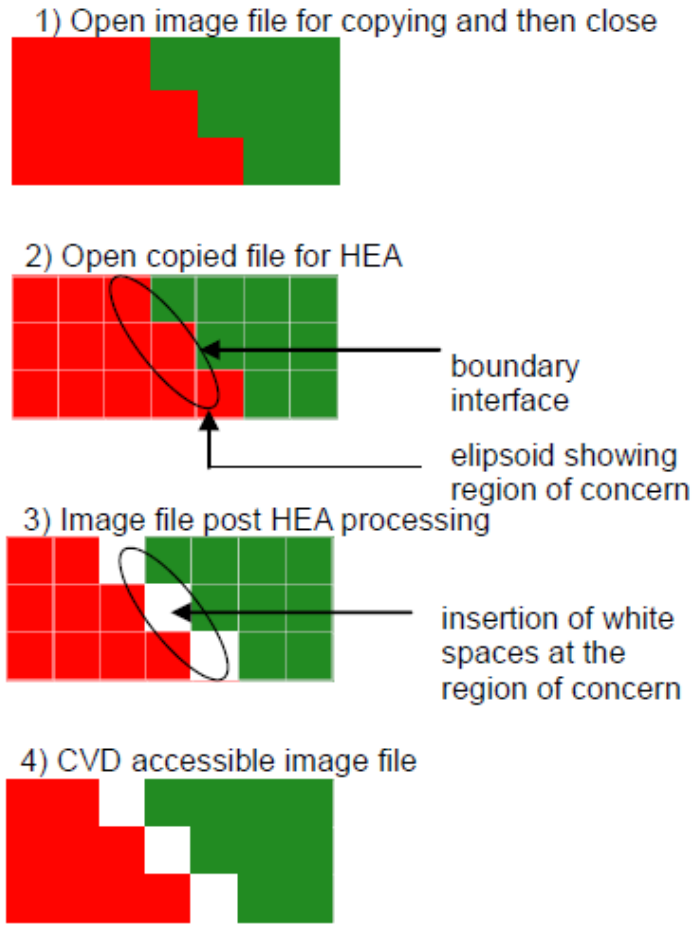

Figure 3.2: Shows image post-processing by Halo-Effect Algorithm (Egan & Alsafyani, 2018)

3.3.3 THE RE-COLOURING ALGORITHM

A re-colouring technique has been developed to assist CVDt individuals to accurately interpret the information being portrayed in a specific context of spectra maps. The technique works by altering the composition of colours in the image so as to make it easier for CVDt to distinguish the different colour mixes. The aim of the re-colouring algorithm is to preserve the abundance of information being communicated by colour while at the same time making it easy for the CVDt individuals to accurately interpret the information (Culp, 2012).

Some limitations associated with Culp's re-colouring algorithm

Even though the re-colouring algorithm is able to transform maps and make them easier for the CVDt to interpret information, the CVDt still have difficulty in defining boundary interfaces (the boundary between some regions) within the maps. Another problem associated with the re-colouring algorithm is that the original colour composition of the map object being viewed is altered which may then lead to a distortion of the information being conveyed.

Figure 3.3 provides the pseudo code of the image processing of the re-colouring algorithm it works by re-plotting the image within a gamut that is perceptible to the CVDt people. This gamut was constructed by combining the region of the redgreen deficient gamut and the region of the blue-green deficient gamut.

```
algorithm Convert-Images-To-OGA-For-Color-Blind-People is
   input: Original-Image With Colored Objects
   output: OGA Colored Objects Image
   FOR each ROW of Pixels in Original Image do
         FOR each Pixel in ROW do
         CALL Get—Opponent-OGA-Color WITH Color of Pixel RETURNING Pixel
OGA Color
         SET Pixel with Pixel OGA Color
         END FOR
   END FOR
   RETURN  OGA Colored Objects Image
FUNCTION Get-Opponent-OGA-Color is
   input: Original Color
   output: OGA Color
         CALL Get—CIELAB-From-RGB-Color WITH Original Color RETURNING
Original CIELAB Color //(3.1a)
         CALL Get—oRGB-From-RGB-Color WITH Original Color RETURNING
Original oRGB Color //(3.1b)
         CALL Get—mapped-Color WITH Original Color RETURNING mapped Color
//(3.1c)(3.1d)(3.1e)
         CALL Get—oRGB-From-RGB-Color WITH mapped Color RETURNING
mapped oRGB Color //(3.1f)
         SET Intermediate lightness oRGB Color by mapped oRGB Color //(3.1g)
         SET L in Intermediate lightness oRGB Color by L from Original oRGB Color
//(3.1g)
         CALL Get—CIELAB-From-oRGB-Color WITH Intermediate lightness oRGB
Color RETURNING Intermediate lightness CIELAB Color //(3.1g)
         SET OGA oRGB Color by mapped oRGB Color //(3.1g)
         SET L in OGA oRGB Color by ((L from Original oRGB Color)*(L from
Original CIELAB Color)/(L from Intermediate lightness CIELAB Color)) //(3.1h)
         CALL Get—RGB-From-oRGB-Color WITH OGA oRGB Color RETURNING
OGA Color //(3.1i)
   return OGA Color
ENDFUNCTION
```

```
FUNCTION Get—oRGB-From-RGB-Color is
   input: RGB Color (R, G, B)
   output: oRGB Color (L, C1, C2)
        SET Intermediate Red Value by Original Color Red Value divided by 255
        SET Intermediate Green Value by Original Color Green Value divided by 255
        SET Intermediate Blue Value by Original Color Blue Value divided by 255
        SET L Value by (Intermediate Red Value*0.2990) + (Intermediate Green
Value*0.5870) + (Intermediate Blue Value*0.1140)
        SET C1 Value by (Intermediate Red Value*0.5000) + (Intermediate Green
Value*0.5000) + (Intermediate Blue Value*1.0000)
        SET C2 Value by (Intermediate Red Value*0.8660) + (Intermediate Green
Value*0.8660) + (Intermediate Blue Value*0.0000)
   return oRGB Color (L, C1, C2)
ENDFUNCTION

FUNCTION Get—RGB-From-oRGB-Color is
   input: oRGB Color (L, C1, C2)
   output: RGB Color (R, G, B)
        SET Intermediate Red Value by (L Value* 1.0000) + (C1 Value*0.1140) + (C2
Value*0.7436)
        SET Intermediate Green Value by (L Value* 1.0000) + (C1 Value*0.1140) +
(C2 Value*−0.4111)
        SET Intermediate Blue Value by (L Value* 1.0000) + (C1 Value*−0.8660) +
(C2 Value*0.1663)
        SET Red Value by Intermediate Red Value Multiplied by 255
        SET Green Value by Intermediate Green Value Multiplied by 255
        SET Blue Value by Intermediate Blue Value Multiplied by 255
   return RGB Color (R, G, B)
ENDFUNCTION
```

```
FUNCTION Get—CIELAB-From-RGB-Color is
   input: RGB Color (R, G, B)
   output: CIELAB Color (L, a, b)
         CALL Get—XYZ-Color WITH RGB Color RETURNING XYZ Color
         CALL Get—CIELAB-From-XYZ-Color WITH XYZ Color RETURNING
CIELAB Color
   return CIELAB Color (L, a, b)
ENDFUNCTION
FUNCTION Get—CIELAB-From-oRGB-Color is
   input: oRGB Color (L, C1, C2)
   output: CIELAB Color (L, a, b)
         CALL Get—RGB-From-oRGB-Color WITH oRGB Color RETURNING RGB
Color
         CALL Get—CIELAB-From-RGB-Color WITH RGB Color RETURNING
CIELAB Color
   return CIELAB Color (L, a, b)
ENDFUNCTION
FUNCTION Get—XYZ-From-RGB-Color is
   input: RGB Color (R, G, B)
   output: XYZ Color (X, Y, Z)
         SET Intermediate Red Value by Original Color Red Value divided by 255
         SET Intermediate Green Value by Original Color Green Value divided by 255
         SET Intermediate Blue Value by Original Color Blue Value divided by 255
         if ( intermediate R > 0.04045 ) intermediate R = ( ( intermediate R + 0.055 ) /
1.055 ) ^ 2.4
         else              intermediate R = intermediate R / 12.92
         if ( intermediate G > 0.04045 ) intermediate G = ( ( intermediate G + 0.055 ) /
1.055 ) ^ 2.4
         else              intermediate G = intermediate G / 12.92
         if ( intermediate B > 0.04045 ) intermediate B = ( ( intermediate B + 0.055 ) /
1.055 ) ^ 2.4
```

```
else            intermediate B = intermediate B / 12.92
        intermediate R = intermediate R * 100
        intermediate G = intermediate G * 100
        intermediate B = intermediate B * 100
        X = intermediate R * 0.4124 + intermediate G * 0.3576 + intermediate B *
0.1805
        Y = intermediate R * 0.2126 + intermediate G * 0.7152 + intermediate B *
0.0722
        Z = intermediate R * 0.0193 + intermediate G * 0.1192 + intermediate B *
0.9505
   return XYZ Color (X, Y, Z)
ENDFUNCTION
FUNCTION Get—CIELAB-From-XYZ-Color is
   input: XYZ Color (X, Y, Z)
   output: CIELAB Color (L, a, b)
        SET intermediate X by X / 111.144
        SET intermediate Y by Y / 100.000
        SET intermediate Z by Z /  35.200
        if ( intermediate X > 0.008856 ) SET intermediate X by SET intermediate X ^ (
1/3 )
        else            SET intermediate X by ( 7.787 * intermediate X ) + ( 16 / 116 )
        if ( intermediate Y > 0.008856 ) SET intermediate Y by SET intermediate Y ^ (
1/3 )
        else            SET intermediate Y by ( 7.787 * intermediate Y ) + ( 16 / 116 )
        if ( intermediate Z > 0.008856 ) SET intermediate Z by SET intermediate Z ^ (
1/3 )
        else            SET intermediate Z by ( 7.787 * intermediate Z ) + ( 16 / 116 )
        SET L* by ( 116 * intermediate Y ) - 16
        SET a* by 500 * ( intermediate X - intermediate Y )
        SET b* by 200 * ( intermediate Y - intermediate Z )
```

```
return CIELAB Color (L, a, b)
ENDFUNCTION
FUNCTION Get—mapped-Color is
   input: Original Color (R, G, B)
   output: mapped Color (R, G, B)
        SET Red Value of mapped Color by minimum of 0 or (Original Color Red Value
- (0.5*Original Color Green Value)) //(3.1c)
        SET Blue Value of mapped Color by minimum of 0 or (Original Color Blue
Value - (0.5*Original Color Green Value)) //(3.1d)
        SET Green Value of mapped Color by ((0.42*Original Color Red Value) -
(0.58*Original Color Blue Value)) //(3.1e)
   return mapped Color (R, G, B)
ENDFUNCTION
```

Figure 3.3: Shows the pseudo code of pixel-by-pixel image processing of the re-colouring algorithm

3.3.4 THE HATCHING ALGORITHM

The Hatching algorithm was developed by Hung & Hiramatsu (2013) with the intent of helping the CVDt to discriminate colour shades without changing the original colour of the image. The algorithm cross-hatches the original pre-processed image using 450 and 1350 lines of same colour to furnish a post-processed image to aid the CVDt (Hung & Hiramatsu, 2013).

Some limitations associated with the Hung's hatching algorithm

The problem with the algorithm is that even though it does not alter the colour original image, it does alter the appearance of the image as lines that were absent in the original colour are included in the post-processed image. This may make matters worse if the original object is already hatched. When a hatched image is hatched again, the resulting image may be excessively hatched that it may end up confusing the CVDt individuals.

Figure 3.4 provides the pseudo code of the image processing of the hatching algorithm it works without changing the colours of the main image by hatching the colours in the image with lines with different angles to allow the CVDt people to distinguish the difference between the colours. The hatching pattern varies in the angle systematically depending on the position on the confusion line that has been determined by the algorithm. The algorithm uses low contrast for red and high contrast for the green with no hatching contrast at grey.

```
algorithm Hatching-Images-For-Color-Blind-People is
  input: Original-Image With Colored Objects
  output: Hatched Colored Objects Image
      INIT OpenCV ImageProcessor with Original Image
      CALCULATE Original Image Polygons from OpenCV ImageProcessor
      SET Hatched Colored Objects Image by Original Image
  FOR each Polygon in Original Image Polygons do
      CALL Get-Hatching-Color WITH Color of Polygon First Point
RETURNING Polygon Hatching Color
      CALL Get-Hatching-Angle WITH Color of Polygon First Point
RETURNING Polygon Hatching Angle
      GENERATE Polygon Vertical Hatch Brush from Polygon Hatching Color
      CALL Get-Textured-Brush WITH Polygon Hatch Brush RETURNING
Polygon Textured Brush
      Rotate Polygon Textured Brush by Polygon Hatching Angle
      Scale Polygon Textured Brush by 1.5
      Fill Poygon With Polygon Textured Brush
      END FOR
      RETURN  Hatched Colored Objects Image
FUNCTION Get-Hatching-Color is
  input: Original Color
  output: Hatching Color
      SET Correction Factor by 1.2
      SET Hatching Color Red Value to Original Color Red Value Multiplied
by Correction Factor
      SET Hatching Color Blue Value to Original Color Blue Value Multiplied
by Correction Factor
      SET Hatching Color Green Value to Original Color Green Value
Multiplied by Correction Factor
      Check if any value of Red or green or blue of Hatching Color exceed 255
and truncate it
  return Hatching Color
ENDFUNCTION
```

```
FUNCTION Get-Hatching-Angle is
  input: Original Color
  output: Hatching Angle
      SET Red Value by Original Color Red Value divided by 255
      SET Green Value by Original Color Green Value divided by 255
      SET Blue Value by Original Color Blue Value divided by 255
      If Red Value greater than 0.04045
      SET Red Value to ((Red Value + 0.055) / 1.055)POW 2.4
      ELSE
      SET Red Value to Red Value / 12.92
      If Green Value greater than 0.04045
      SET Green Value to ((Green Value + 0.055) / 1.055)POW 2.4
      ELSE
      SET Green Value to Green Value / 12.92
      If Blue Value greater than 0.04045
      SET Blue Value to ((Blue Value + 0.055) / 1.055)POW 2.4
      ELSE
      SET Blue Value to Blue Value / 12.92
      SET Red Value to Blue Value multiplied by 100
      SET Green Value to Blue Value multiplied by 100
      SET Blue Value to Blue Value multiplied by 100
      SET X to Red Value * 0.4124 + Green Value * 0.3576 + Blue Value * 0.1805
      SET Y to Red Value * 0.2126 + Green Value * 0.7152 + Blue Value * 0.0722
      SET Z to Red Value * 0.0193 + Green Value * 0.1192 + Blue Value * 0.9505
      SET u' to X * 4 / (X + Y * 15 + Z * 3)
      SET v' to Y * 9 / (X + Y * 15 + Z * 3)
      SET a to -0.31043, b to 0.022392, c to 0.050926, A to -4.0274
      SET Hatching Angle to sgn(au'+bv'+c) * A * (|au'+bv'+c| / SQRT(a2+b2))
  return Hatching Angle
ENDFUNCTION
```

Figure 3.4: Shows the pseudo code of pixel-by-pixel image processing of the hatching algorithm

3.3.5 PHYSICAL SOLUTION OVER LAYERING

The physical solution uses contact lenses or tinted spectacles to help those suffering from CVD conditions to correct or to improve their vision (Badawy et al., 2018). Such optical lenses use a number of layers to filter out particular light wavelengths thus minimising the chances of overlapping occurring between the colours green and red, and between the colours blue and green colours being transmitted to the eye (Badawy et al., 2018). In other words, these optical lenses normally work by either changing the brightness or lightness of different colours by the introduction of luminance hues or by exchanging (altering) confusing colours with those that CVDt individuals can discriminate.

Another way that the use of optical lenses can help CVDt individuals discriminate confusing colours is by use of notch filters (Almutairi et al., 2017). Notch filters artificially separate "the effective peak sensitivities of the expressed X-chromosome-coded photo pigments in red-green anomalous trichromats" (Almutairi et al., 2017, Badawy, et al., 2018). Colour discrimination achieved by such lenses is generally poor when compared to how normal people discriminate different colours. Also, there is a discrepancy in the wavelength of light between the eyes (Badawy, et al., 2018). Such discrepancies reduce the accuracy of the lens when used by CVDt individuals to discriminate confusing colours.

Hence, for physical approaches to be successful a great deal of further work is required, which is out of scope of this dissertation.

3.4 COMPARISON OF STUDIES

Table 3.2 shows the five studies that were undertaken where observations or responses to questions were gathered as data. Study 1 was used to determine the credibility of the novel colour separation post-processing algorithm, HEA, developed and implemented in this thesis, and involved hard-copies of coloured pie-charts. The study separated participants into two sets by coloured pie-chart comparison: non-CVDt and indicative-CVDt. The non-CVDt set had no difficulties in determining information from non-pre-processed images, whereas the indicative-CVDt set had some form of difficulty in doing so. However, after HEA application to the pie-charts, data interpretation of post-processed images for the indicative-CVDt improved.

Study 2 was used to determine the effectiveness of the HEA by showing participants a soft-copy of the same sequence of images used in study 1, and was also to compare non-CVDt and

indicative-CVDt. The non-CVDt set showed no difficulty in identifying information presented in the pre-processed images, whereas the post-processed images gave improved data interpretation for the indicative-CVDt.

Studies 3, 4 and 5 compared the effectiveness of the HEA with two already established algorithms: the hatching and the re-colouring algorithms. Each of the three algorithms were compared in a situation that would be fair to be realistic and also so that each would provide benefit to the CVDt. Soft copy images of pie-charts, a country map and geometric shapes were shown. The comparison highlighted that each of the transformation algorithms requires specific contexts to benefit the CVDt people. Culp (Culp, 2012) used spectra maps of the USA and South America, while Hung (Hung & Hiramatsu, 2013) used text where a background change was highlighted in the foreground. The comparison in this research has focussed on HEA being used in a generic manner unlike the currently available algorithms. The HEA is not a colour transformation, but instead a colour separation algorithm which has been developed with general use in mind. This dissertation demonstrates statistically that this is so.

Table 3.2: Shows the comparison between the studies

	Study 1(Hard copy)		Study 2 (Soft copy)	
	Non-CVDt	Indicative-CVDt	Non-CVDt	Indicative-CVDt
Pie-charts	Pre-processed images	Post-processed HEA	Pre-processed images	Post-processed HEA

	Soft copies			
	Pre-processed images	Post-processed images		
		Halo-Effect Algorithm	Hatching Algorithm	Re-colouring Algorithm
Study 3	Pie-charts	Post HEA	Post Hatching	Post re-colouring
Study 4	Country map	Post HEA	Post Hatching	Post re-colouring
Study 5	Geometric shapes	Post HEA	Post Hatching	Post re-colouring

Before the creation of the concept presented in this research, pie-charts, country maps and geometric shapes have all been used to provide computerised solution to CVDt users. These types of images were compared here for their efficacy due to their importance within work environments and different fields of education. In this dissertation, images were tested for comparison for fairness.

Pie charts were used because of their common usage in data representation. The country map, using solid boundaries, was chosen as a fair post-processed representation of each of the

three algorithms. The country map was used with several colours in the visual spectra, which helped colour interpretation. For that reason, this study uses mathematical algorithms for optimisation and application of models with modern colour appearances between adjacent colour boundaries for optimised object differentiation and accurate perception, enabling CVDt individuals to identify colours correctly.

Lastly, geometric shapes were used, again using solid boundaries, but this time more complex boundaries between segments of shapes. With the imagination of the colours associated with shapes, geometrical shapes guide CVDt users to imagine colours of complete objects made of the combination of shapes. Therefore, in dealing with a colour vision problem, geometric shapes are required for conducting experiments with a system programmed for simulating colour contrast. Geometric shapes represent objects with which CVDt users were familiar with. In order to identify distinguishing features and classes of objects, research (Hobbins, 2019) proposed a combination of a variety of geometric shapes, since they have mixed hues. This research argues that geometrical shapes can be used to accompany colour, but is of minimal assistance to CVDt individuals.

In this dissertation, geometric shapes were selected for improving the visual and cognitive ability of CVDt people, setting a standard for distinguishing shapes that were not perceivable by CVDt individuals, to enable them to distinguish objects by separating the shapes from each other by white solid boundaries.

3.5 DATA COLLECTION METHODS

Surveys are widely used to collect data from large numbers of people at a low cost (Saunders, M. et al., 2009). For this thesis, quantitative data were collected from the responses participants gave to a number of surveys. Collection of quantitative data helps analysis in terms of verifying the reliability of results, and was concerned with answering questions to defined problems. Quantitative data were collected systematically by the gathering of survey question responses from participants and those data were then used to help to understand and/or to predict aspects of behaviour within any given target survey population (Mathers, N. et al., 2009). For such data gathering the following characteristics must be considered very carefully: the design of the survey, how the survey was administered, how data were sampled and finally how those data were analysed to generate information.

3.5.1 TYPES OF SURVEYS

There are a number of ways that surveys can be undertaken. However, what is common to all is data gathering and analysis of those data. The following sub-sections are an overview of the four types of surveys.

3.5.2 PAPER SURVEYS

This type of survey uses a more traditional 'pencil and paper' approach. These types of surveys are becoming less common with the greater use of electronic surveys (e-surveys). However, paper surveys are still useful when surveys are conducted in the field. For example, when a researcher approaches subjects, in a 'cold manner', and asks them to become survey participants 'in the street'. Consequently, paper surveys are extremely flexible and portable, in as much, as they can be used where it is difficult to conduct an e-survey. On the other hand, paper surveys are costly because they use a great deal of man power, resources and time when gathering data sources.

In this thesis paper surveys were conducted, where in the first survey participants were shown a number of paper images and their responses, the data, were also gathered on paper. In subsequent surveys, participants were shown a number of e-images on the two tablets, and their responses (the data) were gathered on paper.

3.5.3 ONLINE SURVEYS

Online surveys tend to consist of number questions that can be easily deployed to survey participants either via an Internet browser or by e-mail or by some other e-means. Online surveys are relatively simple to design, they can be easily mass deployed, they give the survey participants sufficient time and space to provide considered responses to the survey questions. They are less expensive when compared to traditional surveys, data collection can be quick and analysis of those data can also be quick by the use of a fully automated approach. Such surveys are becoming more and more popular.

3.5.4 TELEPHONIC SURVEYS

These are conducted over the telephone, where respondents are asked questions related to the research topic. They are time-consuming and they can be inconclusive, as their success depends on how many people answer the telephone calls and then agree to answer the survey questions.

3.5.5 ONE-TO-ONE INTERVIEWS

Interviews aid in directly collecting data from participants. They are qualitative in nature, they are dependent on the knowledge and experience of the researcher to frame, ask relevant questions and gather pertinent responses.

It was decided not to follow the online surveys approach, telephonic surveys approach and one-to-one interviews approach in this thesis as it was considered that paper surveys gathering of data would provide more credible results.

3.6 SAMPLING METHODS

Sampling can be divided into two major categories: probability and non-probability sampling. With probability sampling, each member of a population has a non-zero chance of participation in research. Chance or randomisation is the main element of probability sampling. On the contrary with non-probability sampling, samples are selected systematically, in a non-randomised way. Thus, in this form of sampling, particular population samples have the opportunity to participate in any given research. Sampling techniques are selected on the basis of the goals and nature of the research.

The work in this thesis used probability sampling because the major benefit of it was that it guarantees that any chosen samples were representative of the population under investigation. Table 3.3 highlights the different types of randomisation sampling methods that can be used, providing a brief description of each.

Table 3.3: Overview of randomisation methods

Probability Sampling Method	Brief Description
Random	Every unit has an equal chance of selection.
Stratified random (proportional or quota)	Divide the population into strata, and then samples are selected randomly from each stratum.
Systematic random	Systematically select every x unit from a list of n units.
Cluster (area) random	Divide the population into groups, and then randomise them. Select groups and sample all the units that are within each.
Multi-stage random	This is a hierarchical combination of random sampling methods.

In this thesis the random sampling method was used, since every participant's responses from each survey were used for statistical purposes.

The target demographic for this research was university members including teaching, academic or administrative staff, or students who voluntarily joined each survey. Participants were of a wide and diverse origin, but the commonality was the university they were based at. For data collection, public places in the university were reserved for several weeks to gather the largest possible number of questionnaires participants. Participants who had given permission to be contacted were invited to conduct further studies.

3.7 ETHICAL CONSIDERATIONS

According to the University of Hertfordshire Policy and Regulations, all studies involving human subjects require ethical approval from the relevant ethics committee before studies were undertaken. The Ethics Committee with Delegated Authority (ECDA) considers requests in the relevant disciplinary area. The committee requires complete information, including study design, number of participants and data collecting details.

Because human subjects were used in these studies, ethical approval was sought from the Ethical Committee for the 'Health Sciences Engineering & Technology' (HSET). The approved protocols numbers and related studies were listed below in Table 3.4. All Ethical approval notifications were presented in Appendix D.

Table 3.4: Shows empirical studies and associated ethical considerations

Research Studies	Protocol Numbers	Date
Empirical Study 1	COM/PGT/UH/02073	19/09/2016
Empirical Study 2	aCOM/PGR/UH/02073(1)	06/01/2017
Empirical Study 3	aCOM/PGR/UH/02073(2)	11/05/2017
Empirical Studies 4 and 5	aCOM/PGR/UH/02073(3)	11/11/2017

3.8 ANALYSIS METHODS

Data analysis refers to the processes and methods used to convert gathered data into meaningful information, frequently applying well known and established statistical methods. In this thesis two statistical tests were used to illustrate the importance of the novel algorithm, and this was also compared statistically to two other colour transformation algorithms previously referred to in this chapter.

3.8.1 THE PEARSON CHI-SQUARE TEST

The Pearson Chi-square test, (Chi-square test), is alternatively known as the Goodness of fit test and provides an understanding of the likeliness of the significance of an observed distribution from a gathered data-set (Pandis, 2016). High significance means results from the data-set can be used with credibility. It is important to appreciate that this test was a measure of how well an observed distribution of data matches an expected distribution where all the variables in the studies were independent of each other. It was used to determine if there was a significant relationship between two nominal variables. The frequency of each category for one nominal variable was compared across the categories of the second nominal variable. Data can be displayed in a contingency table where each row represents a category for one variable and each column represents a category for the other variable.

The equation of the chi-square test eq1.

$$\chi^2 = \sum_{i-1}^{r} \sum_{j-1}^{c} \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}} \qquad \text{(eq1)}$$

3.8.2 THE INDEPENDENT SAMPLE T-TEST

The Independent-Samples T-test is an inferential statistical test (Learntech, 2018) that determines whether there was statistically a significant difference between means from two unrelated sets:

- There was one independent, categorical variable that has two levels/sets. In these studies, all the participants who were independent of each other and the two sets will be non-CVDt or indicative-CVDt.

- There was also one continuous dependent variable which was the frequencies of the percentage responses for the second part of each question. The continuous dependent variable was split into two for each of the two sets. That was, one each for participants identified as non-CVDt or indicative-CVDt.

Unrelated sets, also called unpaired or independent sets, were where cases (e.g., participants) in each set were different; in these studies the two sets were non-CVDt and indicative-CVDt. This test requires that the dependent variable was approximately normally distributed within each set and was described as a robust test with respect to the assumption of normality.

The equation of the Independent-Samples T-test eq2.

$$t = \frac{\mu_A - \mu_B}{\sqrt{\left[\frac{\left(\sum A^2 - \frac{(\sum A)^2}{\eta_A}\right) + \left(\sum B^2 - \frac{(\sum B)^2}{\eta_B}\right)}{\eta_A + \eta_B - 2}\right] \cdot \left[\frac{1}{\eta_A} + \frac{1}{\eta_B}\right]}} \qquad \text{(eq2)}$$

Statistical methods were chosen to show significance or non-significance. This means that in the case of significance, the participant study results were valid.

The chi-square test was chosen as it tests if the likelihood of observed distributions were down to chance, and if which was the case, then the results obtained in the survey were not valid. The Independent-Samples T-test was chosen to determine the probability that two different populations were the same with respect to the individual variable under investigation.

3.9 LEAD INTO NEXT CHAPTER

The following chapter provides details of the evaluation the Halo-Effect Algorithm to demonstrate that there was an improvement in information interpretation by the CVDt.

CHAPTER 4 EVALUATION OF THE HEA

4.1 INTRODUCTION

This chapter was based on using the HEA to demonstrate that there was improvement in information interpretation by the CVD. For this study, it was important to ensure that the HEA was workable and does help to improve information interpretation by the CVD. It was expected that this study will produce one of three results: i) that the HEA does improve information interpretation and no further work is required on the algorithm at this stage; ii) that the HEA does improve information interpretation, but further work is required on the algorithm at this stage; iii) that the HEA does not offer any information interpretation improvement and the algorithm should not be pursued any further.

The Microsoft Developer Network (MSDN) (2020), provides online help tutorials about the creation and use of pie-charts. Some of the pie-charts provided by the MSDN in the tutorials are used in this study to determine which one of the three results will be obtained. Once it has been established that the HEA does improve information interpretation by the CVD then subsequent and more detailed studies can be conducted.

4.2 THE MICROSOFT PIE-CHART TUTORIALS

The online MSDN shows users how to create and save informative pie-charts as a number of short tutorials (Microsoft, 2020). The tutorials show users how to apply many features to pie-charts, for example how the user would choose which type of pie-chart is required for their work, how to display text within a segment of the pie-chart including how to display percentages within each segment, how to combine multiple small segments into one larger segment, how to add a report title to the pie-chart, and so on. However, the MSDN tutorials are not presented in a manner that the CVDt can interpret as, the automated colour mixes are not 'CVDt friendly'. Consequently, these tutorials can be used to define the detailed functionality of the HEA to render them 'CVDt friendly'.

4.3 DETAILS OF THE MICROSOFT PIE-CHART TUTORIALS AND THE IMPACT THEY MAY HAVE ON THE CVD

The MSDN tutorials did not cover the needs of the CVDt. Hence, it can be expected that anyone who has learned how to create pie-charts by using these tutorials may cause the CVD to have difficulty in interpreting information. For example Figure 4.1) is a copy of one of the MSDN tutorial pie-charts (Microsoft ,2020). The CVD would have a great deal of difficulty seeing the different segments of the pie-chart as shown in Figure 4.2). Figure 4.2) is a representation of how the CVD suffering from Deuteranopia would see the same pie-chart as

Figure 4.1). Figure 4.2) has been generated by the Hertfordshire Colour Blind Emulator (HCBE).

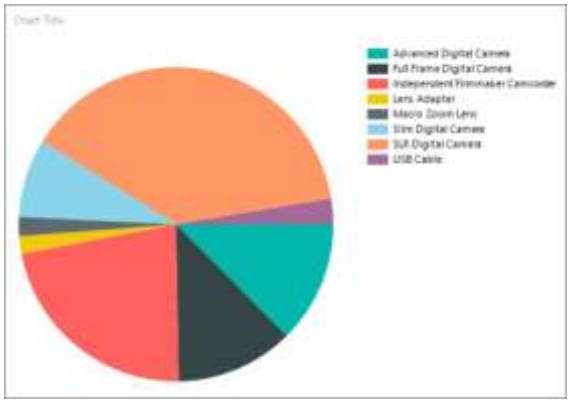

Figure 4.1: A pie-chart of the MSDN tutorial

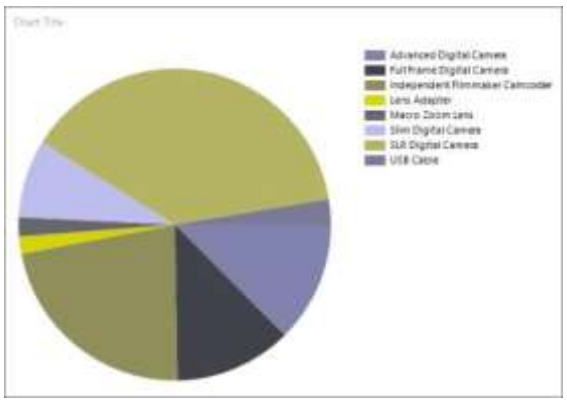

Figure 4.2: The same pie-chart but shown as those suffering from Deuteranopia would see it

Comparing the two figures it can be seen that adjacent colours of violet and blue would be difficult to separate and, hence, those suffering from Deuteranopia would see a far larger segment than there really is. This can also be seen by comparing adjacencies of red with orange and also black with grey. It can be considered that boundary interfaces between adjacent colours cause particular difficulty.

4.4 THE HERTFORDSHIRE COLOUR BLIND EMULATOR (HCBE)

The work of the group at Hertfordshire who originally developed HCBE was targeted at raising awareness of the problems that the CVD suffer (Egan, Jefferies, Dipple, & Smith, 2011). HCBE is a software tool that accepts an image file as input, it prompts the user for the type of CVD under investigation (one from Deuteranopia, Tritanopia, Protanopia and

Monochromacy) and then it generates an output file in the manner that the CVD selected type would see the original image. The user can then compare the two images, the original with the HCBE generated image for any difficulty in interpreting the information the user intended.

HCBE can take its input image in a number of file formats, for example: jpg and png. Once the user has selected the type of CVD the output file image generated by HCBE is in the way that CVD person would see the original image and the output file format would remain the same as the input file format. For example, if a user inputs a .jpg file then a .jpg file would be generated as an output. HCBE processes the input file pixel by pixel, such that there would be at the pixel level a transformation in the output file as would be seen by the selected CVD type. Figures 4.3) and 4.4) shows how the transformations may occur. In all of the following figures, for illustrative purposes, each square represents one pixel.

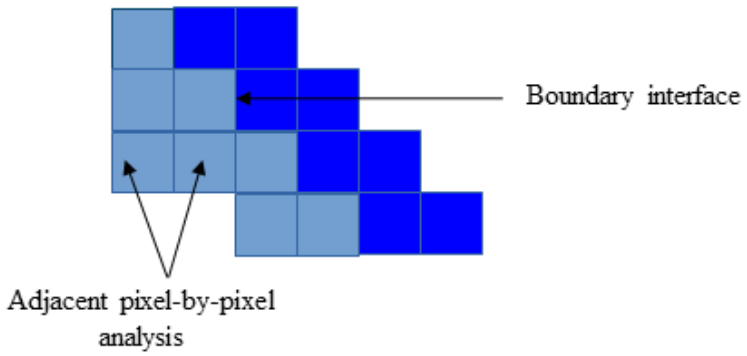

Figure 4.3: The image before transformation

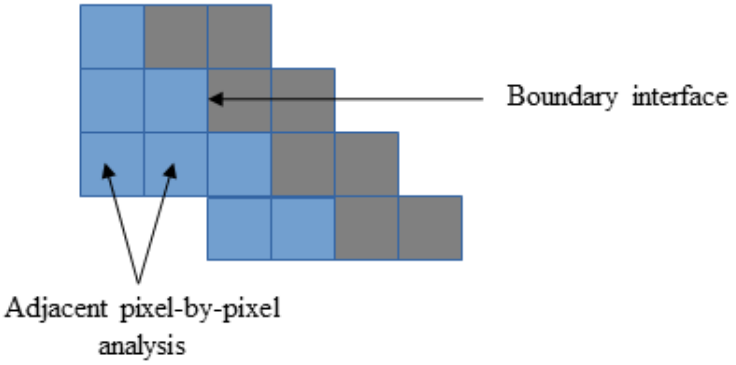

Figure 4.4: The image post transformation in HCBH

A major limitation of HCBE is that, as it stands, it does not show the user any potential solution to any difficulty found and it leaves the user to find their own solution. This is also a major limitation of other CVD comparison software tools (Colblindor, 2016; Etre, 2015; Coblis1, 2016). Consequently, HCBE has been enhanced by use Alsafyani's HEA such that a potential solution can be shown in the output file to the user. However, it always remains the user's responsibility to ensure that the output image does convey the information as intended.

4.5 THE HALO-EFFECT ALGORITHIM (HEA)

The purpose of the HEA is to produce a software tool that will provide a solution, such that those suffering from CVD can potentially interpret information as conveyed by the original author (Alsafyani et al., 2016).

4.5.1 REGION OF CONCERN (ROC)

Earlier in the chapter it is discussed how colour interface boundaries could be problematic to the CVD. Each pixel-by-pixel interface boundary will be associated with two possible cases at each interface: i) both pixels are the same colour or ii) the two pixels are of different colours.

Case i) is not problematic, however, case ii) can be problematic. When all of the pixels at each interface boundary are built up then there is a larger interface set which can be problematic. In this thesis this collective set of problematic boundary interfaces is called the Region of Concern (ROC). Both cases were shown in Figures 4.5) and 4.6).

To provide a potential solution to this problem a white space is introduced at each boundary interface. The white spaces are built up into a collection or set of white spaces, which in this thesis is called the HEA. The halos should provide a clear boundary between the boundary

interfaces enabling the CVD to view adjacency that they might not see but would be seen by the non-CVD. This halo of white spaces becomes a separation of colours at the ROC and therefore the HEA is a novel colour separation algorithm. Hence, the introduction of the HEA should now enable the CVD to correctly identify the information in a given image, but this must be verified by the author of the image.

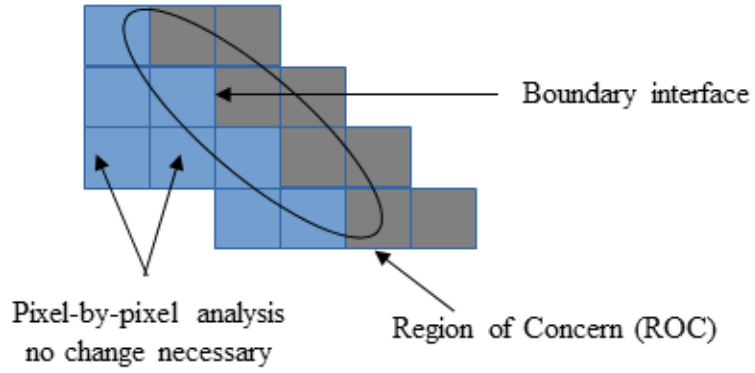

Figure 4.5: Boundary interface and the region of concern

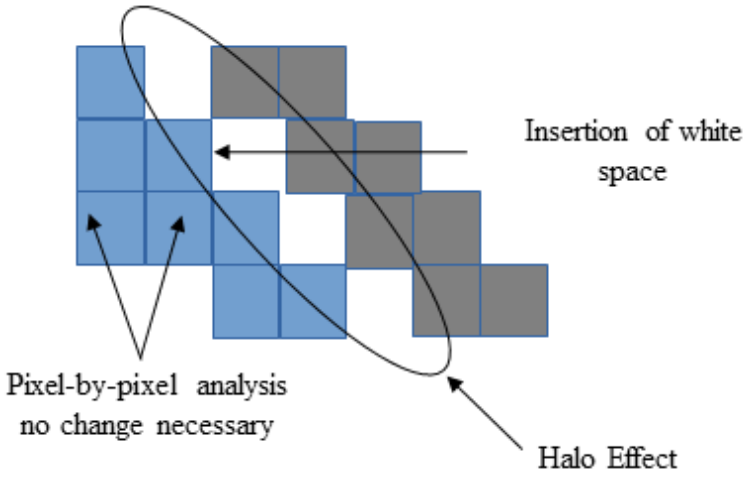

Figure 4.6: Boundary interface and the Halo Effect

4.5.2 THE MSDN PIE-CHART HAVING BEEN PASSED THROUGH HEA

To demonstrate the identified functionality of the HEA a number of pie-charts created by the MSDN tutorials are created by post-processing. Figure 4.7) shows the final image of the MSDN pie-chart having been passed through the HEA. White spaces showing the HEA can now be seen at the interface of each segment of the pie-chart potentially rendering information interpretation by the CVD possible.

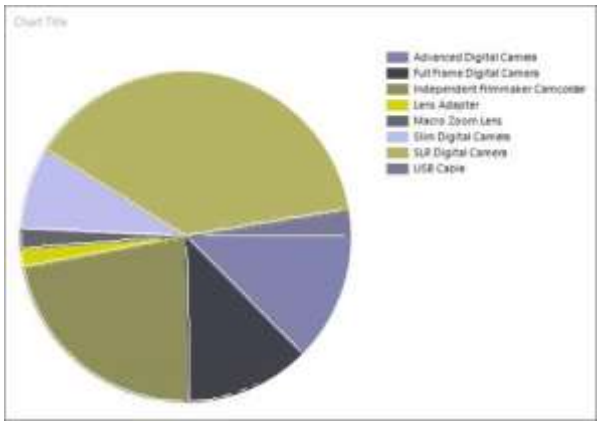

Figure 4.7: The MSDN pie-chart having been passed through HEA

These images can be compared with the original MSDN tutorial pie-chart and difficulties can be found for all of the different CVD types, but once passed through HEA makes information interpretation easier for the CVD and offers a potential positive solution to information interpretation.

4.6 CHAPTER CONCLUSION

From this work it can be concluded that case i) from the introduction has been achieved: that the HEA does improve information interpretation and no further work is required on the algorithm at this stage.

4.7 MICROSOFT TUTORIAL PERFORMANCE OF HEA EVALUATION

For those who do not suffer from CVD there should be no difference in the interpretation of information between the original pre-processed image and the post-processed image having been parsed through HEA. In other words, there will be no performance gain for this set of people. However, for those who do suffer from CVD the HEA (colour separation) should provide significant improvement in information interpretation thereby providing a great deal of performance improvement.

The performance gain is due to the separation of the colour boundaries between the segments of the charts from the tutorial. It is highly likely that the CVD will now be able to visualise the chart segment boundaries correctly and therefore be able to use the Microsoft Tutorial to their benefit. Without the HEA colour separation algorithm, it is highly likely that the CVD would not be able to use the tutorial as intended.

4.8 CHAPTER DISCUSSION

This chapter presented a sub-set of the results that were obtained and has focussed on the problems of Deuteranopia. A full-set of results were presented as Appendix E for the three types of CVD under investigation: Deuteranopia, Protanopia, and Tritanopia. Analysis of these results also confirms the findings that case i) from the introduction holds true. Which further highlights the performance gain of information interpretation that the HEA colour separation will offer.

However, the results also show that there was little that can be done to aid those suffering from Monochromacy as they see everything in black and white. Taking into account the estimated rarity of Monochromacy (1 in 30,000 or 0.000033333% of the population) (National Institute of Health, 2015, Colblidor, 2007) will no longer be considered in this thesis.

The results of this work were presented at ECCS'16 (European Conference on Computer Science – Rome, October, 2016) and the full paper was provided as Appendix F.

Further, more detailed studies can now be carried to rigorously test the validity of the HEA. Different images will be used and human participants will be asked to answer a number of survey questions in 'open access areas'. The results of the surveys should show that two types of sub-sets will be identified: i) the non-CVD, i.e. those who interpret the information in the survey images without problem and ii) those indicative of CVDt, i.e. Those who have problems interpreting the information in the survey images. It must be stressed that there is no clinical diagnosis which means it cannot be conclusively said that any participant involved in the surveys is CVDt.

CHAPTER 5 DETERMINING THE EFFECTIVENESS OF THE HEA BY USE OF VISUAL PAPER AND COMMONLY USED ELECTRONIC VIDEO DISPLAY TECHNOLOGY DEVICE

5.1 INTRODUCTION

In this chapter two survey studies were undertaken, where participants were asked to evaluate a number of different images which might be difficult for the CVDt to interpret. In the first feasibility study, response data were collected and analysed by both the Pearson Chi-squared and Independent Sample T-tests.

The second study used two tablets. These are electronic handheld devices used by a user to enter- store- data/information. They are then used to display data/information to the user after meaning has been applied to those data. Examples are tablets and smart-phones; such devices are rapidly gaining popularity as they offer increased functionality to their users in a cost-effective manner. Main features include small touchscreens, memory cards and wireless connectivity, as well as supporting a display of stored data/information. One of the most important functions of a tablet is that it has a good, brightly coloured visual display unit (VDU) so that the user can easily differentiate and interpret not only colours but also shapes. Samsung and i-Pad tablets were both used in this study (Samsung- Model number SM-T560, android version 4.4.4, total space 8.0GB, i-Pad- Model number MD543B/A, version 9.3.5, capacity 12.5GB).

5.2 FIRST AND SECOND STUDIES

In the first study, hard copies of coloured images were shown to the participants. These images were made up of differently paired coloured squares, where it was expected that the CVDt would have some difficulty in distinguishing the differences of the colours of the pairings. A number of pie-charts which were shown with differently coloured segments. The pie-charts were shown in two modes. The first mode was a number of pie-charts with differently coloured segments, such that it was expected that the CVDt would be unable to distinguish the different colours to some of the adjacent segments. The second mode was the same pie-charts as the first mode, but this time the pie-charts had been processed through the HEA, where the expectation was that now the CVDt would be able to distinguish the colours of all of the adjacent segments due to post-processing colour separation.

Participants were asked questions about the images and from their responses they were divided into two sets: i) non-CVDt and ii) indicative-CVDt. Those belonging to the non-CVDt set had no difficulty in determining information provided in the images, whereas those in the indicative-CVDt set had some form of difficulty in determining information.

The same colour images were also used in the second study, but this time as soft copies. As with the first study the images were shown in two modes. The first mode showed the pie-charts pre-processed, and the second mode showed the pie-charts post-processed through the HEA.

Participants were asked the same questions as the first study and from their responses they were again divided into two the two sets: non-CVDt and indicative-CVDt. Statistical analyses using the Pearson Chi-Squared and the Independent Sample T-tests were applied to the participant responses.

From the statistical analyses of the responses from the second study, there could be three possible outcomes with the post-processed images having been parsed through the HEA: i) Statistical analyses confirm the validity of the HEA, ii) Statistical analyses shows a mixture of validity and non-validity of the HEA and iii) Statistical analyses shows the HEA lacks validity. If case i) is the outcome, then more detailed studies could be performed using the HEA without any modifications. If case ii) is the outcome, it demonstrates revisions of the HEA are needed before any further studies can be conducted. Finally, if case iii) is the outcome, it indicates that the HEA cannot be supported by statistical analyses and hence no further studies are worth pursuing.

5.3 IDENTIFICATION OF THE STUDY HYPOTHESES

Two hypotheses were considered in these two studies:

1) Non-CVDt participants were able to interpret information from the images without the HEA better than those who were identified as indicative-CVDt.

2) Indicative-CVDt participants were able to interpret information from the images better when the HEA had been applied, compared to not being used.

In statistical studies a null hypothesis should also be considered, where the relationship between the two independent sets (non-CVDt and indicative-CVDt) is due to chance, meaning hypotheses 1) and 2) would not have any credibility.

5.4 THE STUDY DESIGN

The survey questions were written as a number of different sections. The first section was to gather personal information; the second section was to asked the participants whether they already had knowledge if they were CVDt or not; the third section was to determine which set

a participant's responses belonged to (non-CVDt or indicative-CVDt) for the purposes of this thesis, and the fourth section was used to determine how the two sets viewed given pre-processed information and also viewed the same information but this time as post-processed information through the HEA.

5.4.1 THE INDICATION OF CVDT OR NON-CVDT

To maintain as much consistency as possible between the studies, colours pairings of question 5 in the first study and question 4 in the second study were chosen such the data captured would separate the participants into the two sets (non-CVDt and indicative-CVDt). The colour paired squares were shown as two columns of six, where the right-hand column was the inverse of the left-hand column, as shown in Figure 5.1. The expectation was that some participants would have difficulty identifying the two individual colours of some of the pairs, in which case subsequent survey question responses would then be considered as indicative-CVDt. Conversely, participants who had no difficulties were considered non-CVDt, with subsequent responses considered accordingly.

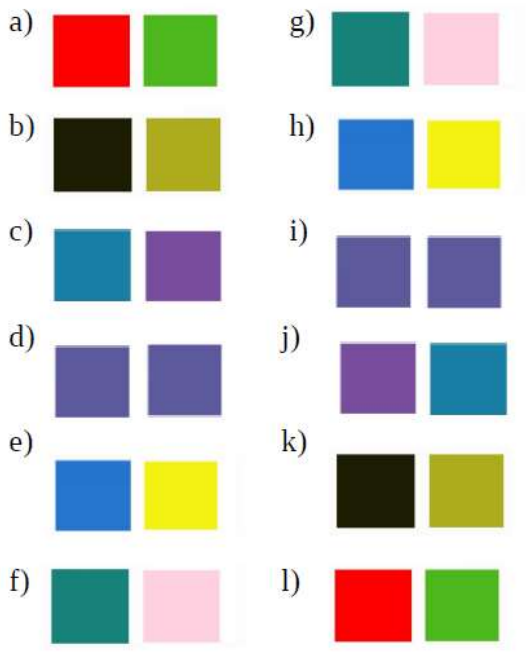

Figure 5.1: Colour pairings used to distinguish non-CVDt from indicative-CVDt

5.4.2 THE PIE-CHARTS

Carefully designed pie-charts were provided to examine the benefit that the HEA might provide to those identified as indicative-CVDt, without benefit to non-CVDt. Three of the pie-charts were shown pre-processed as either a hard-copy in the first survey or as a soft-copy in the second survey. Three corresponding pie-charts were also shown post-processed with the colour separation of HEA, either as hard-copy for the first survey or soft-copy with the second survey.

The three pre-processed pie-charts were designed to support hypothesis 1), in that it was expected that those participants identified as non-CVDt would be able to interpret information from the pie-charts better than those identified as indicative-CVDt.

In contrast, the three post-processed pie-charts were designed to support hypothesis 2). In this case the expectation was that the indicative-CVDt could now interpret the information in the pie-charts correctly.

Figure 5.2 shows the pie-charts used in the two surveys where the left-hand column shows the pre-processed pie-charts the right-hand column shows the corresponding post-processed pie-charts.

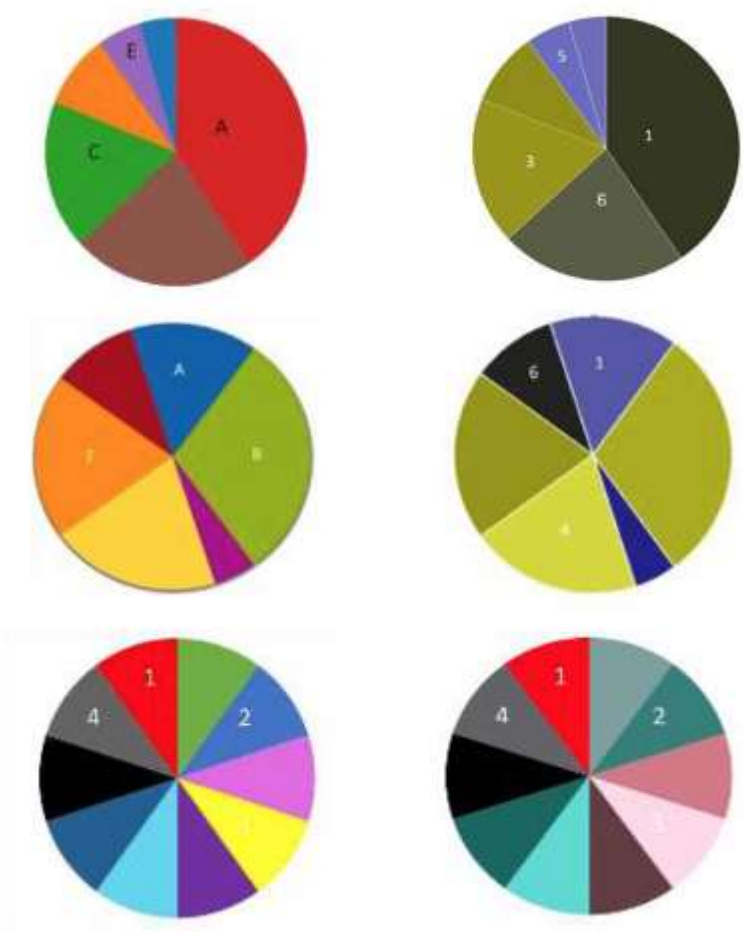

Figure 5.2: The pie-charts used in these two surveys

5.5 CONDUCTING FIRST AND SECOND STUDIES

The following steps were followed:

Step 1) Prior to undertaking the survey, each participant was asked to sign a consent form. Each agreeing participant was then provided with questions on high-quality A4 paper and with the questionnaire to record their responses.

Step 2) Participants were requested to provide written responses to survey questions associated with gathered personal information.

Step 3) Participants were asked to provide written responses to survey questions associated with coloured paired squares.

Step 4) Participants were asked to provide written responses to survey questions associated with pre- and post-processed pie-charts through the HEA.

Step 5) Finally, participants was asked if they would be prepared to be involved in further studies. In which case they were asked to provide their contact details.

The main difference between surveys was the use of tablets in the second one. In steps 3 and 4, participants were provided with one of two tablets and were asked to view and provide their responses to these questions.

5.6 APPLYING STATISTICS

The Pearson Chi-squared and the Independent Sample T-tests provide evidence of any associated relationship and significance (or not) (Field, 2009; Curtis, and Youngquist, 2013; Laura, and Yuan, 2010; Diener, 2008). These two techniques were used such that each should corroborate with one another, and in the case that the results differed between the two, then the validity of the data-set results would be uncertain.

These two tests were applied to data obtained from the participant responses to the pre- and post- processed pie-chart questions in the first and second studies. The results of both techniques were used to support both hypothesis 1 and 2. The expectation was that the two techniques would corroborate each other.

5.7 TWO-TAILED PROBABILITY

In many statistical studies (Bolboacă et al., 2011; Tabachnick & Fidell, 2007) that apply the Pearson Chi-squared test and the Independent Sample T-test a value of 5% ($\rho = 0.05$) used as the significance threshold. For this study the threshold value "tighten" to 1% ($\rho = 0.01$). The justification for this is that a lower ρ will provide far greater confidence in the results than a higher ρ value. With a threshold of $\rho = 0.01$, any result of more than 1 in 100 would be considered insignificant, whereas with a threshold of $\rho = 0.05$ would require a result of > 5 in 100 to be considered insignificant. For a value to be considered as significant it must be in the ρ range 0.00 to 0.01. Therefore, a significance threshold value of $\rho = 0.01$ provides greater validity to the gathered data-set. The significance/insignificance differences between the two threshold values are highlighted in Figure 5.3.

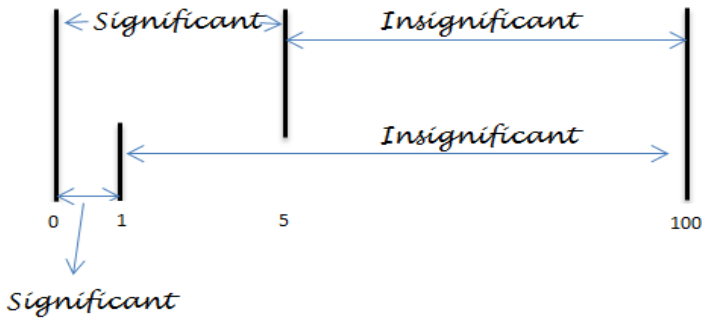

Figure 5.3: The differences of the ρ values

5.8 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 1, FOR FIRST AND SECOND STUDIES

Table 5.1 shows response numbers (total of 573) in the first study to questions 6, 8 and 10 (pre-processed), of which 531 identified as non-CVDt, and 42 as indicative-CVDt.

All of the responses from non-CVDt individuals demonstrated that the segment interface boundaries were detectable, therefore none were identified as problematic. However, from analysis of the indicative-CVDt responses, 28 showed no problems in detecting segment interface boundaries but 14 did (columns 4 and 5 of Table 5.1).

Table 5.1 also shows response numbers (120 in total) from the second study to the pre-processed images of questions 5, 7 and 9. The total number of responses from those identified as non-CVDt was 111, and 9 from those identified as indicative-CVDt.

All of the responses from non-CVDt individuals demonstrated that the segment interface boundaries were detectable, therefore, none of the non-CVDt responses were identified as problematic. However, from analysis of the indicative-CVDt responses, 6 showed no problem in detecting the segment interface boundaries but 3 did (columns 4 and 5 of Table 5.1).

5.9 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, FOR FIRST AND SECOND STUDIES

A total of 84 responses in the first study were obtained for questions 6, 8, 10 (pre-processed and, 7, 9, and 11 (post-processed with HEA) from those deemed as indicative-CVDt as shown on Table, 5.1.

In Table, 5.1, the label Original refers to responses from questions 6, 8 and 10. 28 of the 42 responses showed no difficulty in identifying segment boundary interfaces, but 14 did have difficulty. The label Halo indicates application of HEA, referring to the responses from questions 7, 9 and 11. From the 42 responses, 39 participants had no problems with identification of segment boundary interfaces. However 3 participants still had difficulty in identifying boundary interfaces, even after application of the HEA.

Additionally, 18 responses in the second study were obtained for questions 5, 7, 9 (pre-processed), 6, 8, and 10 (post-processed) from indicative-CVDt participants. Questions 6, 8 and 10 were the corresponding post-processed pie-chart of the pre-processed pie-chart of question 5, 7 and 9 respectively.

Also, in Table 5.1, the label Original refers to responses from questions 5, 7 and 9. 6 of 9 responses showed that no difficulty in identifying boundary interfaces, but 3 did. The label Halo means the application of HEA, referring to the responses from questions 6, 8 and 10. All 9 responses showed no problems with identification of segment boundary interfaces.

Table 5.1: Responses for the two studies on hypothesis 1 and 2

	Hypotheses		Non-Problematic	Problematic	Total
First study (Paper study)	1	Non-CVD	531	0	531
		Indicative-CVD	28	14	42
		Total	559	14	573
	2	Original	28	14	42
		Halo	39	3	42
		Total	67	17	84
Second study (Tablet study)			Non-Problematic	Problematic	Total
	1	Non-CVD	111	0	111
		Indicative-CVD	6	3	9
		Total	117	3	120
	2	Original	6	3	9
		Halo	9	0	9
		Total	15	3	18

5.10 STATISTICAL ANALYSES ON HYPOTHESIS 1, FOR BOTH STUDIES

Using the data-set of 573 responses in the first study, and applying the Pearson Chi-Square test, a ρ value of 0.000 was obtained. This value was less than the threshold significance value of 0.01, and the data-set was considered a significant, which matches expectation. When applying the Independent Sample T-test to the same data-set, a ρ of 0.000 was yielded, which was also less than the threshold significance value (0.01). Hence, the two statistical techniques corroborated with each other for hypothesis 1, as shown in Table 5.2. These results emphasised that the non-CVDt participants were able to interpret information in images without post-processing better than the indicative-CVDt participants.

In the same way when using the data-set of 120 responses in the second study, and applying the Pearson Chi-Square test, a ρ value of 0.000 was yielded which was less than the threshold significance ρ value (0.01) demonstrating significance. Also, the Independent Sample T-test gave a ρ of 0.000, which was less than the threshold significance. Therefore, the two statistical techniques corroborated with each other for hypothesis 1, as shown in Table 5.2. This demonstates that the non-CVDt individuals interpret information better than the indicative-CVDt individuals interprets.

5.11 STATISTICAL ANALYSES ON HYPOTHESIS 2, FOR BOTH STUDIES

Similarly, when hypothesis 2) was considered on the same data-set in the first study, the Pearson Chi-Square test yielded a ρ value of 0.003, which was less than the significance threshold, matching the expectation. Additionally, the Independent Sample T-test gave a ρ value of 0.001, which was less than the threshold value. Again this demonstrated that the two statistical techniques corroborate with each other and shows that the indicative-CVDt people interpret information better having been shown post-processed images, as shown in Table 5.2.

In the same way, when hypothesis 2) was considered in the second study, the Pearson Chi-Square test gave a ρ value of 0.058 which was more than the significance threshold value, meaning it was insignificant, which did not match expectation. While, the Independent Sample T-test gave a ρ value of 0.000, which was less than the threshold ρ value and matching the expectation. This demonstrates that the two statistical techniques were not corroborating with each other, as shown in Table 5.2.

Table 5.2: Results of the two statistical techniques tests

		Pearson Chi-Square test			Independent Sample T-test		
		Yielded ρ value	Result	Expected result	Yielded ρ value	Result	Expected result
First study (Paper study)	Hypothesis 1)	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Halo with Original	0.003	Significant	Significant	0.001	Significant	Significant
Second study (Tablet study)	Hypothesis 1)	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Halo with Original	0.058	Insignificant	Significant	0.000	Significant	Significant

5.12 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHEESES 1, AND 2, FOR FIRST STUDY

From the data-set of 573 in the first study, the Pearson Chi-Square value (χ) was 181.43, (Table 5.3), with a ρ value of 0.000. Since this ρ value was less than the threshold value, then this test demonstrated that hypothesis 1) confirmed a statistically significant association between the two sets (non-CVDt and indicative-CVDt) and the expectation was met. These results showed quantitatively that non-CVDt participants interpret information better than

indicative-CVDt participants in non-processed images. A full set of quantitative SPSS results were presented in Appendix G.

The Chi-square test was calculated as follows:

$$Ei,j = \frac{\sum_{k-1}^{c} O_{i,j} \sum_{k-1}^{r} O_{k,j}}{N}$$

Where,
$E_{i,j}$= expected value

$\sum_{k-1}^{c} O_{i,j}$ = Sum of the column

$\sum_{k-1}^{r} O_{k,j}$ = Sum of the row

N = total number

Once calculated the expected value, the following formula was applied to calculate the value of the Chi-Square test:

$$\chi^2 = \sum_{i-1}^{r} \sum_{j-1}^{c} \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}}$$

χ^2 = Chi-Square test of Independence

$O_{i,j}$ = Observed value of two nominal variables

$E_{i,j}$ = Expected value of two nominal variables

Degree of freedom was calculated by using the following formula:

$$DF = \frac{(r-1)}{(c-1)}$$

Where

DF = Degree of freedom

r = number of rows

c = number of columns

Based on the formula above the expected value was calculated as follows:

$$Ei,j = \frac{304 * 269}{573}$$

Hence, the expected the value Ei,j = 142.72

Further, the chi-square was calculated based on the formula shown above:

$$\chi^2 = \frac{(304 - 142.72)^2}{142.72}$$

Hence, the chi-square value χ^2 = 181.43

To find the ρ value for the chi-square value, need's to find the degrees of freedom to check the P table the tabular value of χ^2. Since the 2 observations were used the degrees of freedom can be calculated by the formula below:

df = number of observations – 1

= 2 – 1

= 1

Hence, the tabular value in the first row of the P table need's checked to compare the χ^2 calculated with χ^2 tabular value. If χ^2 calculated > χ^2 tabular then there is a relation between the two variables. After checking the 1st row of the P table, it was found that χ^2 calculated > χ^2 tabular and that the ρ value = 0.000. This means that the chi-square test was significant which confirms that there is a relation between the two variables.

From the total number of responses in the same study, 84, the Pearson Chi-Square value (Χ) 8.924 was yielded (Table 5.3). The obtained ρ value was less than the threshold ρ value, showing statistical significance between the original the corresponding pie-charts with the HEA applied, for hypothesis 2). Hence, the expectation was met in that indicative-CVDt participants were able to interpret information in the pie-charts better when the HEA was applied compared to without it. A full set of quantitative SPSS results were presented as an Appendix G.

5.13 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHEESES 1, AND 2, FOR SECOND STUDY

From the responses (120), in the second study, the Pearson Chi-Square value (Χ) was 37.949 (Table 5.3), with a ρ value of 0.000. As the ρ value was less than the threshold value, this test demonstrates that hypothesis 1) confirms a statistically significant association between the non-CVDt and indicative-CVDt sets. This shows quantitatively that the non-CVDt participants interpret information better than the indicative-CVDt participants in non-processed images.

Also, from the responses (18), in the same study, the Pearson Chi-Square value (Χ) was 3.600 (Table 5.3). The ρ value was greater than the threshold value, showing no statistical significance between the original and the corresponding pie-charts with HEA applied, for

hypothesis 2). The expectation was not met in that the indicative-CVDt participants statistically were not able to interpret post-processed images better than pre-processed images. A full set of quantitative SPSS results were presented in Appendix G.

Table 5.3: The pearson chi-square value χ for hypotheses 1) and 2) for both studies

	hypothesis	Pearson Chi-Square Value χ	ρ value
First study (Paper study)	1	181.433	0.000
	2	8.924	0.003
Second study (Tablet study)	1	37.949	0.000
	2	3.600	0.058

5.14 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESES 1, AND 2, FOR FIRST STUDY

Table 5.4 shows two separate statistical tests of participant responses in the first study. Column 4 of Table 5.4 shows that the Levene's Test for Equality of Variances was used to show that the means from the two sets (non-CVD and indicative-CVD) have equal variance. It was used to confirm the null hypothesis, in that there was no relationship between the two independent groups.

Levene's Test for Equality of Variance yielded ρ = 0.000, which was less than the threshold value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000, which was less than the threshold significance ρ value 0.01, hence the data-set was considered as significant. All of these results demonstrated that the Independent Sample T-test can be used to quantitatively demonstrate that images without post-processing were interpreted better by non-CVDt participants than indicative-CVDt participants. Hence, there was validity with the first hypothesis, with the relationship was not due to chance. A full set of quantitative SPSS software results were presented in Appendix G.

The Independent Sample T-test was calculated as follows:

Step 1: Sum of two groups are calculated

Step 2: Square of the sums from step 1 for two groups are calculated

Step 3: Mean of the two groups is calculated

Step 4: Individual values are squared and then added

Step 5: Value is then replaced in the formula below

$$t = \frac{\mu_A - \mu_B}{\sqrt{\left[\frac{\left(\sum A^2 - \frac{(\sum A)^2}{\eta_A}\right) + \left(\sum B^2 - \frac{(\sum B)^2}{\eta_B}\right)}{\eta_A + \eta_B - 2}\right] \cdot \left[\frac{1}{\eta_A} + \frac{1}{\eta_B}\right]}}$$

$(\Sigma A)^2$: Sum of data set A, squared (Step 2).

$(\Sigma B)^2$: Sum of data set B, squared (Step 2).

μ_A: Mean of data set A (Step 3)

μ_B: Mean of data set B (Step 3)

ΣA^2: Sum of the squares of data set A (Step 4)

ΣB^2: Sum of the squares of data set B (Step 4)

η_A: Number of items in data set A

η_B: Number of items in data set B

Step 6: Find the degrees of freedom ($\eta_A - 1 + \eta_B - 1$)

Step 7: Check t-table for degrees of freedom using the alpha value of 0.05 i.e. 99% confidence interval

Step 8: Compare value of steps 5 and 7 and if ρ value ≤ 0.05 there is significant difference between the two groups.

Other point to take into consideration is variance as seen below:

a. If equal variances are assumed than

$$s^2 = \frac{\sum_{i-1}^{\eta_A}(x_i - \mu_A)^2 + \sum_{j-1}^{\eta_B}(x_j - \mu_B)^2}{\eta_A + \eta_B - 2}$$

Where

s^2 = sample variance

x_i = individual value in sample A

x_j = individual value in sample B

b. If unequal variances are assumed than

$$d = \frac{\mu_A - \mu_B}{\sqrt{\frac{s_A^2}{\eta_A} + \frac{s_B^2}{\eta_B}}}$$

$$df = \frac{\left[\frac{s_A^2}{\eta_A} + \frac{s_B^2}{\eta_B}\right]^2}{\frac{(s_A^2/\eta_A)^2}{\eta_A - 1} + \frac{(s_B^2/\eta_B)^2}{\eta_B - 1}}$$

$$s_A^2 = \frac{\sum_{i-1}^{\eta_A}(x_i - \mu_A)^2}{\eta_A - 1}$$

$$s_B^2 = \frac{\sum_{j-1}^{\eta_B}(x_j - \mu_B)^2}{\eta_B - 1}$$

In this situation equal variance is observed, hence the results obtained using the Independent Sample T-test formula.

$$t = \frac{1 - 0.05}{\sqrt{\left[\frac{\left(196 - \frac{196}{14}\right) + \left(312481 - \frac{312481}{559}\right)}{559 + 14 - 2}\right] \cdot \left[\frac{1}{559} + \frac{1}{14}\right]}}$$

$$t = \frac{0.95}{\sqrt{\left[\frac{182 + 311922}{571}\right] . [0.001789 + 0.071429]}}$$

$$t = \frac{0.95}{\sqrt{[546.5919] . [0.073217]}}$$

$$t = \frac{0.95}{\sqrt{40.02008}}$$

$$t = 0.15017$$

When the calculations were performed it was found that the t-value = 0.15017. Therefore, to find the ρ value of for the Independent Sample T-test value need's to find the degrees of freedom and check the table for t-distribution critical value (the tail probability) the tabular value of Independent Sample T-test. As previously shown above the degrees of freedoms was calculated and compared with the t-distribution table to establish the ρ value for the Independent Sample T-test. It was observed from the table that the ρ value = 0.000 which shows that there was significant difference between the two sets of non-problematic and problematic participants.

Similarly, when hypothesis 2) was considered on the same data-set (Table 5.4), Levene's Test for Equality of Variance yielded ρ = 0.002 (less than the threshold value of 0.01). Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.001, which was less than the threshold significance value of 0.01 and hence the data-set was considered as significant, which matches the expectation when the HEA applied, for hypothesis 2). These results showed that quantitative analyses using the Independent Sample T-test when post-processed images were shown to the indicative-CVDt participants better information interpretation occurred. A full set of quantitative SPSS software results were presented in Appendix G.

5.15 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESES 1, AND 2, FOR SECOND STUDY

From the responses (120), in the second study, Table 5.4 shows that Levene's Test for Equality of Variance yielded ρ = 0.400 when hypothesis 1) was considered. This was greater than the threshold value of 0.01. Therefore, the significance ρ value of the Equal variances assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances assumed was 0.000 which was less than the threshold significance value, a hence the data-set was considered significant, matching expectation.

In the same way when hypothesis 2) was considered on the same data-set (Table 5.4), Levene's Test for Equality of Variance yielded ρ = 0.000 when hypothesis 2) was considered on the same data-set. This was less than the threshold value of 0.01, therefore the ρ value of the Equal variances not assumed was used as the significant value for the Independent Sample T-test. The ρ = 0.000 for the Equal variances not assumed, which was less than the threshold significance value of 0.01 and hence the data-set was considered significant and matches the

expectation when the HEA was applied, for hypothesis 2). These results demonstrate that the Independent Sample T-test can be used to quantitatively demonstrate that images without post-processing were interpreted better by non-CVDt participants than indicative-CVDt participants. Also, demonstrate that when images with post-processed were shown to the indicative-CVDt people better information interpretation occurred. Hence, there was validity with hypothesis 1 and 2 and the relationships were not due to chance. A full set of quantitative SPSS software results were presented in Appendix G.

Table 5.4: The independent sample t-test value for hypotheses 1) and 2) for both studies

	Hypothesis		Levene's Test for Equality of Variances ρ	Significance level ρ
First study (Paper study)	1		0.000	
		Equal variances assumed		0.000
		Equal variances not assumed		0.000
	2		0.002	
		Equal variances assumed		0.002
		Equal variances not assumed		0.001
Second study (Tablet study)			0.400	
	1			
		Equal variances assumed		0.000
		Equal variances not assumed		0.000
	2		0.000	
		Equal variances assumed		0.063
		Equal variances not assumed		0.000

5.16 UPHOLDING THE TWO HYPOTHESES

Table 5.5 provides a summary of statistical results from both studies. In the first, the HEA upheld hypotheses 1) and 2) and significance was obtained. In the second, post-processed images using the HEA upheld hypothesis 1) and significance was obtained with both statistical techniques. The HEA upheld hypothesis 2) only when the Independent Sample T-test was applied.

Table 5.5: Table comparing results of the two studies (pie-charts)

		Pie-charts		
		Pearson Chi-Square test	Independent Sample T-test	Corroborate
First study (Paper study)	Hypothesis 1)	Significant	Significant	Yes
	Hypothesis 2) Compare Halo-Effect with Original	Significant	Significant	Yes
Second study (Tablet study)	Hypothesis 1)	Significant	Significant	Yes
	Hypothesis 2) Compare Halo-Effect with Original	Insignificant	Significant	No

5.17 CHAPTER CONCLUSION

The first study was used to determine the credibility of the novel algorithm developed and implemented in this thesis. The difference in performance between non-CVDt and indicative-CVDt individuals were analysed using Pearson Chi-Squared and the Independent Sample T-tests. The statistical techniques not only corroborated which each other, but also highlighted the gains that post-processed images gave to indicative-CVDt individuals.

It can be further concluded that the results of the first study showed that with the two sets, significance and a relationship between the two variables were obtained. With regards to hypothesis 1), it was found that non-CVDt participants were able to interpret information portrayed by different colours better than indicative-CVDt participants without the use of the

HEA. With regards to hypothesis 2), it was found that when the HEA is used, indicative-CVDt individuals interpret colour information more effectively than without.

The second study showed that the HEA does improve information-interpretation by use of electronic devices. Furthermore, it showed that the two statistical techniques corroborated with each other for hypothesis 1, but did not for hypothesis 2), indicating that the HEA is useful on commonly used electronic devices.

In the second study, statistical techniques demonstrated significant relationships and it can be concluded that it is beneficial to use post-processed images that have been passed through the HEA. Considering hypothesis 1), both techniques not only showed a significant relationship but also corroborated with each other. When hypothesis 2) was considered, significance with Independent Sample-T test was achieved, but insignificance with the Pearson Chi-Square test. This difference can be ascribed to the sample size of the data-set. In the context of the general population, CVDt is not a significant problem, however in the specific CVDt population, there is a significant problem. This thesis focuses on the specific problem associated with the indicative-CVDt people. In all of these studies the expectation is that the control sets would not have any problems. In the case that problems were encountered by the control set then that study would be invalid.

The work of this chapter has shown that post-processing using the HEA does improve information interpretation by use of electronic devices. Chapter 6 continues this work by comparing the benefits gained from each of three algorithms: The two transformation algorithms of Re-Colouring (Culp, 2012), and Hatching (Hung, 2013) with the colour separation algorithm of the HEA (Alsafyani, Egan and Jefferies, 2016) by using pie-charts, map of Australia and geometric shapes.

CHAPTER 6: ENSURING AND COMPARING THE HEA AND OTHER TRANSFORMATION ALGORITHMS IN IMPROVING INTERPRETATION INFORMATION FOR CVDT PARTICIPANTS USING PIE-CHARTS, MAP OF AUSTRALIA AND GEOMETRIC SHAPES.

6.1 INTRODUCTION

This chapter were first show that Hung's Hatching Accumulation Algorithm (HAA) and Culp's Re-Colouring Algorithm (RCA) do provide improvement in information interpretation. It will also be demonstrated that both of these algorithms also show statistical credibility with hypothesis 1) and hypothesis 2) in a manner similar to Al safyani's Halo-Effect Algorithm (HEA).

Second, the chapter were then be extended to show a third hypothesis, where the HEA has greater statistical credibility than the other two algorithms and also the HEA provides a greater amount of improvement in information interpretation than the other two algorithms.

Three survey studies were undertaken where participants were asked to evaluate a number of different images which might be difficult for the CVDt to interpret. A number of coloured pie-charts in four modes were shown in the first study. The first pie-chart mode was without the use of any algorithm, the second was with the use of the HEA, the third was with the use of the HAA and the fourth was with the use of the RCA.

This chapter moves onto the second study to compare the three algorithms in a situation that would be fair to be realistic and also such that each algorithm would provide benefits to the CVDt. In which case, a further survey is proposed such that participant responses' can be statistically analysed to evaluate each of the algorithms and, hence to determine, which if any, of them provides the most benefit. The algorithms were compared for their effectiveness by using a map of Australia shown in four modes, such as the first study.

The third study attempts to compare the effectiveness of each algorithm on a platform that is fair to all by using different but similar, geometric shapes. The geometric shapes used were the same to the previous surveys and participants' responses were analysed statistically.

6.2 HYPOTHESIS 1 AND 2 WITH HUNG'S AND CULP'S ALGORITHMS

To date and to author knowledge, statistical studies have not been applied to Hung's nor Culp's algorithms. Using these algorithms, the Pearson Chi-Square and Independent Sample T-tests were applied to data obtained from a survey using the same pie-chart images in addition to the use of the Australian map and geometric shapes with the same hardware as previously considered. Furthermore, to ensure statistical credibility between the three algorithms, participants' were asked to consider the HEA. The expectation was that both

Hung's and Culp's algorithms would show statistical credibility and improvement in information interpretation, in a manner associated with the HEA.

6.3 HYPOTHESIS 3

Hung's Algorithm and Culp's algorithms have been considered and shown to have statistical credibility and to improve information interpretation then a third hypothesis were considered.

- Hypothesis 3) The HEA provides a better means of information interpretation than Hung's Algorithm and also that the HEA provides better information interpretation than Culp's Algorithm.

6.4 THE STUDIES DESIGN

Hypothesis 3) cannot be considered in the case that HAA and/or RCA do not uphold Hypothesis 1) and/or Hypothesis 2). It can, therefore, be considered that upholding Hypothesis 1) and also Hypothesis 2) is a Quality Control test before consideration of Hypothesis 3). Furthermore, it must also be shown that the HEA also continues to uphold Hypothesis 1) and Hypothesis 2) as the statistical analyses were applied to new data-set. Therefore, this is also a Quality Control test of the HEA.

The pie-charts, map of Australia and geometric shapes were shown as:

- in their original form,
- after they had been passed through the HEA,
- after they had been passed through the HAA,
- and after they had been passed through the RCA.

This meant that the survey participants were asked to view the pie-charts, map of Australia and geometric shapes in 12 different forms.

6.4.1 THE PIE-CHARTS DESIGN

Sixteen questions were asked of survey participants'. Questions 1 – 3 were the same as previous surveys which relate to gender, knowledge of CVDt or not, and if so the type of colour-blindness if known. As with previous studies, question 4 was used to separate the participants into the two sets, non-CVD and indicative-CVD. In this participant study, pie-charts were used to identify the number of segments they saw in each individual pie-chart. Also, estimated the space that particular segments of the pie-chart took was asked in questions 5 – 16. The images were shown to participants as e-images using the same tablets.

For standardisation, the same pie-charts as those used in chapter 5 were used in this study. Each of the three original pie-chart images had associated pie-chart image post-processing from each of the three algorithms. The survey participants' were asked to view the different pie-chart images as shown in the order of Table 6.1.

Table 6.1: Shows pie-chart images as shown in the order for participants

Original pie-chart	Post HEA	Post HAA	Post RCA
Question 5 associated with:	Question 7	Question 8	Question 12
Question 6 associated with:	Question 9	Question 10	Question 13
Question 16 associated with:	Question 11	Question 15	Question 14

Survey questions five, six and sixteen showed three different pie-chart images without the application of any of the improvement algorithms. Questions seven, nine and eleven were the same pie-chart except with the HEA applied. Survey questions eight, ten and fifteen showed the corresponding same pie-chart images with the HAA applied. Survey questions twelve, thirteen and fourteen showed the corresponding same pie-chart images with the RCA applied. Figure 6.1 shows all twelve pie-charts that participants were asked to consider as part of the survey.

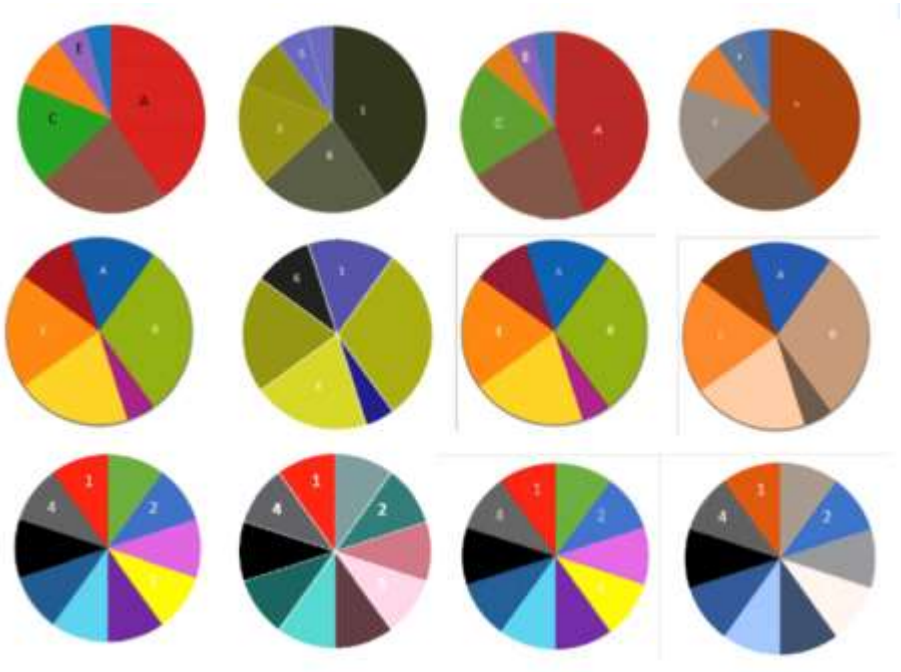

Figure 6.1: Shows the pie charts in twelve different forms

Figure 6.2 shows two adjacent segments from the pie-chart associated with question 5 where the HEA has been applied. That is, a white spaces have been inserted among the segment boundary interfaces.

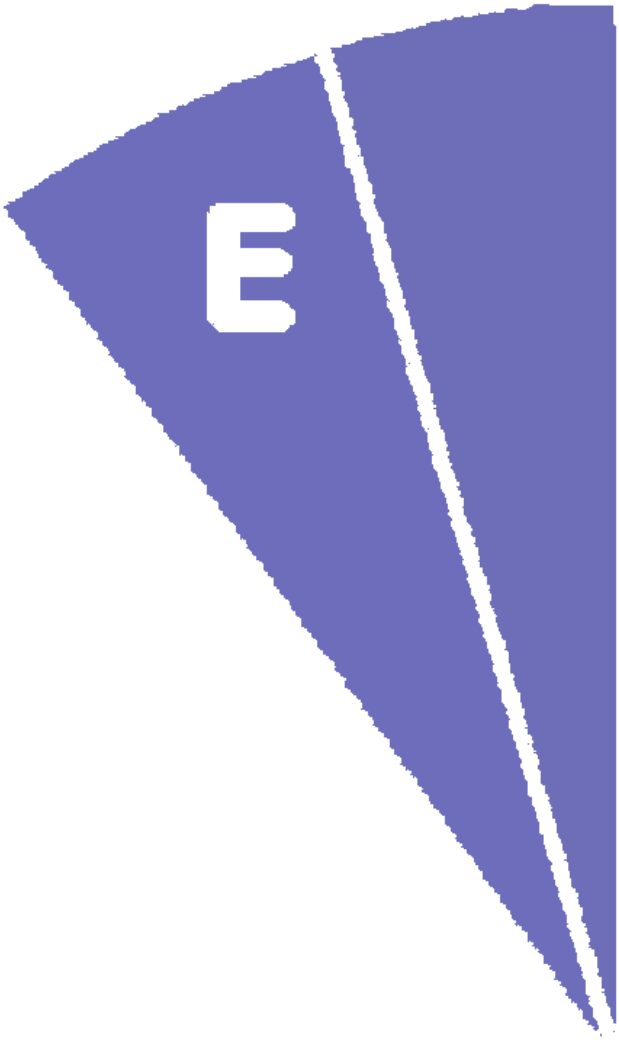

Figure 6.2: Shows two adjacent segments colours of the pie-chart having been post-processed with the HEA

Figure 6.3 shows the same two adjacent segments from the pie-chart associated with question 5 where the HAA has been applied. That is, crossed lines to form hatches of a similar colour to the original were over layered onto the corresponding pie-chart segment.

Figure 6.3: Shows two adjacent segments colours of the pie-chart having been post-processed with the HAA

Figure 6.4 shows the same two adjacent segments from the pie-chart associated with question 5 where the RCA has been applied. That is, a transformation of the colours of the corresponding pie-chart segment.

Figure 6.4: Shows two adjacent segments colours of the shape having been post-processed with the RCA

6.4.2 MAP SELECTION

Figures 6.5, 6.6 and 6.7 respectively show maps of the UK, USA and Australia. Even though improvements can be seen in each map, the map of the Australian provinces provides the most clearly defined improvements for the CVD. The map of the UK (Figure 6.5) shows many interfaces at county boundaries. From the view-point of a participant survey the numerous county boundaries and also the polymorphism of the boundaries would render a survey far too complex to define. The map of the USA (Figure 6.6) is more clear but there are still too many interface boundaries. Similarly to the map of the UK the high numbers of state boundaries also show polymorphism which renders this map too complex to define for a survey. In contrast, the map of Australia (Figure 6.7) has few boundaries interfaces, due to the small number of provinces. Furthermore, these boundaries are clear, distinct and lack polymorphism. This suggests that the map of the Australian provinces should provide a fair

comparison for the three algorithms, where the benefits of each of the three algorithms could be rigorously investigated. Hence, the map of the Australian provinces was chosen for the survey and participants' responses would then be analysed statistically.

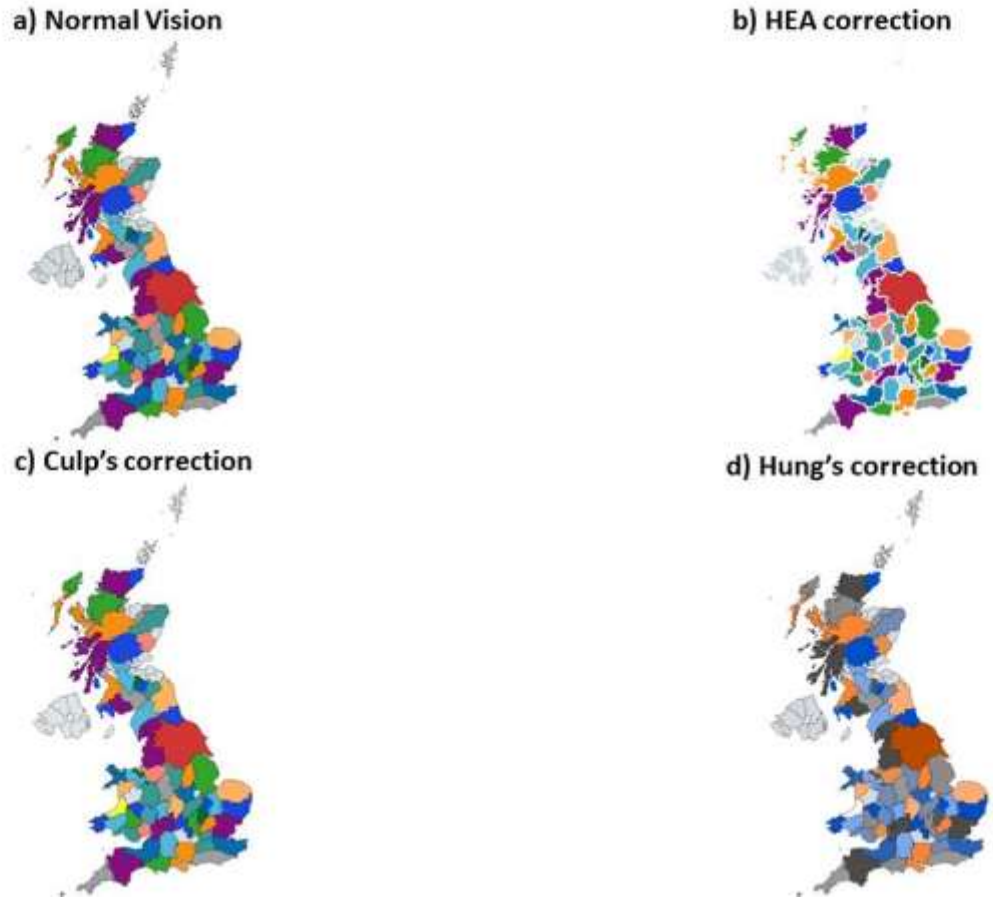

Figure 6.5: The counties of the UK

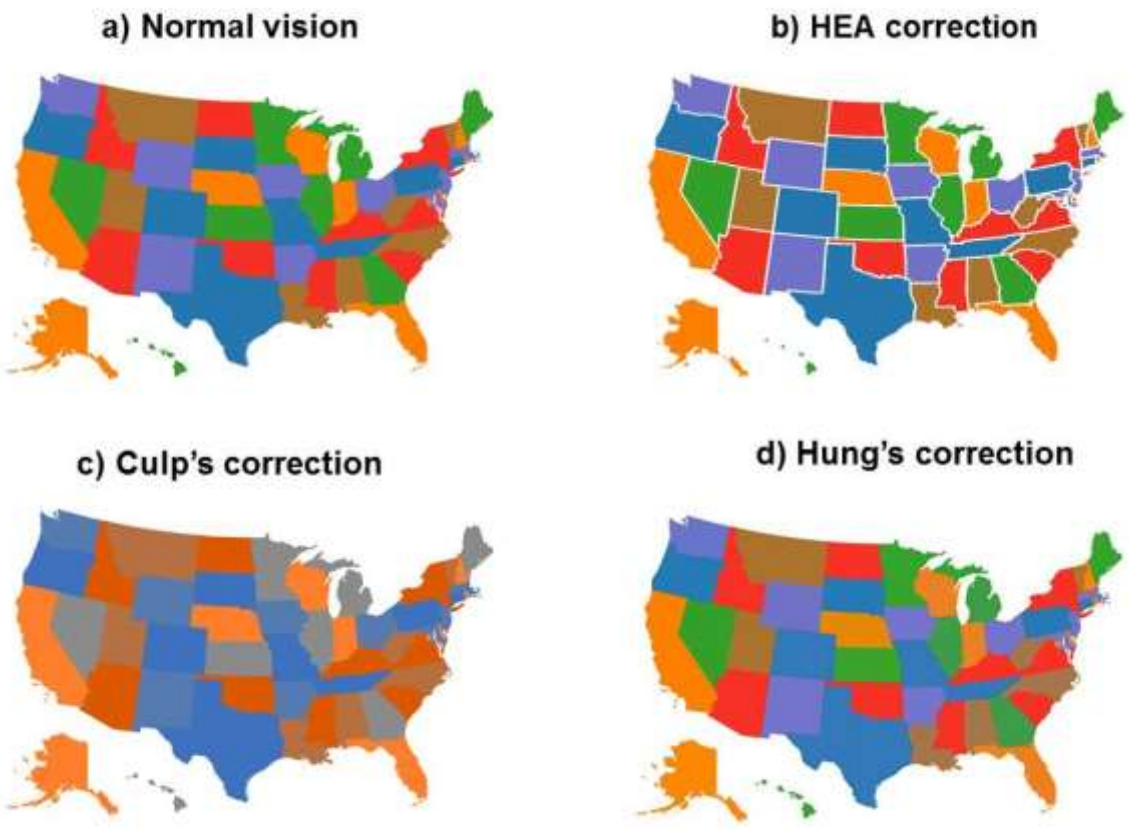

Figure 6.6: The states of the USA

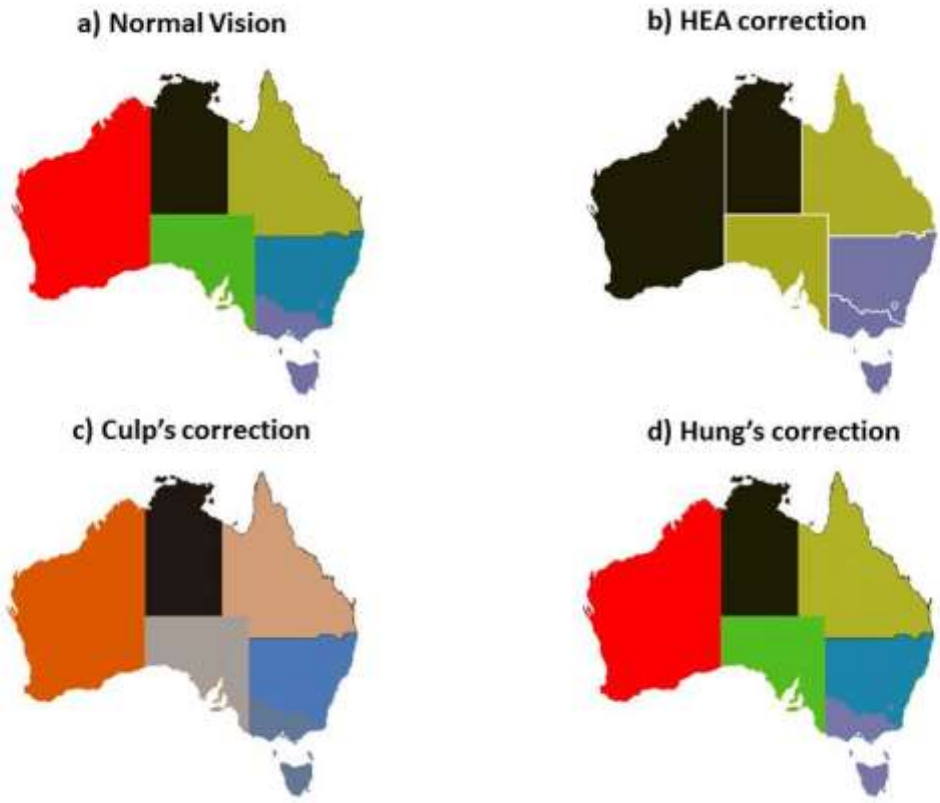

Figure 6.7: The provinces of Australia

Figure 6.8 highlights the problems that the different types of CVD would have. All three types of CVD will have difficulty in interpreting the information provided in the original the Australian map. Comparing the normal vision map a) with each of the three different types of CVD Deuteranopia map b), Protanopia map c) and Tritanopia map d) the arrows have been added to highlight the colours that the CVD would have difficulties. Thus, it is unlikely that they will be able interpret the information correctly as intended.

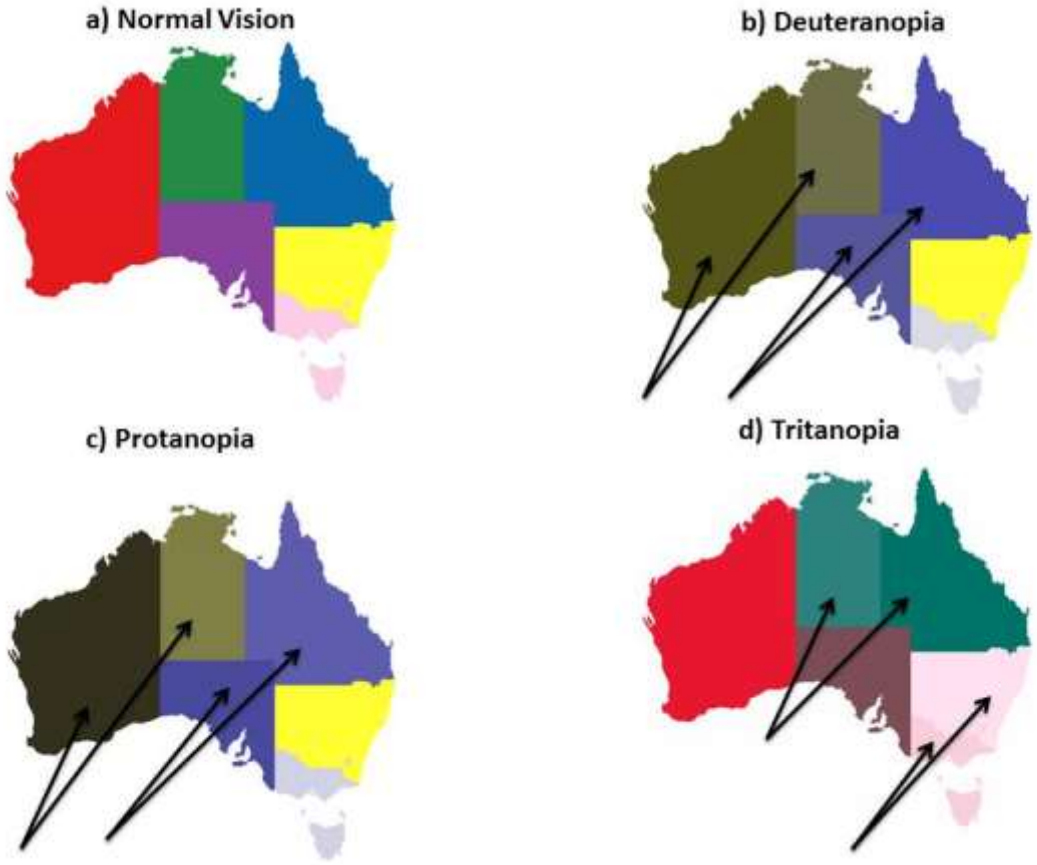

Figure 6.8: Show provinces of Australia with Protanopia, Deuteranopia and Tritanopia

Figure 6.9 is an enlarged map of the Australian provinces showing how the non-CVD would see it. The map is labelled A – F to show each of the following provinces:

- A is Western Australia (WA),
- B is Northern Territory (NT),
- C is South Australia (SA),
- D is Queensland (QLD),
- E is New South Wales (NSW),
- F is Victoria (VIC).

In the actual survey the labels A – F were removed as these labels may interfere with the responses that the survey participants' might provide. For example, the boundary interface between Western Australia (A) and the Northern Territory (B) will be difficult to observe by the indicative-CVDt, but the labels (A and B) may offer a hint that there is a boundary somewhere in the image. This hint may then be used by the indicative-CVDt participants to provide false responses.

Figure 6.9: The Australia provinces

6.4.3 THE MAP OF AUSTRALIA DESIGN

For standardisation with the previous survey, the steps in this study are kept as much as possible to the same as the steps of the previous studies. Sixteen questions were asked of survey participants'. Questions 1 – 3 were the same as previous surveys which relate to gender, knowledge of colour-blindness or not, and if so the type of colour-blindness if known. As with previous studies, question 4 was used to separate the participants into the two sets, non-CVD and indicative-CVD. In the previous participant study, pie-charts were used to identify the number of segments they saw in each individual pie-chart. Also, estimate the space that particular segments of the pie-chart took was asked in questions 5 – 16. In this survey, only count the number of different colours interface the Australia map were asked in questions 5 – 16. All images were shown as individual screen pages on the two tablets.

Table 6.2 cross-references the non-post-processed images of questions five, six and sixteen and were designed to consider if hypothesis 1) is upheld or not. Table 6.2 also cross-references questions seven through to fifteen which are post-processed images. Questions seven, nine and eleven are post-processed through HEA, questions eight, ten and fifteen are post-processed through HAA and questions twelve, thirteen and fourteen are post-processed

through RCA. These questions have, therefore, been designed to consider whether hypotheses 2) and 3) were upheld or not.

Table 6.2: Shows map of Australia images as shown in the order for participants

Original Australia map	Post-processed HEA	Post-processed HAA	Post-processed RCA
Question 5 associated with:	Question 7	Question 8	Question 12
Question 6 associated with:	Question 9	Question 10	Question 13
Question 16 associated with:	Question 11	Question 15	Question 14

Consequently, the survey participants' were shown a map of the Australian provinces in 12 different forms ranging from a pre-processed map (the original) through to post-processing with the three improvement algorithms (Figure 6.10).

Column a) shows the map in normal form (pre-processing), column b) shows the map post-processed with HEA, column c) shows the map post-processed with HAA and column d) shows the map post-processed with RCA.

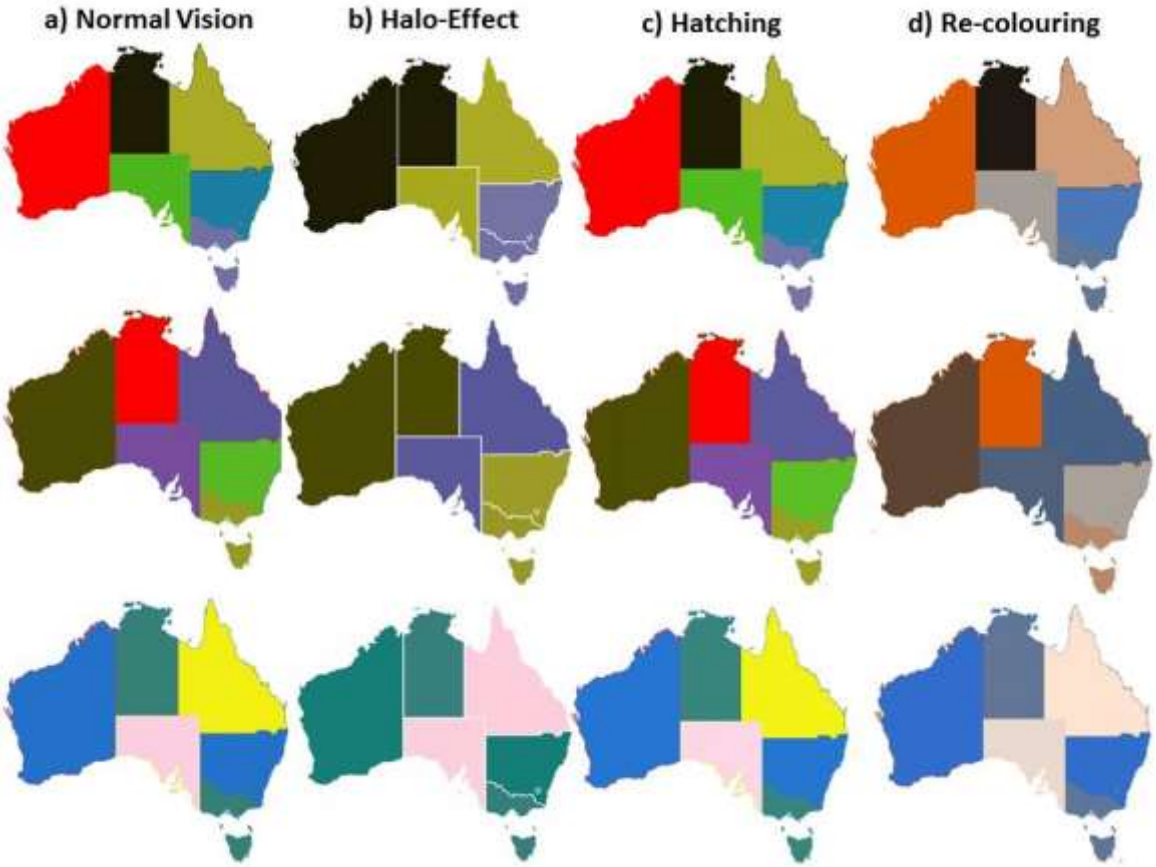

Figure 6.10: Shows the maps used in twelve different forms

Figure 6.11 is an enlarged image of two provinces, Western Australia and the Northern Territory (with the labels removed). The boundary interface was well defined because the image has been post-processed with HEA, and it corresponds to row 3, column 2 of Table 6.2. It was anticipated that the indicative-CVD should be able to observe this new boundary interface.

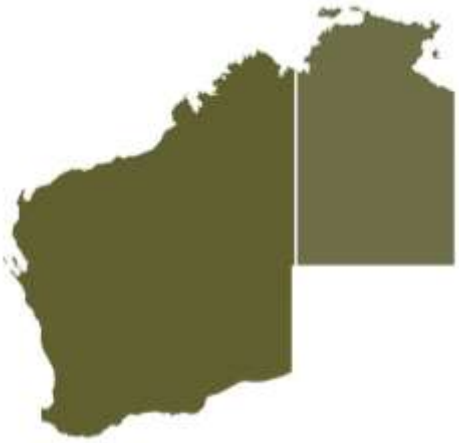

Figure 6.11: Shows two adjacent colours were separated by a white line having been post-processed with the HEA

Figure 6.12 repeats Figure 6.11, but this time the image has been post-processed with HAA and corresponds to row 3, column 3 of Table 6.2. Even though hatching was present in the image, the hatching was difficult to see and hence it is expected that the indicative-CVD may have difficulty in observing this boundary interface.

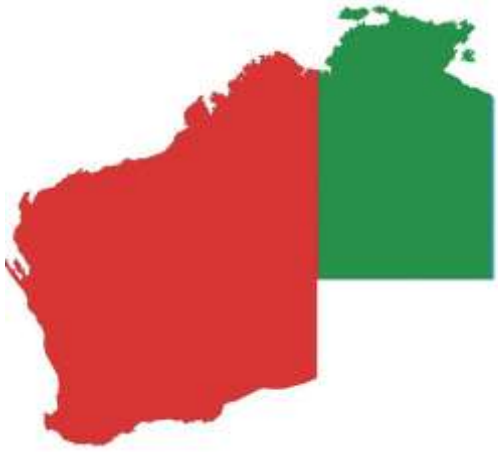

Figure 6.12: Shows cross-lines hatches to the original map having been post-processed with the HAA

Figure 6.13 repeats Figure 6.11 again, but it relates to row 2, column 4 of Table 6.2 and hence shows RCA. This time there was a clearly defined boundary interface and therefore it was expected that the indicative-CVD should be able to identify this colour change.

Figure 6.13: Shows transformed the colours of Australian map having been post-processed with the RCA

6.4.4 THE GEOMETRICAL SHAPES DESIGN

Three basic shapes were used, but the inner portions of those shapes differed considerably. One consisted of a number of differently coloured triangles which were built up to form a square. This was then replicated with the same triangles but differently coloured to form another square. The two squares were then joined together to form a rectangle as seen in Figure 6.14.

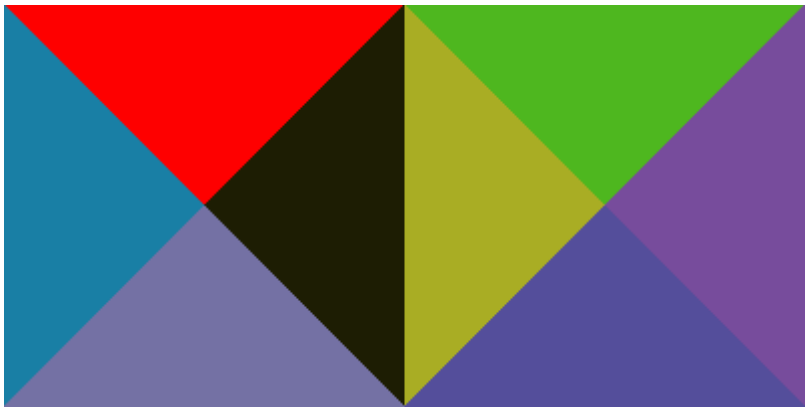

Figure 6.14: Illustrate shape one

The second shape was similar to the first shape but, a greater number of coloured triangles (and hence smaller triangles) were used to form a square. This square was then replicated but with yet more differently coloured triangles to form a second square. The two squares were then joined together to form a rectangle as seen in Figure 6.15.

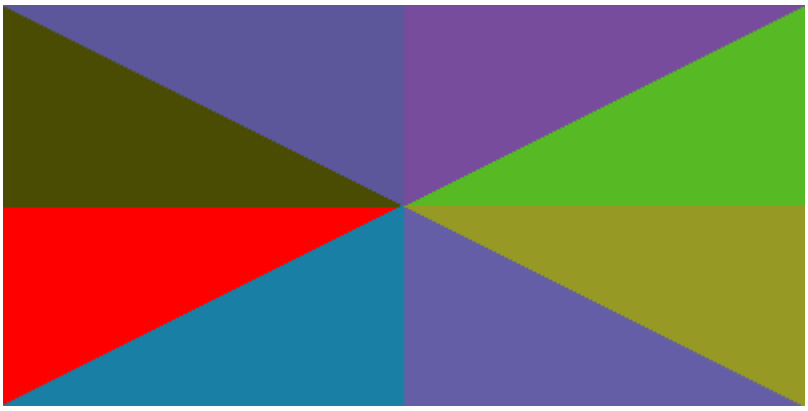

Figure 6.15: Illustrate shape two

The final shape was a rectangle with a circle inside joined together with another rectangle, but differently coloured, which also had a differently coloured circle inside it. The two rectangles were then joined together to form a greater rectangle as seen in Figure 6.16.

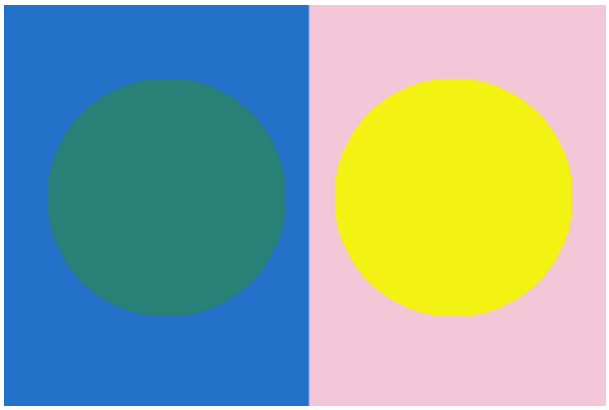

Figure 6.16: Illustrate shape three

Sixteen questions were asked of survey participants'. Questions 1 – 3 were the same as previous surveys which relate to gender, knowledge of colour-blindness or not, and if so the type of colour-blindness if known. As with previous studies, question 4 was used to separate the participants into the two sets, non-CVD and indicative-CVD. In the previous participant study, Australia map was used and count the number of different colours interface was asked in questions 5 – 16. In this survey, only the numbers of different shapes were asked in

questions 5 – 16. The images were shown to participants as e-images using the same two tablets.

Table 6.3 cross-references the non-post-processed images of questions five, six and sixteen and were designed to consider if hypothesis 1) is upheld or not. Table 6.3 also cross-references questions seven through to fifteen which were post-processed images. Questions seven, nine and eleven were post-processed through HEA, questions eight, ten and fifteen were post-processed through HAA and questions twelve, thirteen and fourteen were post-processed through RCA. These questions have, therefore, been designed to consider whether hypotheses 2) and 3) were upheld or not.

Table 6.3: Shows geometric shapes images as shown in the order for participants

Original geometric shapes	Post HEA	Post HAA	Post RCA
Question 5 associated with:	Question 7	Question 8	Question 12
Question 6 associated with:	Question 9	Question 10	Question 13
Question 16 associated with:	Question 11	Question 15	Question 14

For standardisation with the previous surveys, the steps in this study were kept as much as possible to the same as the steps of the previous studies. Consequently, the survey participants' were shown geometrical shapes in 12 different forms ranging from a pre-processed shapes (the original) through to post-processing with the three improvement algorithms as seen in Figure 6.17.

Shapes were used to test participant's abilities to detect geometrical shapes such as triangles, squares, rectangles and circles which were encapsulated on to a common large rectangle. The shapes were then shown as post-processed images i) with the HEA, ii) with HAA and iii) with RCA. Figure 6.17 shows the pre-processed images alongside the post-processed images.

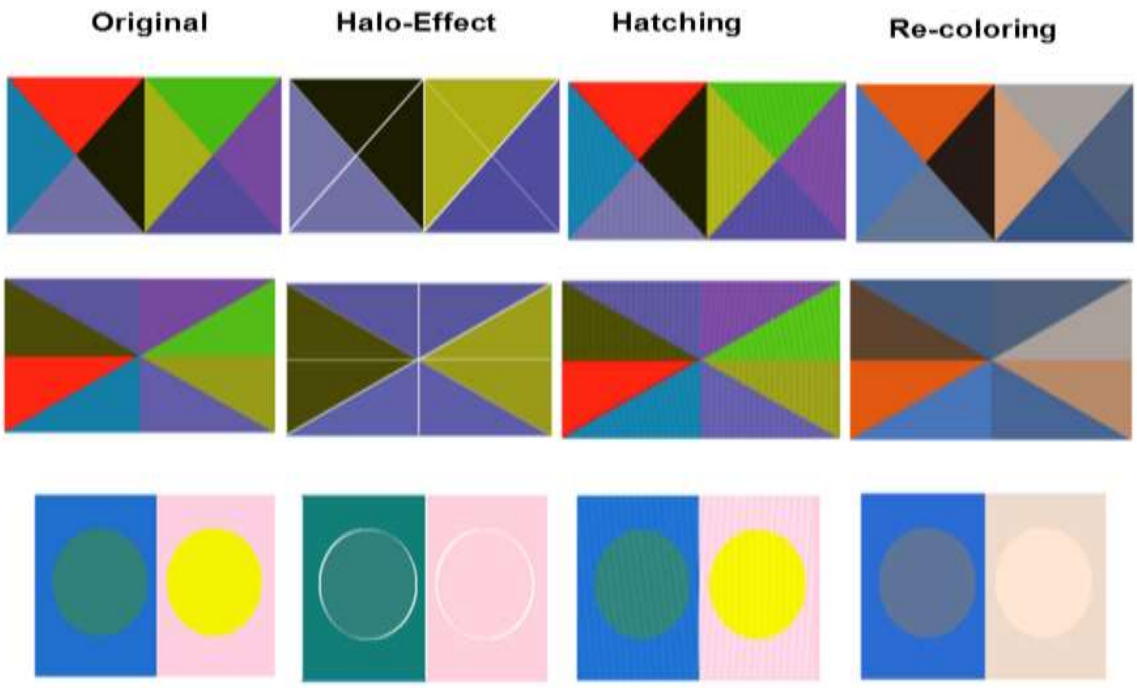

Figure 6.17: Shows geometrical shapes in twelve different forms

Figure 6.18 shows two adjacent colours from geometrical shapes associated with survey question six this time having been post-processed with HEA as seen in the shape two of row 2 also, shape two of column 2 of Figure 6.17. As explained above in this chapter white space has been inserted at the colour boundary interfaces which will identify shape interface boundaries for indicative-CVDt participants clearly. Figure 6.18 was represented from the upper side of shape of survey question nine.

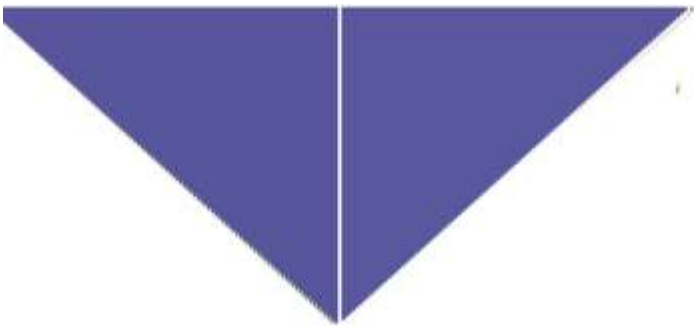

Figure 6.18: Shows two adjacent colours of shape two were separated by a white line having been post-processed with the HEA

Figure 6.19 shows the same two adjacent colours from geometrical shape associated with survey question six but this time having been post-processed with HAA as shown in the shape three of row 2 also, shape two of column 3 of Figure 6.17. As explained early the cross-lines

were form hatches of same colours were over layered onto the original shape. Figure 6.19 was represented from the top side of shape of survey question ten.

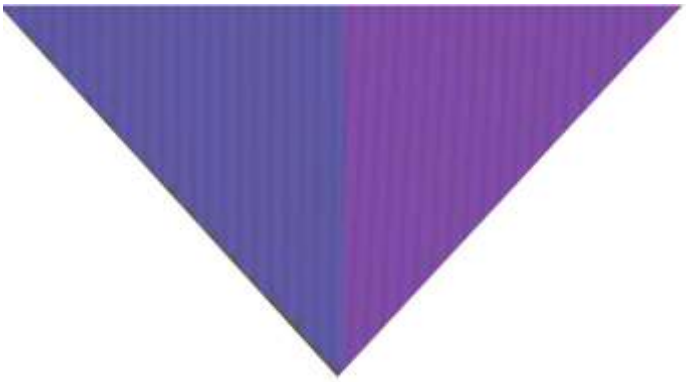

Figure 6.19: Shows cross-lines hatches to the shape two having been post-processed with the HAA

Figure 6.20 shows the same two adjacent colours from the geometrical shape associated with survey question six but this time having been post-processed with the RCA as seen in the shape four of row 2 also, shape two of column 4 of Figure 6.17. This algorithm transformed the colours of the shape into a way to make them easier to distinguish between colours for indicative-CVDt participants. Figure 6.20 was represented from the top side of shape of survey question thirteen.

Figure 6.20: Shows transformed the colours of shape two having been post-processed with the RCA

6.5 CONDUCTING THE STUDIES

For standardisation whenever possible, the steps in conducting these studies were as described in chapter 5, section 5.5.

6.6 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 1, FOR THE FIRST STUDY (PIE-CHARTS)

Table 6.4 shows the numbers of responses to survey questions five, six and sixteen. The total number of responses from those identified as non-CVD was 498 and the total number of responses from those identified as indicative-CVD was 90, providing a total number of responses as 588.

All of the responses from those identified as non-CVD demonstrated that the segment interface boundaries were detectable. Therefore, none of the non-CVD responses were identified as problematic. However, when the responses of those identified as indicative-CVDt were analysed, 60 responses showed no problem in detecting the segment interface boundaries but 30 did (columns 3 and 4 of Table 6.4). Hence, from the total number of responses of 588, 558 responses showed no problem in detecting segment interface boundaries but 30 did (columns 3 and 4 of Table 6.4).

6.7 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL CHART WITH HALO) FOR THE FIRST STUDY (PIE-CHARTS)

A total number of 180 responses were obtained for survey questions five, six, sixteen, seven, nine, and eleven from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question seven was the same pie-chart as survey question five, but with the HEA applied. Similarly, survey question nine was the same pie-chart as survey question six, but also with the HEA applied. Survey question eleven was the same pie-chart as survey question sixteen, but again with the HEA applied.

In Table 6.4, the label Original refers to the responses from questions five, six and sixteen. 60 of the 88 responses showed that there was no difficulty in identifying segment boundary interfaces, but 30 did have difficulty. The label Halo means that the HEA has been applied. 2 of the 30 responses showed that there were difficulty in identifying segment boundary interfaces, but 28 did not have difficulty.

6.8 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL CHART WITH HATCH) FOR THE FIRST STUDY (PIE-CHARTS)

A total number of 180 responses were obtained for survey questions five, six, sixteen, eight, ten, and fifteen from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question eight was the same pie-chart as survey question five, but with the HAA applied. Similarly, survey question ten was the same pie-chart as survey question six, but also with the HAA applied. Also, survey question fifteen was the same pie-chart as survey question sixteen, but again with the HAA applied.

60 of the 77 responses showed that there was no difficulty in identifying segment boundary interfaces, but 30 did have difficulty as shown in Table 6.4. The label Hatch means that the HAA has been applied. 13 of the 30 responses showed that there were difficulty in identifying segment boundary interfaces, but 17 did not have difficulty.

6.9 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL CHART WITH RE_COLOUR) FOR THE FIRST STUDY (PIE-CHARTS)

A total number of 180 responses were obtained for survey questions five, six, sixteen, twelve, thirteen and fourteen from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question twelve was the same pie-chart as survey question five, but with the RCA applied. Similarly, survey question thirteen was the same pie-chart as survey question six, but with the RCA applied. Also, survey question fourteen was the same pie-chart as survey question sixteen, but again with the RCA applied.

60 of the 80 responses showed that there was no difficulty in identifying segment boundary interfaces, but 30 did have difficulty as shown in Table 6.4. The label Re-colour means that the RCA has been applied. 10 of the 30 responses showed that there were difficulty in identifying segment boundary interfaces, but 20 did not have difficulty.

6.10 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 1, FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Table 6.4 shows the numbers of responses to survey questions five, six and sixteen. The total number of responses from those identified as non-CVD was 642 and the total number of responses from those identified as indicative-CVD was 72, providing a total number of responses as 714.

All of the responses from those identified as non-CVD demonstrated that the interface boundaries were detectable. Therefore, none of the non-CVD responses were identified as problematic. However, when the responses of those identified as indicative-CVD were analysed, 48 responses showed no problem in detecting the interface boundaries but 24 did (columns 3 and 4 of Table 6.4). Hence, from the total number of responses of 714, 690 responses showed no problem in detecting interface boundaries but 24 did (columns 3 and 4 of Table 6.4).

6.11 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL MAP WITH HALO) FOR THE SECOND STUDY (MAP OF AUSTRALIA)

A total number of 144 responses were obtained for survey questions five, six, sixteen, seven, nine, and eleven from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question seven was the same map as survey question five, but with the HEA applied. Similarly, survey question nine was the same map as survey question six, but also with the HEA applied. Survey question eleven was the same map as survey question sixteen, but this time with the HEA applied.

48 of the 70 responses showed that there was no difficulty in identifying boundary interfaces, but 24 did have difficulty as shown in Table 6.4. Also, 2 of the 24 responses showed that there were difficulty in identifying boundary interfaces, but 22 did not have difficulty.

6.12 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL MAP WITH HATCH) FOR THE SECOND STUDY (MAP OF AUSTRALIA)

A total number of 144 responses were obtained for survey questions five, six, sixteen, eight, ten, and fifteen from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question eight was the same map as survey question five, but with the HAA applied. Similarly, survey question ten was the same map as survey question six, but also with the HAA applied. Also, survey question fifteen was the same map as survey question sixteen, but again with the HAA applied.

48 of the 56 responses showed that there was no difficulty in identifying boundary interfaces, but 24 did have difficulty as shown in Table 6.4. Also, 16 of the 24 responses showed that there were difficulty in identifying boundary interfaces, but 8 did not have difficulty.

6.13 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL MAP WITH RE-COLOUR) FOR THE SECOND STUDY (MAP OF AUSTRALIA)

A total number of 144 responses were obtained for survey questions five, six, sixteen, twelve, thirteen and fourteen from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question twelve was the same map as survey question five, but with the RCA applied. Similarly, survey question thirteen was the same map as survey question six, but with the RCA applied. Also, survey question fourteen was the same map as survey question sixteen, but again with the RCA applied.

48 of the 64 responses showed that there was no difficulty in identifying boundary interfaces, but 24 did have difficulty as shown in Table 6.4. Also, 8 of the 24 responses showed that there were difficulty in identifying boundary interfaces, but 16 did not have difficulty.

6.14 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 1, FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Table 6.4 shows the numbers of responses to survey questions five, six and sixteen. The total number of responses from those identified as non-CVD was 597 and the total number of responses from those identified as indicative-CVD was 42, providing a total number of responses as 639.

All of the responses from those identified as non-CVD demonstrated that the interface boundaries were detectable. Therefore, none of the non-CVD responses were identified as problematic. However, when the responses of those identified as indicative-CVD were analysed, 28 responses showed no problem in detecting the interface boundaries but 14 did (columns 3 and 4 of Table 6.4). Hence, from the total number of responses of 639, 625 responses showed no problem in detecting interface boundaries but 14 did (columns 3 and 4 of Table 6.4).

6.15 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL SHAPE WITH HALO) FOR THE THIRD STUDY (GEOMETRIC SHAPES)

A total number of 84 responses were obtained for survey questions five, six, sixteen, seven, nine, and eleven from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question seven was the same shape as survey question five, but with the HEA applied. Similarly, survey question nine was the same shape as survey question six, but also this time with the HEA applied. Survey question eleven was the same shape as survey question sixteen, but again this time with the HEA applied.

28 of the 42 responses showed that there was no difficulty in identifying boundary interfaces, but 14 did have difficulty as shown in Table 6.4. The HEA showed that there were no responses have difficulty in identifying boundary interfaces.

6.16 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL SHAPE WITH HATCH) FOR THE THIRD STUDY (GEOMETRIC SHAPES)

A total number of 84 responses were obtained for survey questions five, six, sixteen, eight, ten, and fifteen from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question eight was the same shape as survey question five, but with the HAA applied. Similarly, survey question ten was the same shape as survey question six, but this time with the HAA applied. Also, survey question fifteen was the same shape as survey question sixteen, but again with the HAA applied.

28 of the 32 responses showed that there was no difficulty in identifying boundary interfaces, but 14 did have difficulty as shown in Table 6.4. Also, 10 of the 14 responses showed that there were difficulty in identifying boundary interfaces, but 4 did not have difficulty.

6.17 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 2, (ORIGINAL SHAPE WITH RE-COLOUR) FOR THE THIRD STUDY (GEOMETRIC SHAPES)

A total number of 84 responses were obtained for survey questions five, six, sixteen, twelve, thirteen and fourteen from the participants who were deemed as indicative-CVDt as shown in Table 6.4. Survey question twelve was the same shape as survey question five, but with the RCA applied. Similarly, survey question thirteen was the same shape as survey question six, but also with the RCA applied. Also, survey question fourteen was the same shape as survey question sixteen, but again this time with the RCA applied.

28 of the 38 responses showed that there was no difficulty in identifying boundary interfaces, but 14 did have difficulty as shown in Table 6.4. In addition, 4 of the 14 responses showed that there were difficulty in identifying boundary interfaces, but 10 did not have difficulty.

Table 6.4: Responses for the three studies on hypothesis 1 and 2

			Non-Problematic	Problematic	Total
The first study (Pie-charts)	Hypothesis 1)	Non-CVD	498	0	498
		Indicative-CVD	60	30	90
		Total	558	30	588
	Hypothesis 2)	Original	60	30	90
		Halo	88	2	90
		Total	148	32	180
	Hypothesis 2)	Original	60	30	90
		Hatch	77	13	90
		Total	137	43	180
	Hypothesis 2)	Original	60	30	90
		Re-colour	80	10	90
		Total	140	40	180
			Non-Problematic	Problematic	Total
The second study (Map of Australia)	Hypothesis 1)	Non-CVD	642	0	642
		Indicative-CVD	48	24	72
		Total	690	24	714
	Hypothesis 2)	Original	48	24	72
		Halo	70	2	72
		Total	118	26	144
	Hypothesis 2)	Original	48	24	72
		Hatch	56	16	72
		Total	104	40	144
	Hypothesis 2)	Original	48	24	72
		Re-colour	64	8	72
		Total	112	32	144
			Non-Problematic	Problematic	Total
The third study (Geometric shapes)	Hypothesis 1)	Non-CVD	597	0	597
		Indicative-CVD	28	14	42
		Total	625	14	639
	Hypothesis 2)	Original	28	14	42
		Halo	42	0	42
		Total	70	14	84
	Hypothesis 2)	Original	28	14	42
		Hatch	32	10	42
		Total	60	24	84
	Hypothesis 2)	Original	28	14	42
		Re-colour	38	4	42
		Total	66	18	84

6.18 STATISTICS ON HYPOTHESIS 1, FOR THE FIRST STUDY (PIE-CHARTS)

Using the data-set of 588 responses, and applying the Pearson Chi-Square test a ρ value of 0.000 was yielded. As this ρ value was less than the threshold significance ρ value of 0.01 then the data-set was considered significant, which matches the expectation. Also applying the Independent Sample T-test to the same data-set, a ρ of 0.000 was yielded. As this value was less than the threshold significance ρ value of 0.00 then the data-set was also considered as significant, which matches the expectation. Hence, the two statistical techniques

corroborated with each other for hypothesis 1, as shown in the cells of row 3 of the columns 3 and 6 of Table 6.5.

6.19 STATISTICS ON HYPOTHESIS 2, HALO WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

Similarly when hypothesis 2) Halo with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.000. As this ρ value was less than the significance threshold value then it was significant, which matches the expectation. Also, when the Independent Sample T-test was applied to the same data-set a ρ value of 0.000 was yielded. As this ρ value was less than the threshold ρ value then it was also considered significant, which matches the expectation. This demonstrates that the two statistical techniques were corroborating with each other, as shown in the cells of row 4 of the columns 3 and 6 of Table 6.5.

6.20 STATISTICS ON HYPOTHESIS 2, HATCH WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

Same when hypothesis 2) Hatch with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.003. As this ρ value was less than the significance threshold value then it was significant, which matches the expectation. Also, when the Independent Sample T-test was applied to the same data-set a ρ value of 0.002 was yielded. As this ρ value was also less than the threshold ρ value then was considered significant, which matches the expectation. This demonstrates that the two statistical techniques were corroborating with each other, as shown in the cells of row 5 of the columns 3 and 6 of Table 6.5.

6.21 STATISTICS ON HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

Similarly when hypothesis 2) Re-colour with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.000. As this ρ value was less than the significance threshold value then it was significant, which matches the expectation. Likewise, when the Independent Sample T-test applied to the same data-set a ρ value of 0.000 was yielded. As this ρ value was also less than the threshold ρ value then was considered significant, which matches the expectation. This demonstrates that the two statistical techniques were corroborating with each other, as shown in the cells of row 6 of the columns 3 and 6 of Table 6.5.

6.22 STATISTICS ON HYPOTHESIS 1, FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Using the data-set of 714 responses, and applying the Pearson Chi-Square test a ρ value of 0.000 was yielded. As this ρ value was less than the threshold significance ρ value of 0.01 then the data-set it was significant, which matches the expectation. Also applying the Independent Sample T-test to the same data-set, a ρ of 0.000 was yielded. As this value was less than the threshold significance ρ value of 0.01 then the data-set was also considered as significant, which matches the expectation. Hence, the two statistical techniques corroborated with each other for hypothesis 1, as shown in the cells of row 7 of the columns 3 and 6 of Table 6.5.

6.23 STATISTICS ON HYPOTHESIS 2, HALO WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Similarly when hypothesis 2) Halo with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.000. As this ρ value was less than the significance threshold value then it was significant, which matches the expectation. Also, when the Independent Sample T-test was applied to the same data-set a ρ value of 0.000 was yielded. As this ρ value was less than the threshold ρ value then was considered significant, which matches the expectation. This demonstrates that the two statistical techniques were corroborating with each other, as shown in the cells of row 8 of the columns 3 and 6 of Table 6.5.

6.24 STATISTICS ON HYPOTHESIS 2, HATCH WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Same when hypothesis 2) Hatch with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.137. As this ρ value was more than the significance threshold value then it was insignificant, which did not match the expectation. Also, when the Independent Sample T-test was applied to the data-set a ρ value of 0.139 was yielded. As this ρ value was also more than the threshold ρ value then was considered insignificant, which did not match the expectation. This demonstrates that the two statistical techniques were not corroborating with each other, as shown in the cells of row 9 of the columns 3 and 6 of Table 6.5.

6.25 STATISTICS ON HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Similarly when hypothesis 2) Re-colour with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.001. As this ρ value was less than the significance threshold value then it was significant, which matches the expectation. Likewise, when the Independent Sample T-test applied to the data-set a ρ value of 0.001 was yielded. As this ρ value was also less than the threshold ρ value then was considered significant, which matches the expectation. This demonstrates that the two statistical techniques were corroborating with each other, as shown in the cells of row 10 of the columns 3 and 6 of Table 6.5.

6.26 STATISTICS ON HYPOTHESIS 1, FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Using the data-set of 639 responses, and applying the Pearson Chi-Square test a ρ value of 0.000 was yielded. As this ρ value was less than the threshold significance ρ value of 0.01 then the data-set was considered significant, which matches the expectation. Also applying the Independent Sample T-test to the same data-set, a ρ of 0.000 was yielded. As this value was less than the threshold significance ρ value of 0.01 then the data-set was also considered as significant, which matches the expectation. Hence, the two statistical techniques corroborated with each other for hypothesis 1, as shown in the cells of row 11 of the columns 3 and 6 of Table 6.5.

6.27 STATISTICS ON HYPOTHESIS 2, HALO WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Similarly when hypothesis 2) Halo with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.000. As this ρ value was less than the significance threshold value then it was significant, which matches the expectation. Also, when the Independent Sample T-test was applied to the same data-set a ρ value of 0.000 was yielded. As this ρ value was less than the threshold ρ value then was considered significant, which matches the expectation. This demonstrates that the two statistical techniques were corroborating with each other, as shown in the cells of row 12 of the columns 3 and 6 of Table 6.5.

6.28 STATISTICS ON HYPOTHESIS 2, HATCH WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Same when hypothesis 2) Hatch with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.334. As this ρ value was more than the significance threshold value then it was insignificant, which did not match the expectation. Also, when the Independent Sample T-test was applied to the data-set a ρ value of 0.340 was yielded. As this ρ value was also more than the threshold ρ value then was considered insignificant, which did not match the expectation. This demonstrates that the two statistical techniques were not corroborating with each other, as shown in the cells of row 13 of the columns 3 and 6 of Table 6.5.

6.29 STATISTICS ON HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Similarly when hypothesis 2) Re-colour with Original) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.008. As this ρ value was less than the significance threshold value then it was significant, which matches the expectation. Likewise, when the Independent Sample T-test applied to the data-set a ρ value of 0.005 was yielded. As this ρ value was also less than the threshold ρ value then was considered significant, which matches the expectation. This demonstrates that the two statistical techniques were corroborating with each other, as shown in the cells of row 14 of the columns 3 and 6 of Table 6.5.

Table 6.5: Results of the two statistical tests

		Pearson Chi-Square test			Independent Sample T-test		
		Yielded ρ value	Result	Expected result	Yielded ρ value	Result	Expected result
The first study (Pie-charts)	Hypothesis 1	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Halo with Original	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Hatch with Original	0.003	Significant	Significant	0.002	Significant	Significant
	Hypothesis 2) Re-colour with Original	0.000	Significant	Significant	0.000	Significant	Significant
The second study (Map of Australia)	Hypothesis 1	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Halo with Original	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Hatch with Original	0.137	Insignificant	Significant	0.139	Insignificant	Significant
	Hypothesis 2) Re-colour with Original	0.001	Significant	Significant	0.001	Significant	Significant
The third study (Geometric shapes)	Hypothesis 1	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Halo with Original	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 2) Hatch with Original	0.334	Insignificant	Significant	0.340	Insignificant	Significant
	Hypothesis 2) Re-colour with Original	0.008	Significant	Significant	0.005	Significant	Significant

6.30 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 1, FOR THE FIRST STUDY (PIE-CHARTS)

From the data-set of 588 in the first study, the Pearson Chi-Square value (χ) 174.925 was yielded and a ρ value of 0.000 was also yielded as shown in Table 6.6. Since, this ρ value was less than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 1) confirmed that there was statistically significant association between the two sets (non-CVD and indicative-CVD) and the expectation was met. A full set of the SPSS results were presented as Appendix H.

6.31 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, HALO WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

From the total number of responses, 180, the Pearson Chi-Square value (χ) 29.797 was yielded as shown in Table 6.6. The obtained ρ value was less than the threshold ρ value. This shows that there was statistical significance between the original pie-chart images and the corresponding pie-charts with the HEA applied, for hypothesis 2). Hence, the expectation was met in that the indicative-CVDt participants were able to interpret the information in the pie-charts with the HEA applied better than the original pie-charts. A full set of the SPSS results were presented as Appendix H.

6.32 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, HATCH WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

Similarly from the same total number of responses, 180, the Pearson Chi-Square value (χ) 8.830 was yielded as shown in Table 6.6. The obtained ρ value was less than the threshold ρ value. This shows that there was statistical significance between the original pie-charts and the corresponding pie-charts with the HAA applied, for hypothesis 2). Hence, the expectation was met in that the indicative-CVDt participants were able to interpret the information in the pie-charts with the HAA applied better than the original pie-charts. A full set of the SPSS results were presented as Appendix H.

6.33 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

The same total number of responses, 180, the Pearson Chi-Square value (χ) 12.857 was yielded as shown in Table 6.6. The obtained ρ value was less than the threshold ρ value. This shows that there was statistical significance between the original pie-chart images and the corresponding pie-charts with the RCA applied, for hypothesis 2). Hence, the expectation was met in that the indicative-CVDt participants were able to interpret the information in the pie-charts with the RCA applied better than the original pie-charts. A full set of the SPSS results were presented as Appendix H.

6.34 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 1, FOR THE SECOND STUDY (MAP OF AUSTRALIA)

From the data-set of 714 in the second study, the Pearson Chi-Square value (χ) 221.443 was yielded and a ρ value of 0.000 was also yielded as shown in Table 6.6. Since, this ρ value was less than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 1) confirmed that there was statistically significant association between the two sets (non-CVD and indicative-CVD) and the expectation was met. A full set of the SPSS results were presented in Appendix H.

6.35 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, HALO WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

From the total number of responses, 144, the Pearson Chi-Square value (χ) 22.717 was yielded as shown in Table 6.6. The obtained ρ value was less than the threshold ρ value. This shows that there was statistical significance between the original map images and the corresponding maps with the HEA applied, for hypothesis 2). Hence, the expectation was met in that the indicative-CVDt participants were able to interpret the information in the maps with the HEA applied better than the original maps. A full set of the SPSS results were presented as Appendix H.

6.36 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, HATCH WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Similarly from the same total number of responses, 144, the Pearson Chi-Square value (χ) 2.215 was yielded as shown in Table 6.6. The obtained ρ value was more than the threshold ρ value. This shows that there was no statistical significance between the original map images and the corresponding maps with the HAA applied, for hypothesis 2). Hence, the expectation was not met in that the indicative-CVDt participants were able to interpret the information in the maps with the HAA applied better than the original maps. A full set of the SPSS results were presented as Appendix H.

6.37 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

The same total number of responses, 144, the Pearson Chi-Square value (χ) 10.286 was yielded as shown in Table 6.6. The obtained ρ value was less than the threshold ρ value. This shows that there was statistical significance between the original map images and the corresponding maps with the RCA applied, for hypothesis 2). Hence, the expectation was met in that the indicative-CVDt participants were able to interpret the information in the maps with the RCA applied better than the original maps. A full set of the SPSS results were presented as Appendix H.

6.38 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 1, FOR THE THIRD STUDY (GEOMETRIC SHAPES)

From the data-set of 639 in the third study, the Pearson Chi-Square value (χ) 203.458 was yielded and a ρ value of 0.000 was also yielded as shown in Table 6.6. Since, this ρ value was less than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 1) confirmed that there was statistically significant association between the two sets (non-CVD and indicative-CVD) and the expectation was met. A full set of the SPSS results were presented as Appendix H.

6.39 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, HALO WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

From the total number of responses, 84, the Pearson Chi-Square value (χ) 16.800 was yielded as shown in Table 6.6. The obtained ρ value was less than the threshold ρ value. This shows that there was statistical significance between the original shape images and the corresponding shapes with the HEA applied, for hypothesis 2). Hence, the expectation was met in that the indicative-CVDt participants were able to interpret the information in the shapes with the HEA applied better than the original shapes. A full set of the SPSS results were presented as Appendix H.

6.40 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, HATCH WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Similarly from the same total number of responses, 84, the Pearson Chi-Square value (χ) 0.933 was yielded as shown in Table 6.6. The obtained ρ value was more than the threshold ρ value. This shows that there was no statistical significance between the original shape images and the corresponding shapes with the HAA applied, for hypothesis 2). Hence, the expectation was not met in that the indicative-CVDt participants were able to interpret the information in the shapes with the HAA applied better than the original shapes. A full set of the SPSS results were presented as Appendix H.

6.41 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

From the total number of responses, 84, the Pearson Chi-Square value (χ) 7.071 was yielded as shown in Table 6.6. The obtained ρ value was less than the threshold ρ value. This shows that there was statistical significance between the original shape images and the corresponding shapes with the RCA applied, for hypothesis 2). Hence, the expectation was met in that the indicative-CVDt participants were able to interpret the information in the shapes with the RCA applied better than the original shapes. A full set of the SPSS results were presented as Appendix H.

Table 6.6: The pearson chi-square value χ for hypotheses 1) and 2) for the three studies

	Hypotheses	Pearson Chi-Square Value χ	ρ value
The first study (Pie-charts)	Hypothesis 1	174.925	0.000
	2) Halo with Original	29.797	0.000
	2) Hatch with Original	8.830	0.003
	2) Re-colour with Original	12.857	0.000
The second study (Map of Australia)	Hypothesis 1	221.443	0.000
	2) Halo with Original	22.717	0.000
	2) Hatch with Original	2.215	0.137
	2) Re-colour with Original	10.286	0.001
The third study (Geometric shapes)	Hypothesis 1	203.458	0.000
	2) Halo with Original	16.800	0.000
	2) Hatch with Original	0.933	0.334
	2) Re-colour with Original	7.071	0.008

6.42 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 1, FOR THE FIRST STUDY (PIE-CHARTS)

From the total number of responses in the first study, 588, Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. All of these results show that the Independent Sample T-test demonstrated that images without post-processing were interpreted better by the non-CVDt participants than the indicative-CVDt participants. Hence, there was validity with hypothesis 1) and the relationship was not due to chance. A full set of quantitative SPSS software results were presented in Appendix H.

6.43 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, HALO WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

From the total number of responses, 180, Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the

Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the original pie-charts. A full set of the SPSS software results were presented in Appendix H.

6.44 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, HATCH WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.002 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the HAA showed improvement in information interpretation for indicative-CVDt participants better than the original pie-charts. A full set of the SPSS software results were presented in Appendix H.

6.45 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL CHART FOR THE FIRST STUDY (PIE-CHARTS)

Similarly Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the RCA showed improvement in information interpretation for indicative-CVDt participants better than the original pie-charts. A full set of the SPSS software results were presented in Appendix H.

6.46 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 1, FOR THE SECOND STUDY (MAP OF AUSTRALIA)

From the total number of responses in the second study, 714, Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.004. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for

the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. All of these results show that the Independent Sample T-test demonstrated that images without post-processing were interpreted better by the non-CVDt participants than the indicative-CVDt participants. Hence, there was validity with hypothesis 1) and the relationship was not due to chance. A full set of quantitative SPSS software results were presented in Appendix H.

6.47 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, HALO WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

From the total number of responses, 144, Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the original maps. A full set of the SPSS software results were presented in Appendix H.

6.48 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, HATCH WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.139. This was more than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value bigger than the threshold value then significance ρ value of the Equal variances assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances assumed was 0.139 which was more than the threshold significance ρ value of 0.01 and hence the data-set was considered as insignificant, which was not matches the expectation. Based on this it can be said that the HAA showed no improvement in information interpretation for indicative-CVDt participants better than the original maps. Details why the two techniques do not corroborate will be considered later in this chapter. A full set of the SPSS software results were presented in Appendix H.

6.49 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL MAP FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.001 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the RCA showed improvement in information interpretation for indicative-CVDt participants better than the original maps. A full set of the SPSS software results were presented in Appendix H.

6.50 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 1, FOR THE THIRD STUDY (GEOMETRIC SHAPES)

From the total number of responses in the third study, 639, Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.090. This was more than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value bigger than the threshold value then significance ρ value of the Equal variances assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. All of these results show that the Independent Sample T-test demonstrated that images without post-processing were interpreted better by the non-CVDt participants than the indicative-CVDt participants. Hence, there was validity with hypothesis 1) and the relationship was not due to chance. A full set of quantitative SPSS software results were presented in Appendix H.

6.51 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, HALO WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

From the total number of responses, 84, Table 6.7 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the HEA could help the

improve of vision for indicative-CVDt participants better than the original shapes. A full set of the SPSS software results were presented in Appendix H.

6.52 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, HATCH WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Table 6.7 shows that the Levene's Test for Equality of Variance yielded $\rho = 0.363$. This was more than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value bigger than the threshold value then significance ρ value of the Equal variances assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances assumed was 0.340 which was more than the threshold significance ρ value of 0.01 and hence the data-set was considered as insignificant, which did not match the expectation. Based on this it can be said that the HAA showed no improvement in information interpretation for indicative-CVDt participants better than the original shapes. Details why the two techniques do not corroborate will be considered later in this chapter. A full set of the SPSS software results were presented in Appendix H.

6.53 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 2, RE-COLOUR WITH ORIGINAL SHAPE FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Table 6.7 shows that the Levene's Test for Equality of Variance yielded $\rho = 0.000$. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.005 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the RCA showed improvement in information interpretation for indicative-CVDt participants better than the original shapes. A full set of the SPSS software results were presented in Appendix H.

Table 6.7: The independent sample t-test value for hypotheses 1) and 2) for the three studies

	Hypotheses		Levene's Test for Equality of Variances ρ	Significance level ρ
The first study (Pie-charts)			0.000	
	Hypothesis 1	Equal variances assumed		0.000
		Equal variances not assumed		0.000
			0.000	
	2) Halo with Original	Equal variances assumed		0.000
		Equal variances not assumed		0.000
			0.000	
	2) Hatch with Original	Equal variances assumed		0.003
		Equal variances not assumed		0.002
			0.000	
	2) Re-colour with Original	Equal variances assumed		0.000
		Equal variances not assumed		0.000
			0.004	
The second study (Map of Australia)	Hypothesis 1	Equal variances assumed		0.000
		Equal variances not assumed		0.000
			0.000	
	2) Halo with Original	Equal variances assumed		0.000
		Equal variances not assumed		0.000
			0.139	
	2) Hatch with Original	Equal variances assumed		0.139
		Equal variances not assumed		0.139
			0.000	
	2) Re-colour with Original	Equal variances assumed		0.001
		Equal variances not assumed		0.000
			0.090	
The third study (Geometric shapes)	Hypothesis 1	Equal variances assumed		0.000
		Equal variances not assumed		0.000
			0.000	
	2) Halo with Original	Equal variances assumed		0.000
		Equal variances not assumed		0.000
			0.363	
	2) Hatch with Original	Equal variances assumed		0.340
		Equal variances not assumed		0.343
			0.000	
	2) Re-colour with Original	Equal variances assumed		0.007
		Equal variances not assumed		0.005

6.54 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 3, HALO WITH HATCH FOR THE FIRST STUDY (PIE-CHARTS)

Table 6.8 shows the numbers of 180 responses in the first study were obtained for survey questions seven, nine, eleven, eight, ten and fifteen from the participants who were deemed as indicative-CVDt. Survey questions eight, ten and fifteen were the same pie-charts as survey questions seven, nine and eleven but with the HAA applied. In contrast, survey questions seven, nine and eleven were the same pie-charts as survey questions eight, ten and fifteen but with the HEA applied.

From Table 6.8 the label Halo shows 77 of the 88 responses illustrated that there was no difficulty in identifying segment boundary interfaces, but 2 did have difficulty. Whilst, the label Hatch showed that 13 of the 30 responses showed that there were difficulty in identifying segment boundary interfaces, but 17 did not have difficulty. Therefore, it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the HAA. A full set of the SPSS software results were presented in Appendix H.

6.55 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE FIRST STUDY (PIE-CHARTS)

Similarly from the same total number of, 180, responses were obtained for survey questions seven, nine, eleven, twelve, thirteen and fourteen from the participants who were deemed as indicative-CVDt as shown in Table 6.6. Survey questions twelve, thirteen and fourteen were the same pie-charts as survey questions seven, nine and eleven but with the RCA algorithm applied.

From Table 6.8 the label Halo shows 80 of the 88 responses illustrated that there was no difficulty in identifying segment boundary interfaces, but 2 did have difficulty. While, the label Re-colour showed that 10 of the 30 responses showed that there were difficulty in identifying segment boundary interfaces, but 20 did not have difficulty. Based on this it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the RCA. A full set of the SPSS software results were presented in Appendix H.

6.56 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 3, HALO WITH HATCH FOR THE SECOND STUDY (MAP-AUSTRALIA)

Table 6.8 shows the numbers of 144 responses in the second study were obtained for survey questions seven, nine, eleven, eight, ten and fifteen from the participants who were deemed as indicative-CVDt. For standardisation whenever possible, survey questions ordering numbers were the same as in the previous study.

From Table 6.8 the label Halo shows 56 of the 70 responses illustrated that there was no difficulty in identifying boundary interfaces, but 2 did have difficulty. However, the label Hatch showed that 16 of the 24 responses showed that there were difficulty in identifying boundary interfaces, but 8 did not have difficulty. Therefore, it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the HAA. A full set of the SPSS software results were presented in Appendix H.

6.57 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE SECOND STUDY (MAP-AUSTRALIA)

Similarly from the same total number of, 144, responses were obtained for survey questions seven, nine, eleven, twelve, thirteen and fourteen from the participants who were deemed as indicative-CVDt. Also, for standardisation whenever possible, survey questions ordering numbers were the same as in the previous study.

From Table 6.8 the label Halo shows 64 of the 70 responses illustrated that there was no difficulty in identifying boundary interfaces, but 2 did have difficulty. While, the label Re-colour showed that 8 of the 24 responses showed that there were difficulty in identifying boundary interfaces, but 16 did not have difficulty. Based on this it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the RCA. A full set of the SPSS software results were presented in Appendix H.

6.58 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 3, HALO WITH HATCH FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Table 6.8 shows the numbers of 84 responses in the third study were obtained for survey questions seven, nine, eleven, eight, ten and fifteen from the participants who were deemed as indicative-CVDt. For standardisation whenever possible, survey questions ordering numbers were the same as in the previous studies.

In the Table, 6.8, the label Halo showed that there were no difficulty responses in identifying boundary interfaces. While, the label Hatch showed that 10 of the 14 responses illustrated that there were difficulty in identifying boundary interfaces, but 4 did not have difficulty. Based on this it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the HAA. A full set of the SPSS software results were presented in Appendix H.

6.59 IDENTIFYING THE DATA-SET FOR STATISTICAL ON HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Similarly from the same total number of, 84, responses were obtained for survey questions seven, nine, eleven, twelve, thirteen and fourteen from the participants who were deemed as indicative-CVDt. For standardisation whenever possible, survey questions ordering numbers were the same as in the previous studies.

In the Table, 6.8, the label Halo showed that there were no difficulty responses in identifying boundary interfaces. Whilst, the label Re-colour showed that 4 of the 14 responses illustrated that there were difficulty in identifying boundary interfaces, but 10 did not have difficulty. Therefore, it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the RCA. A full set of the SPSS software results were presented in Appendix H.

Table 6.8: Responses for the three studies on hypothesis 3

		Non-Problematic	Problematic	Total
The first study (Pie-charts)	Halo	88	2	90
	Hatch	77	13	90
	Total	165	15	180
	Halo	88	2	90
	Re-colour	80	10	90
	Total	168	12	180
The second study (Map of Australia)				
	Halo	70	2	72
	Hatch	56	16	72
	Total	126	18	144
	Halo	70	2	72
	Re-colour	64	8	72
	Total	134	10	144
The third study (Geometric shapes)				
	Halo	42	0	42
	Hatch	32	10	42
	Total	74	10	84
	Halo	42	0	42
	Re-colour	38	4	42
	Total	80	4	84

6.60 STATISTICS ON HYPOTHESIS 3, HALO WITH HATCH FOR THE FIRST STUDY (PIE-CHARTS)

Having shown that all three improvement algorithms uphold hypotheses 1) and 2), in the first study, hypothesis 3) was considered. For hypothesis 3) the Pearson Chi-Square test yielded a ρ value of 0.003. As this ρ value was less than the threshold significance ρ value of 0.01 then the data-set was considered as significant, which matches the expectation. Applying the Independent Sample T-test to the same data-set, a ρ of 0.001 was yielded. As this value was also less than the threshold significance ρ value of 0.00 then the data-set was considered as significant, which matches the expectation. Hence, the two statistical techniques corroborated each with regard to hypothesis 3. Based on this it can be said that the HEA provides a better means of information interpretation than the HAA, as shown in the cells of row 3 and columns 3 and 6 of Table 6.9.

6.61 STATISTICS ON HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE FIRST STUDY (PIE-CHARTS)

Similarly when hypothesis 3) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.017. As this ρ value was more than the significance threshold value then it was insignificant, which did not match the expectation. While, when the Independent Sample T-test was applied to the same data-set a ρ value of 0.010 was yielded. As this ρ value was equal to the threshold ρ value then it was considered as significant, which matches the expectation. In this case the results show that the two statistical techniques did not corroborate each other, as shown in the cells of row 4 and columns 3 and 6 of Table 6.9.

6.62 STATISTICS ON HYPOTHESIS 3, HALO WITH HATCH FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Having shown that all three improvement algorithms uphold hypotheses 1) and 2), in the second study, hypothesis 3) was considered. For hypothesis 3) the Pearson Chi-Square test yielded a ρ value of 0.000. As this ρ value was less than the threshold significance ρ value of 0.01 then the data-set was considered as significant, which matches the expectation. Applying the Independent Sample T-test to the same data-set, a ρ value of 0.000 was yielded. As this value was also less than the threshold significance ρ value of 0.01 then the data-set was considered as significant, which matches the expectation. Hence, the two statistical techniques corroborated each with regard to hypothesis 3). Therefore it can be said that the HEA provides a better means of information interpretation than the HAA as shown in the cells of row 5 and columns 3 and 6 of Table 6.9.

6.63 STATISTICS ON HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Similarly when hypothesis 3) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.049. As this ρ value was more than the significance threshold value then it was insignificant, which did not match the expectation. Also, when the Independent Sample T-test was applied to the same data-set a ρ value of 0.042 was yielded. As this ρ value was more than the threshold ρ value then it was also insignificant, which did not match the expectation. In this case the results show that the two statistical techniques did not corroborate as shown in the cells of row 6 and columns 3 and 6 of Table 6.9. Details why the two statistical techniques did not corroborate will be considered later in this chapter.

6.64 STATISTICS ON HYPOTHESIS 3, HALO WITH HATCH FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Having shown that all three improvement algorithms uphold hypotheses 1) and 2), in the third study, hypothesis 3) was considered. For hypothesis 3) the Pearson Chi-Square test yielded a ρ value of 0.001. As this ρ value was less than the threshold significance ρ value of 0.01 then the data-set was considered as significant, which matches the expectation. Applying the Independent Sample T-test to the same data-set, a ρ of 0.000 was yielded. As this value was also less than the threshold significance ρ value of 0.01 then the data-set was considered as significant, which matches the expectation. Hence, the two statistical techniques corroborated each with regard to hypothesis 3). Based on this it can be said that the HEA provides a better means of information interpretation than the HAA as shown in the cells of row 7 and columns 3 and 6 of Table 6.9.

6.65 STATISTICS ON HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Similarly when hypothesis 3) was considered on the same data-set, the Pearson Chi-Square test yielded a ρ value of 0.040. As this ρ value was more than the significance threshold value then it was insignificant, which did not match the expectation. When the Independent Sample T-test was applied to the same data-set a ρ value of 0.000 was yielded. As this ρ value was less than the threshold ρ value then it was considered as significant, which matches the expectation. In this case the results show that the two statistical techniques did not corroborate as shown in the cells of row 8 and columns 3 and 6 of Table 6.9. Details why the two statistical techniques did not corroborate will be considered later in this chapter.

Table 6.9: Results of the two statistical tests

		Pearson Chi-Square test			Independent Sample T-test		
		Yielded ρ value	Result	Expected result	Yielded ρ value	Result	Expected result
The first study (Pie-charts)	Hypothesis 3) Halo better than Hatching	0.003	Significant	Significant	0.001	Significant	Significant
	Hypothesis 3) Halo better than Re-colouring	0.017	Insignificant	Significant	0.010	Significant	Significant
The second study (Map of Australia)	Hypothesis 3) Halo better than Hatching	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 3) Halo better than Re-colouring	0.049	Insignificant	Significant	0.042	Insignificant	Significant
The third study (Geometric shapes)	Hypothesis 3) Halo better than Hatching	0.000	Significant	Significant	0.000	Significant	Significant
	Hypothesis 3) Halo better than Re-colouring	0.040	Insignificant	Significant	0.000	Significant	Significant

6.66 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 3, HALO WITH HATCH FOR THE FIRST STUDY (PIE-CHARTS)

From the total number of responses 180 in the first study, the Pearson Chi-Square value (χ) 8.800 was yielded. A ρ value of 0.003 was also yielded as shown in Table 6.10. Since, this ρ value was less than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 3) confirmed that there was statistically significant association between the two algorithms HEA and HAA which matches the expectation. A full set of the SPSS results were presented as Appendix H.

6.67 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE FIRST STUDY (PIE-CHARTS)

Similarly from the same total number of responses 180, the Pearson Chi-Square value (χ) 5.714 was yielded. A ρ value of 0.017 was also yielded as shown in Table 6.10. Since, this ρ value was more than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 3) confirmed that there was statistically insignificant association between the two algorithms HEA and RCA which did not match the expectation. Details why the two statistical techniques did not corroborate will be considered later in this chapter. A full set of the SPSS results were presented as Appendix H.

6.68 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 3, HALO WITH HATCH FOR THE SECOND STUDY (MAP OF AUSTRALIA)

From the total number of responses 144 in the second study, the Pearson Chi-Square value (χ) 12.444 was yielded. A ρ value of 0.000 was also yielded as shown in Table 6.10. Since, this ρ value was less than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 3) confirmed that there was statistically significant association between the two algorithms HEA and HAA which matches the expectation. A full set of the SPSS results were presented as Appendix H.

6.69 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Similarly from the same total number of responses 144, the Pearson Chi-Square value (χ) 3.869 was yielded. A ρ value of 0.049 was also yielded as shown in Table 6.10. Since, this ρ value was more than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 3) confirmed that there was statistically insignificant association between the two algorithms HEA and RCA which did not match the expectation. A full set of the SPSS results were presented as Appendix H.

6.70 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 3, HALO WITH HATCH FOR THE THIRD STUDY (GEOMETRIC SHAPES)

From the total number of responses 84 in the third study, the Pearson Chi-Square value (χ) 11.351 was yielded. A ρ value of 0.001 was also yielded as shown in Table 6.10. Since, this ρ value was less than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 3) confirmed that there was statistically significant association between the two algorithms HEA and HAA which matches the expectation. A full set of the SPSS results were presented as Appendix H.

6.71 THE PEARSON CHI-SQUARE TEST RESULTS FOR HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Similarly from the same total number of responses 84, the Pearson Chi-Square value (χ) 4.200 was yielded. A ρ value of 0.040 was also yielded as shown in Table 6.10. Since, this ρ value was more than the threshold ρ value then the Pearson Chi-Square test demonstrated that hypothesis 3) confirmed that there was statistically insignificant association between the two algorithms HEA and RCA which did not match the expectation. A full set of the SPSS results were presented as Appendix H.

Table 6.10: The pearson chi-square value χ for hypothesis 3) for the three studies

	hypothesis	Pearson Chi-Square Value X	ρ value
The first study (Pie-charts)	3) Halo better than Hatching	8.800	0.003
	3) Halo better than Re-colouring	5.714	0.017
The second study (Map of Australia)	3) Halo better than Hatching	12.444	0.000
	3) Halo better than Re-colouring	3.869	0.049
The third study(Geometric shapes)	3) Halo better than Hatching	11.351	0.001
	3) Halo better than Re-colouring	4.200	0.040

6.72 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 3, HALO WITH HATCH FOR THE FIRST STUDY (PIE-CHARTS)

From the total number of responses 180 in the first study, Table 6.11 shows that the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.001 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the HEA showed improvement in information interpretation for indicative-CVDt participants better than HAA. A full set of the SPSS software results were presented in Appendix H.

6.73 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE FIRST STUDY (PIE-CHARTS)

Similarly Table 6.11 shows that from the same total number of responses 180, the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.010 which was equal to the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Therefore, it can be said that the HEA showed improvement in information interpretation for indicative-CVDt participants better than RCA. A full set of the SPSS software results were presented in Appendix H.

6.74 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 3, HALO WITH HATCH FOR THE SECOND STUDY (MAP OF AUSTRALIA)

From the total number of responses 144 in the second study, Table 6.11 shows that the Levene's Test for Equality of Variance yielded $\rho = 0.000$. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the HEA showed improvement in information interpretation for indicative-CVDt participants better than HAA. A full set of the SPSS software results were presented in Appendix H.

6.75 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE SECOND STUDY (MAP OF AUSTRALIA)

Similarly Table 6.11 shows that from the same total number of responses 144, the Levene's Test for Equality of Variance yielded $\rho = 0.000$. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.042 which was more than the threshold significance ρ value of 0.01 and hence the data-set was considered as insignificant, which did not match the expectation. However, it can be said that the HEA could help the improve of vision for indicative-CVDt participants better than the RCA. A full set of the SPSS software results were presented in Appendix H.

6.76 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 3, HALO WITH HATCH FOR THE THIRD STUDY (GEOMETRIC SHAPES)

From the total number of responses 84 in the third study, Table 6.11 shows that the Levene's Test for Equality of Variance yielded $\rho = 0.000$. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Based on this it can be said that the HEA showed improvement in information interpretation for indicative-CVDt participants better than HAA. A full set of the SPSS software results were presented in Appendix H.

6.77 THE INDEPENDENT SAMPLE T-TEST RESULTS FOR HYPOTHESIS 3, HALO WITH RE-COLOUR FOR THE THIRD STUDY (GEOMETRIC SHAPES)

Similarly Table 6.11 shows that from the same total number of responses 84, the Levene's Test for Equality of Variance yielded ρ = 0.000. This was less than the threshold ρ value of 0.01. Since, Levene's test yields a ρ value smaller than the threshold value then significance ρ value of the Equal variances not assumed was used as the significance value for the Independent Sample T-test. The ρ value of the Equal variances not assumed was 0.000 which was less than the threshold significance ρ value of 0.01 and hence the data-set was considered as significant, which matches the expectation. Therefore, it can be said that the HEA showed improvement in information interpretation for indicative-CVDt participants better than RCA. A full set of the SPSS software results were presented in Appendix H.

Table 6.11: The independent sample t-test values for hypothesis 3) for three studies

	Hypotheses		Levene's Test for Equality of Variances ρ	Significance level ρ
			0.000	
The first study (Pie-charts)	3) Halo better than Hatching	Equal variances assumed		0.003
		Equal variances not assumed		0.001
	3) Halo better than Re-colouring		0.000	
		Equal variances assumed		0.017
		Equal variances not assumed		0.010
			0.000	
The second study (Map of Australia)	3) Halo better than Hatching	Equal variances assumed		0.000
		Equal variances not assumed		0.000
	3) Halo better than Re-colouring		0.000	
		Equal variances assumed		0.050
		Equal variances not assumed		0.042
			0.000	
The third study (Geometric shapes)	3) Halo better than Hatching	Equal variances assumed		0.001
		Equal variances not assumed		0.000
	3) Halo better than Re-colouring		0.000	
		Equal variances assumed		0.041
		Equal variances not assumed		0.000

6.78 UPHOLDING THE THREE HYPOTHESES

Table 6.12 summarises the results of the three studies, showing some differences in the credibility as significant and insignificant results were obtained after statistical analyses.

Table 6.12: Table comparing results of the three studies

	The first study (Pie-charts)		
	Pearson Chi-Square test	Independent Sample T-test	Corroborate
Hypothesis 1)	Significant	Significant	Yes
Hypothesis 2) Compare Halo-Effect with Original	Significant	Significant	Yes
Hypothesis 2) Compare Hatching with Original	Significant	Significant	Yes
Hypothesis 2) Compare Re-colouring with Original	Significant	Significant	Yes
Hypothesis 3) Compare Halo-Effect with Hatching	Significant	Significant	Yes
Hypothesis 3) Compare Halo-Effect with Re-colouring	Insignificant	Significant	No
	The second study (Map of Australia)		
	Pearson Chi-Square test	Independent Sample T-test	Corroborate
Hypothesis 1)	Significant	Significant	Yes
Hypothesis 2) Compare Halo-Effect with Original	Significant	Significant	Yes
Hypothesis 2) Compare Hatching with Original	Insignificant	Insignificant	No
Hypothesis 2) Compare Re-colouring with Original	Significant	Significant	Yes
Hypothesis 3) Compare Halo-Effect with Hatching	Significant	Significant	Yes
Hypothesis 3) Compare Halo-Effect with Re-colouring	Insignificant	Insignificant	No
	The third study (Geometric shapes)		
	Pearson Chi-Square test	Independent Sample T-test	Corroborate
Hypothesis 1)	Significant	Significant	Yes
Hypothesis 2) Compare Halo-Effect with Original	Significant	Significant	Yes
Hypothesis 2) Compare Hatching with Original	Insignificant	Insignificant	No
Hypothesis 2) Compare Re-colouring with Original	Significant	Significant	Yes
Hypothesis 3) Compare Halo-Effect with Hatching	Significant	Significant	Yes
Hypothesis 3) Compare Halo-Effect with Re-colouring	Insignificant	Significant	No

6.79 CHAPTER CONCLUSION

First Study

The first study presented in this chapter was a credibility study using pie-charts. Table 6.12 shows that the two statistical techniques corroborated with each other for hypothesis 1). It also showed that all improvement algorithms upheld hypothesis 2) with both statistical techniques. Significance was obtained for hypothesis 3) between the HEA and the HAA when both statistical techniques were applied. It can therefore be concluded that the HEA provides greater benefit than the HAA. Significance was also obtained for hypothesis 3) between the HEA and the RCA when the Independent Sample's T-test was applied. However, insignificance was obtained for hypothesis 3) between the HEA and the RCA when the Pearson Chi-Square Test was applied, detailed in sections 6.67 and 6.73.

It can be concluded that this work shows that HAA and RCA provide improvement in information interpretation by use of electronic devices. It also demonstrated that both of these algorithms show statistical credibility with hypothesis 2) in a manner similar to the HEA. Therefore, the two statistical techniques corroborated with each other for hypothesis 2). Significance was obtained for hypothesis 3) between the HEA and the HAA with both statistical techniques. However, insignificance was obtained for hypothesis 3) between the HEA and the RCA when the Pearson Chi-Square Test was applied.

From the viewpoint of this dissertation it can be concluded that the HEA provides greater benefit than the HAA. At this point, it cannot be concluded that the HEA provides greater benefit than the RCA, but it can be considered to be a hint that it does. As mentioned in chapter 5, this difference in significant and insignificant results associated with the comparison of performance of HEA and the RCA can be ascribed to the sample size of the data-set. Therefore, it must be taken into a consideration that in the general population context, CVD is not a significant problem. However, when viewed in a specific population, then there is a significant problem. Therefore, all of the studies in this dissertation focused on the specific problem that associated with the indicative-CVDt participants.

Second Study

The second study was also a credibility study but this time instead of using pie-charts an Australian map was used. Table 6.12 shows that the two statistical techniques corroborated with each other for hypothesis 1), and that all improvement algorithms upheld hypotheses 2). However, insignificance was obtained for HAA with original maps with both statistical

techniques, as detailed in sections 6.36 and 6.48. Significance was obtained for hypothesis 3) between the HEA and the HAA when both statistical techniques were applied, concluding that the HEA provides greater benefit than the HAA.

Insignificance was obtained between the HEA and the RCA when both statistical techniques were applied as shown in Table 6.12. Therefore at this point it cannot be concluded that the HEA provides greater benefit than the RCA, but it can be considered to be a hint that it does. Similarly to the previous study in this chapter, the difference in the significant/insignificant result may be due to the small data-set size,

The results of this study showed that two of the three algorithms HEA and RCA improved information interpretation portrayed by colour in an Australian map. Therefore, these can be used to help people who are CVDt to read and interpret information in maps. HAA did not show statistical significant improvement in the interpretation of the maps by the indicative-CVDt participants. Even though the hatching was present in the processed image, it was difficult to see, making it difficult for the indicative-CVDt individuals to distinguish between colours, thus it was difficult for them to see the border between the colours. While, in RCA there was a clearly defined boundary interface which made it relatively easy for the indicative-CVDt participants to identify colour differences on the map. Also, in the HEA, the halo between the different colours was clearly visible, making it easy for the indicative-CVDt people to accurately interpret information.

It can be concluded that the results of this study demonstrated that RCA shows statistical credibility with hypothesis 2) in a manner similar to the HEA, while HAA did not. On the other hand, significance was obtained for hypothesis 3) between the HEA and HAA with both statistical techniques. However, insignificance was obtained for hypothesis 3) between the HEA and RCA when both statistical techniques were applied. Nonetheless, it can be considered a hint that the HEA provides greater benefit than the RCA.

Third Study

In the third study, using geometric shapes, statistical techniques corroborated with each other for hypothesis 1) as shown in Table 6.12, and all improvement algorithms upheld hypotheses 2). However, insignificance was obtained for hypothesis 2) between HAA with original geometric shapes when both statistical techniques were applied, detailed in sections 6.40 and

6.52. Significance was obtained for hypothesis 3) between the HEA and the HAA with both statistical techniques, concluding that the HEA provides greater benefit than the HAA.

Insignificance was obtained between the HEA and RCA when the Pearson Chi-Square test was applied, detailed in section 6.71. In contrast, significance was obtained between the HEA and RCA when the Independent Sample T-test was applied in section 6.77. The difference in the significant/insignificant result could be due to the small data-set size, like in previous studies.

It can be concluded that this study shows that the HEA and RCA offer a significant improvement in information interpretation portrayed by colours in different geometric shapes for indicative-CVDt participants, whereas the HAA did not show statistical significant improvement for indicative-CVDt people. When the performance of HEA was compared to that of the other two algorithms, results indicated that it performed better than HAA. However, when the performance of HEA was compared to that of RCA, conclusive results could not be found as the two statistical techniques did not corroborate.

From the viewpoint of this thesis, the HEA provides greater benefit than the HAA. It cannot at this point be concluded that the HEA provides greater benefit than RCA, but it can be considered to be a hint that it does.

CHAPTER 7 CONCLUSION

7.1 INTRODUCTION

This chapter presents a comprehensive conclusion in this PhD by revising the research aims and objectives and answer the research question of this programme of work. It also atomises the contribution to knowledge and highlights areas for future work.

7.2 REVISING THE RESEARCH AIMS AND OBJECTIVES

The aim of this thesis has been to provide an improved computerised solution to the problem of how CVDt read day-to-day information that is presented in a non-monochromatic form, in the form of pie-charts, maps and geometric-shapes.

This thesis consisted of three objectives. The first objective was to develop a novel colour separation algorithm such that the CVDt would be able to interpret given information which they ordinarily would not.

Objective 1) was achieved by the development of the colour separation HEA where ROCs were identified at a colour interface boundary. A white space was then inserted to separate the two colours of the interface boundary. By building up such white spaces a 'halo-effect' was created by the post-processed image thereby making the presented information more interpretable by the CVDt.

The second objective was to compare the colour separation HEA with a number of currently available and leading algorithms. The two leading algorithms were: Culp's re-colouring algorithm and Hung's hatching algorithm. Both algorithms are considered to be transformation algorithms, where Culp's is more strongly transformed than Hung's. In Culp's algorithm adjacent colours of the post-processed image are changed and in Hung's algorithm the colours of the post-processed image remain the same but hatched lines of the same colour are added.

Objective 2) was achieved by conducted three surveys which rigorously tested each algorithm in a fair and scientific manner. In each survey questions were asked such that the participants could be separated into the two sets non-CVDt and indicative-CVDt. Their responses to the remaining questions were then used to compare how well each of the three algorithms faired. It was concluded that in the majority of cases the HEA faired better than the other two.

The third objective was to evaluate the novel colour separation HEA with the two current and leading algorithms identified in Objective 2) by statistical analyses, using the Pearson Chi-squared test and the Independent Sample T-test. It was concluded that in all of the surveys the the statistical analyses showed that in the majority of cases the colour separation HEA provided the greatest benefit to the CVDt.

7.3 HOW TO IMPROVE CVD SUFFERS' ABILITY TO INTERPRET IMAGES WITH SOLID COLOURS?

To answer the research question from chapter 1 section 1.5 (How to improve CVDt suffers' ability to interpret images with solid colours?), a selection of well-established computer algorithms for assisting the CVDt individuals in interpreting colour vision were reviewed. Amongst the algorithms reviewed were Culp's re-colouring algorithm and hung's hatching algorithm as they are excellent examples of transformation algorithms. It was found that the existing computerised techniques could not effectively solve the problem of colour vision by the CVDt as they are associated with a number of problems. The weaknesses of these algorithms were identified, and HEA developed to provide a solution to these weaknesses. Operation of the HEA is based on maintaining the original colour combination of the CVDt individuals have a problem interpreting while introducing halos (whitespaces) along the colour boundaries. Such introduction of halos enhances the colour interpretation by the CVDt. The performance of the HEA was then compared with the performance of the existing algorithms using statistical techniques. It was concluded that in most of the cases the HEA performs better in assisting the CVDt individuals in interpret information portrayed by colours than the other two.

7.4 THE USEFULNESS OF STATISTICAL ANALYSIS TECHNIQUES

In this thesis, the gathered data concerned two identifiable subject groups the non-CVDt and the indicative-CVDt. By the use of two statistical methods (Pearson Chi-Square test and Independent Sample T-test) the validity of the three algorithms were analysed. The results showed that HEA, hatching algorithm and re-colouring algorithm are credible and are able to improve interpretation of information by CVDt individuals. Also, the results have shown that HEA performs better than hatching algorithm and the re-colouring algorithm.

The use statistics in evaluating the performance of algorithms is important since statistics give evidence-based performance results which are generally more accurate than perceived performance. By using statistics, accurate, informed and verifiable decisions and conclusions

can be made. This means through statistics validity of performance of computer algorithms can be accurately determined.

Surveys are extremely important when investigating problems that real people may have. The data collected from surveys must then be collated and analysed to furnish meaningful information. This thesis has shown the importance of the use of the two statistical techniques to furnish meaningful information regarding the indicative-CVDt (and also the non-CVDt).

This work is novel to this thesis and is still in its infancy with a great deal of further work that could be undertaken. Two statistical techniques have been considered in this dissertation for corroboration and the analyses have been in great depth and detail. Future studies may use one statistical technique and it will be up to the researchers to decide which technique is used. The statistical analyses have been considered in great depth and detail in this thesis, and the depth of statistical analyses in future studies may not be so necessary.

7.5 MAJOR CONTRIBUTIONS:

This work is a continuation of previous researches in the field of the verification of interpretation of information for people who are CVDt correctly. The contributions of this program of research will add to the existing body of research where, it provides an improved computerised solution to the problem of how CVDt approach in the context of reading day-to-day information. This research has made the following contributions to add to the existing corpus of knowledge:

i. A colour separation algorithm, the HEA, has been developed. The algorithm works in a way that it adds halos (white spaces) along the boundaries of the colours that may confuse the CVDt while interpreting the information being portrayed by the colours. The HEA is a different paradigm to the currently available colour transformation algorithms, as it is a colour separation algorithm and not a colour transformation algorithm.

ii. The statistical comparison in empirical studies of the performance of the HEA with the other algorithms: the Hatching Algorithm and the Re-colouring Algorithm in aiding the CVDt has shown that, HEA performs better.

iii. It has been shown that the colour separation of the HEA is beneficial to the CVDt in a number of different contexts such as pie-charts, map and geometric shapes when compared with transformation algorithms.

iv. This work has shown there is no 'capture all' algorithm that fully aids the CVDt. This work therefore shows that a greater amount of future work is required to services the needs of the CVDt.

7.6 THE IMPACT OF THE INCIDENCE OF CVD USING ELECTRONIC DEVICES

As the global population size increases, then it correlates that the incidence of CVDt will also increase. Furthermore, as the popularity, and the ever growing number of, of electronic devices increases, then it also correlates that the problems facing the CVDt will also increase. Hence, this demonstrates the importance for new innovative work to be conducted, to devise, develop and implement ways of assisting the CVDt on new and emerging electronic devices.

7.7 SHOULD THE CVD BE LEFT TO COPE WITH THEIR COLOUR VISION DEFICIENCY PROBLEMS?

Currently the CVDt, as a whole, are left to develop their coping strategies, and generally speaking, the CVDt have been reasonably successful in this. This is substantiated by the work of (Chan, et al., 2014), where he states that on the whole the CVDt are left to solve or cope with the problems they face with some success. However, he continues to say that all persons who experience abnormal colour vision (expect the mildly affected), do experience problems associated with colour while going through their daily activities.

This leads to a dilemma associated with the Equality Act 2010 whether the CVDt should be recognised as disabled? The wording of the act defines that any person who suffers from some condition which impacts on their daily activities (whether they are medically treated or not) are considered to be disabled (Office for Disability Issues, 2011). The problem is that when the act is read in deep detail, examples (or not) of disabilities are provide and one of those examples states a "simple inability to distinguish between red and green, which is not accompanied by any other effect such as blurring of vision showing that those who suffer from correctly interpreting colours considered as disabled." (Office for Disability Issues, 2011) Hence, this example excludes the CVDt as disabled.

The outcome of this thesis contradicts this example, since this thesis shows that the indicative-CVDt can have substantial difficulties without blurring and hence the Act and its examples should be reviewed and amended to recognise that CVDt is a disability. Once, this legislation change has been made then the CVDt will be protected by the act.

However the outcome of this thesis suggests that the work into aiding the CVDt is still in its infancy and that the act should be reviewed to encompass the CVDt as disabled.

This thesis highlights that the use of electronic devices, commonly used in daily activities, can cause the CVDt considerable problems in colour interpretation. Suggesting that, even though, the CVDt may have coping strategies, such coping strategies have not been enhanced sufficiently to cope with modern day daily demands. This means that future software development, must allow for the problems associated with CVDt. Consider, the predicted future expansion of electronic devices will, with certainty, exacerbate the problems faced by the CVDt, unless such assistive software is provided.

Hence, from the viewpoint of this thesis the answer to the question of this section is: "No, in the modern world, the CVDt should not be left to cope with their colour vision problems." The answer is the opposite: "Yes, it is a necessity to provide help and support in the form of assistive software."

7.8 THE NOVELTY OF THE PROPOSED HEA

The novelty of the HEA has shown that it is the most generic of the three algorithms meaning that HEA has multiple context applications and not just one specific application as with the other two algorithms. The results of statistical comparison have shown that HEA performs better than hatching algorithm and the re-colouring algorithm. For example, even though hatching algorithm was able to modify original images so as to enable CVDt individuals to interpret confusing colours by introducing hatching lines, it was found that these hatching lines are not visible in a number of applications that limit the interpretation of information for people who are CVDt correctly. The problem with re-colouring algorithm is that some of the new colours generated by algorithm could still confuse people who are CVDt, making it difficult for them to accurately interpret the information being portrayed by the colour. On the other hand, the HEA adds halos between various colour boundaries existing in an image. The halo is present and visible in all applications there by making the technique applicable in many environments.

A further novelty of this thesis has shown that empirical studies are an essential and effective manner for providing evidence of algorithm validity by using real live participants instead of a purely theoretical approach. The studies have been discussed above.

7.9 AGE RELATED MACULAR DEGENERATION

There is also an additional emerging problem that with an ever increasingly aging global population there is degeneration of the macula region of the eye. The problem of macular-degeneration is already significant and will become more significant in the future. The actual cause of Age Related Macular-Degeneration (ARMD) is currently not known but cones are located in the macula and there is damage to these with age. Since, rods and cones become damaged and lose their function, it can be argued that the process utilised in this research can be adopted to address the problem of ARMD.

The macula is a region in the central position of the retina and located around the optic nerve, see Figure 7.1. Since the retina is the eye's light sensing tissue (nerve tissue), then any deterioration of the macula region will affect the eye's ability to see and differentiate colours clearly, (Downie, et al., 2014). She further states that macular degeneration may be because cones are not only located in the fovia but are also located in the macula. Since the disease (macular degeneration) affects the macula region macular region of the retina, these cones can be destroyed or weakened (Mitchell, et al., 2018). This suggests that when cones are destroyed or weakened by macular-degeneration, such cones tend to lose their sensitivity to light signals with lower-intensity wavelengths and hence, as with the CVDt, they send improper signals to the brain along the optic nerve.

The work of (Campagne, et al., 2014), shows that macular degeneration is considered as one of the leading causes of irreversible loss of vision in people who are more than 60 years old. Therefore, it can interfere with an aging population's ability to differentiate colour mixes. An individual suffering from macular degeneration may not, in the early stages, realise they have problems as this is a slow degenerative problem over time.

Figure 7.1: The macula of the eye adapted from (Helmenstine, 2019)

For those ARMD who show commonalities with the CVDt then the research process to arrive at the HEA may be able to provide some benefit to those who have ARMD. This will only be known if future surveys include those diagnosed with ARMD showing CVD.

7.10 FUTURE WORK

The HEA currently provides the greatest benefit in assisting the CVDt, but it is unknown whether it would assist those with macular degeneration. The work of this dissertation suggests that HEA may be of benefit to those suffering macular degeneration, therefore future studies into aiding those who suffer from it may be of value. This research is on-going and many further developments and enhancements may be worth considering, some of which are highlighted in the following paragraphs.

It is becoming increasingly common when presenting graphical information, in say a business context, to use what is termed as the "traffic light system", using the three colours of red, amber and green. Red is synonymous with poor, amber with acceptable and green with good. In a physical traffic light system where static space or position is used in conjunction with colours, red is only adjacent to and above amber, amber is adjacent to both red and green, and finally green is adjacent to and below amber.

However with the traffic light system, information representation does not tend to use static space or position, and any of the three colours may be adjacent to each other with no fixed positions of the colour matrix. Therefore these adjacencies could cause considerable difficulties to the CVDt population. One solution would be to discourage the use of the traffic light system, using a different system more suitable to the CVDt. Alternatively, a software approach could be taken such that the CVDt would visualise the traffic light system in a manner that is suitable to their needs.

Adverts and announcements made on social e-media and e-networks are often colour coded, but such codes usually do not take into account problems that are associated by the CVDt nor those with macular degeneration. Rather than enforcing the developer/implementer to consider the CVDt and those with macular degeneration in such announcements, a better proposal may involve using corrective software.

Application Software (apps) are provided by vendors to smart device users and are positioned on the desk-top of smart phones in a manner that is determined automatically by the smart phone or manually by the user. It could be argued that user positioning is not a problem to the CVDt user, as they would use their existing coping to position their apps so that any colour mix problems would be overcome. It could also be argued that positioning of apps may be problematic to those with macular degeneration as the elderly are more likely to be considered as 'novices' when using electronic devices and therefore instead of them 'driving the device' the 'device drives them.'

The problem is mostly associated with automatic app positioning. Some smart devices will position apps alphabetically and others by linearly adding new apps to become the last displayed on the desk-top. Automatic app positioning may cause problems to both sufferers of CVDt and macular degeneration. One solution to this could involve changing the app positioning algorithm to suit the users' needs. Alternatively, different background colours could be used and the user would then select the most beneficial colour to help them. This could be considered similar to the Augmented Reality of over layering of colours that are already used by those who are dyslexic (Stevens, 2018).

7.10.1 HYBRID ALGORITHM

Having identified some of the additional and futuristic problems that CVDt and macular degeneration sufferers could encounter, this work suggests a need to expand and apply it to other contexts, offering a general solution. The outcome of this work shows that there is a need to present a new solution by further enhancements.

One approach could be the design, development, implementation and testing of a hybrid algorithm, combining the best features of the HEA, RCA and HAA algorithms.

The concept of a new algorithm would furnish an output file that is CVDt and macular degeneration friendly after up to three passes or parses as shown in Figure 7.2. The sequence of parses is ordered in such a way because this research has shown that HEA is currently the most generic algorithm and that the RCA provides greater benefit than the HAA.

- **Parse 1: Halo-Effect Algorithm Image file post-processing**

This would be to pass the input file through a further enhanced version of the HEA, generating an output file. The user would then be asked a simple question of whether they could now interpret the information portrayed in the post imaging output file or not. In the case of not, parse 2 would be invoked.

- **Parse 2: Re-colouring Algorithm image file post-processing**

This would then pass the original input file (not the output file from parse 1) through the RCA, which also may have been amended with the user's views in mind. As with parse 1, the user would be asked a simple question of whether they could now interpret the information in the post imaging output file or not. In the case of not, parse 3 would be invoked.

- **Parse 3: Hatching Accumulation Algorithm image file post-processing**

Having failed with the two other algorithms, the third and final parse would be to process the original input file through the HAA, which also may have been amended to suit user's needs. As with parse 1 and 2, the user would be asked if the final post-processed image is helpful or not. In the case of not, then the user would be supplied with a helpful message stating that currently there is no solution available to help them. In other words "still no panacea".

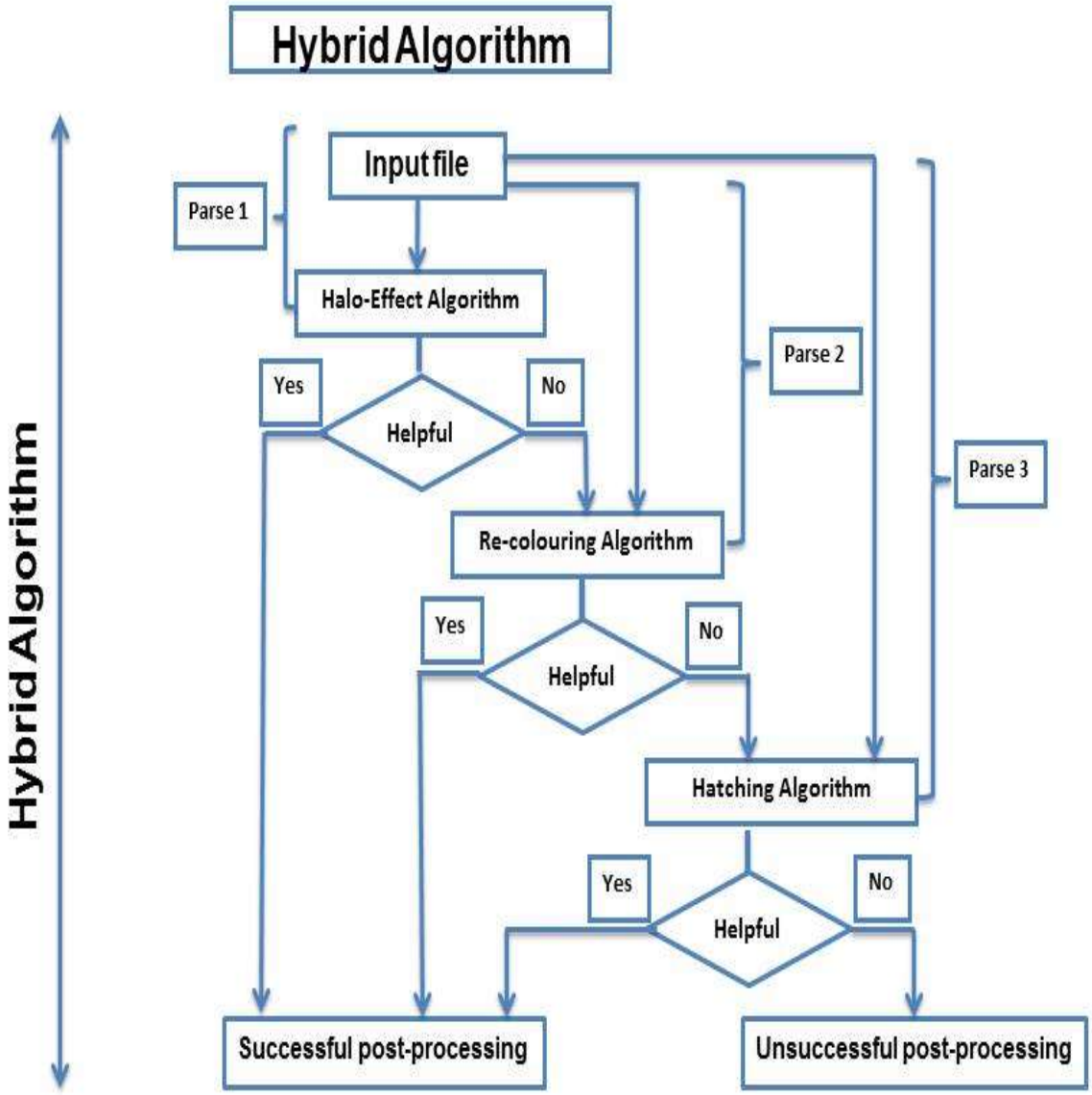

Figure 7.2: Schematic of the hybrid algorithm process

Transformational algorithms pose the problem of potentially confusing CVDt individuals, making it difficult for them to interpret information. Whereas the boundary colour separation HEA currently provides the greatest benefit to those who are CVDt. For example, if the current colour is green and the next colour is red, the HEA will provide better results to the CVDt by colour separation, make information interpretation easier. While with any colour transformations algorithms it maybe converts the green colour to red colour and the next colour may be from the shades of red, which causes the colours to mix with each other, leading to the failure in the interpretation of colours by CVDt individuals. Therefore, all transformation algorithms still face the same problem with complex images.

All transformation algorithms are meant to help CVDt individuals. However the one problem remains is the difficulty in converting the colours by varying the wavelengths (λ) that form them. Even with the variation of wavelengths, CVDt individuals still have difficulty in interpreting these colours and extract colour information as expected. This dissertation focuses on the HEA as well as the RCA and the HAA as examples of transformation algorithms. The hybrid algorithm offers reasonable levels of proposed solutions, and would help CVDt individuals at different levels, by integrating the post- and pre-processed images of colour separation/ conversion and extraction of colour information from the separated or converted colours. Because the hybrid algorithm aims to provide maximal assistance to CVDt individuals, it introduces the Culp's and Hung's transformation algorithms that perform colours conversion. At the same time, it proposes the Alsafyani's HEA algorithm, which applies a different technique from the transformations algorithm, as it does colour separation regardless of their mixture are and helps CVDt individuals in interpreting colours information as intended.

The hybrid algorithm integrates elements of the three algorithms to make the difference in colour wavelengths relevant for all CVDt people. After the transformation, all residual challenges require several tests with CVDt participants. With the hybrid algorithm, the transformation of colour vision quality highly relies on the wavelengths of the colours, but the clarity of the colour also needs to be taken into account. Therefore, numerous experiments with CVDt individuals as participants are required to achieve truly beneficial and satisfactory results to help CVDt people in interpreting colour information correctly. The future versions ought to simplify colour interpretation by CVDt people and quicken their processes of acquisition of colour information from all objects. This section highlights that together the Alsafyani's, Culp's `and Hung's algorithms could form an improved hybrid system, with the consideration that those who interested in this field as researchers or developers can apply using any other transformation algorithms.

7.10.2 FUTURE STUDIES

It is proposed that any future studies be composed of three groups of participants:

- A control group of individuals who are not identified as CVDt or macular degenerative;
- A CVDt group who have been diagnosed clinically and do not suffer from macular degeneration;

- A macular degenerative group who have been diagnosed clinically and do not are CVDt.

So far, no research other than this has included the two sub-groups of indicative-CVDt and non-CVDt. In the future, true clinical trials may be conducted in conjunction with recognised ophthalmic practitioners. The three groups would be identified clinically prior to any study. However, there would have to be a pre-clinical study to show that the Control group should not present any problems in the actual clinical trial. Those showing potential problems in the pre-trial would have been deemed as indicative-CVDt in this thesis and hence they would have to be excluded.

7.11 CONCLUDING REMARKS

Currently there is no single solution to the generic problems faced on a daily basis by the CVDt when using modern day electronic devices. The CVDt are faced with considerable difficulties with the discrimination between certain colours, which could result in disadvantaging them from the non-CVDt.

The work of this thesis has shown that HEA is currently the most beneficial algorithm for the CVDt. However, the HEA has its limitations, and hence as yet there is no single 'capture all' solution.

In the discussion section of this chapter, it has been highlighted that those suffering from macular degeneration may face similar, if not the same, problems as the CVDt and hence, the macular degenerative should also be considered in future studies.

This work is still in its infancy and there is a great deal of future research. Some initial ideas have been mentioned above. It cannot be emphasised enough that the gathering of participant survey responses is an essential facet of any future study regarding the CVDt and those with macular degeneration. Furthermore, those gathered data must then analysed with appropriate statistical techniques to furnish verifiable, meaningful and credible information for dissemination in the public domain.

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GLOSSARY

A glossary of terms used in this dissertation. N.B. these definitions are particular to the contexts of this dissertation.

Term	**Definition or** **Brief description.**	**Page of the first reference**
Dissertation	A written document that defends a thesis	iii
Thesis	An intellectual position capable of being maintained by argument.	3
Colour Vision Deficiency (CVD)	The condition of the inability to differentiate certain colours.	iii
Colour Vision Deficient (CVDt)	A person who has the inability to differentiate certain colours.	iii
Indicative-CVD	A survey participant in this dissertation who has been identified as having problems to differentiate certain colours.	iii
Non-CVD	A survey participant in this dissertation who has been identified to not have any problems in differentiating certain colours.	iii
Significant	Statistical survey results that have been proven to be true in this dissertation.	75
Insignificant	Statistical survey results that have either not been proven to be true or have been proven to be false, in this dissertation.	75
Deuteranope	A person who suffers from a particular type of CVD in termed deuteranopia	6
Deuteranopia	The inability to differentiate	6

	between red and green colours.	
Protanope	A person who suffers from a particular type of CVD in termed protanopia.	6
Protanopia	The inability to differentiate between red and green colours.	6
Tritanope	A person who suffers from a particular type of CVD in termed tritanopia	6
Tritanopia	The inability to differentiate between blue and yellow colours.	6
Monochromate	A person who suffers from a particular type of CVD in termed monochromacy. Such sufferers are out of the scope of this dissertation.	6
Monochromacy	The total inability to be able to differentiate colours.	6
HEA	Halo-Effect Algorithm. This is the new proposed algorithm (HEA). This technique works by introducing halos between colours, providing clear boundaries, enabling CVDt individuals to view contrasting colours accurately.	iii
Validity	Validity refers to the trustworthiness (or not) of a piece of information.	8
Corroborate	To confirm and give support to any outcomes.	3
LMS-RGB	LMS-RGB transformation matrix and reverse transformation matrix.	22

	Uses a digital video technology which constructs LMS specifications based on a standard video monitor consisting of 256 colours. The algorithm specifications are based on the relative extension of LMS waves.	
SOCT	Self-organizing Color Transformation. It is focused on the red-green CVD to increase the ability to access website images. In this algorithm, RGB colours spaces are converted to HSV (hue, saturation and brightness values) colour spaces.	23
DT	Dichromat Technique. Uses the automatic image re-colouring technique based on Gaussian pairing technique.	24
IPT	Imaging Processing Technique. Involves 3 techniques: Image simulation technique, Colour transformation-colour difference scaling, and Colour transformation-red/green scaling.	26
CPD	Characteristics of Protanopia and Deuteranopia. Is based on the conventional un-sharp masking and filtering blending. Preserves the original standard colour of the image for easy interpretation.	27
CSA	Colour Simulation Algorithm. Uses Colour-Bless technology. The colour simulation algorithm uses the linear filters which are fitted to colour outputs systems.	28

RCA	Re-colouring Algorithm. Uses Re-colouring Algorithm for the maps. Was developed to enhance colour readability by the CVDt.	28
RrA	Re-ranking Algorithm. The algorithm re-ranks web results based on the relevance of the ranked images. Image accessibility is quantified based on the degree of the colour information as perceived by the person with CVDt.	29
PTECT	Pattern Technique to Encode Colour Transformation. The algorithm uses overlaying patterns in the visualised content.	30
RCA	Re-colouring Algorithm. The algorithm improves the hue and luminance value of the colours in the image during the conversion to HSV colour space.	31
HAA	Hatching Accumulation Algorithm. The algorithm uses the variation of the position of the confusion line while maintaining the average colour of the original image.	31
CMA	Colour Matching Algorithm. Was developed to assist people with CVDt to choose to clothing and read the other factors such as cost, size, material and length. The algorithm consists of an integrated system in which the camera that is connected to the computer performs the colour and pattern matching processes.	33

ICTBA	Information Communication Technology-Based Algorithm. Uses a complex system consisting of a camera, daltoniser and a computer.	34
CT	Chroma Technique. This is a wearable augmented reality system employing Google Glass technology.	34
COA	Colour Optimisation Algorithm. The algorithm uses perception models and perceptual metrics to reduce the colour effects caused by physiological contrasts.	35
RGB to HSV algorithm	In this algorithm, RGB values containing each pixel of a given image are converted to HSV values using pre-defined regulations. The algorithm enables the overall contrast of the visualised image to be constant throughout.	35
Colour Cat algorithm	The algorithm was developed to enable the CVDt to read and interpret information on a map.	36
Atomisation method	The method uses a technique in which the image colour centre is placed on a single confusion centre. It allows the use of chroma to filter out objects.	36
CIHOA	Colour Input to Haptic Output Algorithm. The technique involves the use of Chroma Glove. It is a device that is worn on the hands to improve the perception of colour through touch.	37
MNNA	Multilayer Neural Network Algorithm. The technique	38

	comprises of a set of inputs, processing unit and output. It uses a number of layers to transform the original image to an image with colours that can be seen and interpreted by those with CVDt.	
XYZ	Also known as Tristimulus values. They are extrapolations of RGB colour spaces in order to avoid negative values. Y generally means luminance, Z means somewhat equal to blue, and X means a mix of cone responses.	26
LiMiSi	This a representation of 3D LMS in which "i" stands for either letter P or D. Where p is protanopes and "D" deuteranopes.	26
L*a*b*	Also known as LAB colour space. It is a combination of Colour model and space. In this combination, L is the colour brightness component while "a" and "b" are the chromatographic components. This colour space has imaginary colours cannot be produced in real circumstances. That is, colour values are beyond the human gamut.	26

APPENDIX A: COLOUR VISION DEFICIENCY AND SOME RECENT APPROACHES TO ADDRESSING THIS PROBLEM

1 INTRODUCTION

This chapter provides background reading about the biology of the eye and difficulties that can be caused when problems occur. In this detail, the researcher highlights the anatomy of the eye, the different types of CVD and also genetic/chromosomal CVD. Also, this chapter introduces computerised techniques to aid the CVDt and also a physical technique of over-layering in the form of spectacles to aid the CVDt.

2 ANATOMY OF THE EYE

The human eye sees through the stimulation of the retina, which is a neuromembrane lining at the back of the eye. The major stimuli are gathered in the macula region of the retina. The macula is located close to the optic nerve. Cones and rods are responsible are the actual photoreceptor cells within the macula. Cones tend to be more photoreceptive to daylight vision and rods tend to be more photoreceptive to night vision (Wong, 2011).

Photoreceptive cells contain light sensitive pigments that cover a multitude of different wavelengths. Visible light is seen as different colours because each individual colour has a different wavelength (Lambda sign) and the different colours cover a broad spectrum from approximately 400nm to 700 nm (Neitz & Neitz, 2011). For example in daylight vision the primary colours red, green blue are detected over a wide wavelength spectrum. Shades of red are detected between 620nm and 750nm, shades of green are detected between 500nm and 570nm, and shades of blue are detected between 400nm and 500nm. This leads to the idea of three different types of cones which have different light sensitivities over the colour spectrum from around 400m to 700nm. Long cones which are most light sensitive between 620nm and 750nm, medium cones which are most light sensitive between 500nm and 570nm and short cones which are most light sensitive between 400nm and 500nm.

3 BACKGROUND OF COLOUR VISION DEFICIENCY

Colour Vision Deficiency (CVD) is commonly (and incorrectly) termed as Colour-blindness. CVD varies from person to person, with four main types: protanopia, deuteranopia, tritanopia and monochromacy. Protanopia and deuteranopia are the most common types of CVD and are manifested as dichromacy, which is a condition that affects those with one or more cones that are wrongly light sensitive. It is a condition where a person cannot distinguish between red and green colours. While Tritanopia is a condition in which a person cannot distinguish

between blue and yellow colours. As such, identifying these attributes provides a better understanding of the different aspects of the colour-blind issues that affect the majority of the people today (Carlson, 2007). The fourth type monochromacy, defines an individual who has the total absence of colour sensitivity, and is extremely rare (Wong, 2011).

4 RODS AND CONES

Before delving deep into the main types of CVD, it is important to look at the way human beings see colour. Colour is made up of red, green and blue and these colours are the primary colours of the colour spectrum. When one looks at an object, the vision starts when the light enters the eye. This allows the cornea and the lens to focus the light into the retina. Considered to be part of the brain itself, the retina has approximately 7 million cones compared to 120 million rods (National Institute of Health, 2013) as seen in Figure 1. These receptors process the light into nerve impulses and pass them along to the brain via the optic nerve, which produces the familiar sensations of colour.

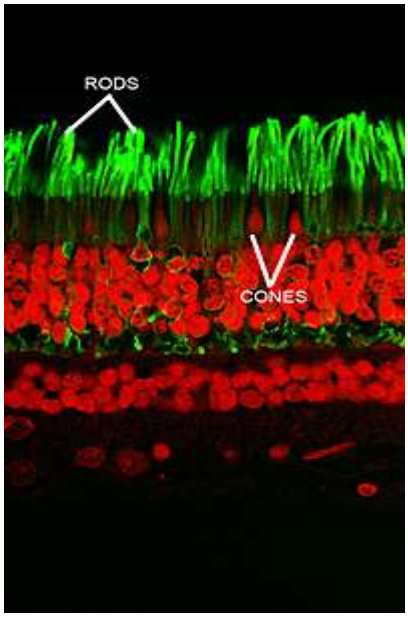


Figure 1: Rods and cones in the eye adapted from (National institute of health, 2013)

Rods are responsible for vision at low light levels (scotopic vision). While cones are active at higher light levels (photopic vision). There are 3 types of cones which we will refer to as the short-wavelength sensitive cones, the middle-wavelength sensitive cones and the long-wavelength sensitive cones (Wong, 2011).

4.1 TRICHROMACY

Normal vision is the ability to differentiate the three primary colours of red, green and blue. Blue cones are associated with small wavelengths, green cones are associated with medium wavelengths and red cones are associated with long wavelengths.

4.2 DICHROMACY

Dichromacy is a condition in which two types of working colour receptors, called cone cells, are present in the eye. This category involves people who have colour visions that allow them to see colours based on two main primary colours. This is unlike the normal human being who has the ability to seeing the three primary colours and distinguishing them (Neitz & Neitz, 2011). These individuals understand that they have this problem and it affects their daily lives and interactions (Nevid, 2011). It is hereditary and sex-linked, affecting males more than females.

5 TYPES OF CVD

There are four major types of CVD which manifest in different ways. The typrs of CVD are: Protanopia, Deuteranopia, Tritanopia and Monochromacy. What is common to all is an inability to correctly interpret various colours. The following sub-sections are an overview of the types of CVD.

5.1 MONOCHROMACY

This form of CVD shows a complete inability to make any distinctions between the different colours in the world. Monochromacy is the condition of possessing only one channel for conveying colour information to the brain. This does not allow the individual to have a complete distinction of any colours and perception are only variations in brightness rather than the colours viewed from a spectrum. The rod monochromacy is one of the main issues affect the eyes where the cones do not contain any cells in them. This means that the functions of the eye that depend on the cones are missing (Goldstein, 2007). As seen below in Figure 2 a), the normal retina has rods that see only black, white, and shades of grey with three forms of colour cones, red, green, and blue. People with Monochromacy as seen below in Figure 2 b), have a failure of the red (L-cones) and green (M-cones). Thus blue (S-cones) monochromats are left with only rods (Goldstein, 2007). People in this category are taught how to associate the colours with objects and differentiate the colours based on their brightness (Xin Bei et al, 2014). It is one of the most common types of complete colour

blindness despite the small number of people noted in that occurrence ratio (National Institute of Health, 2013).

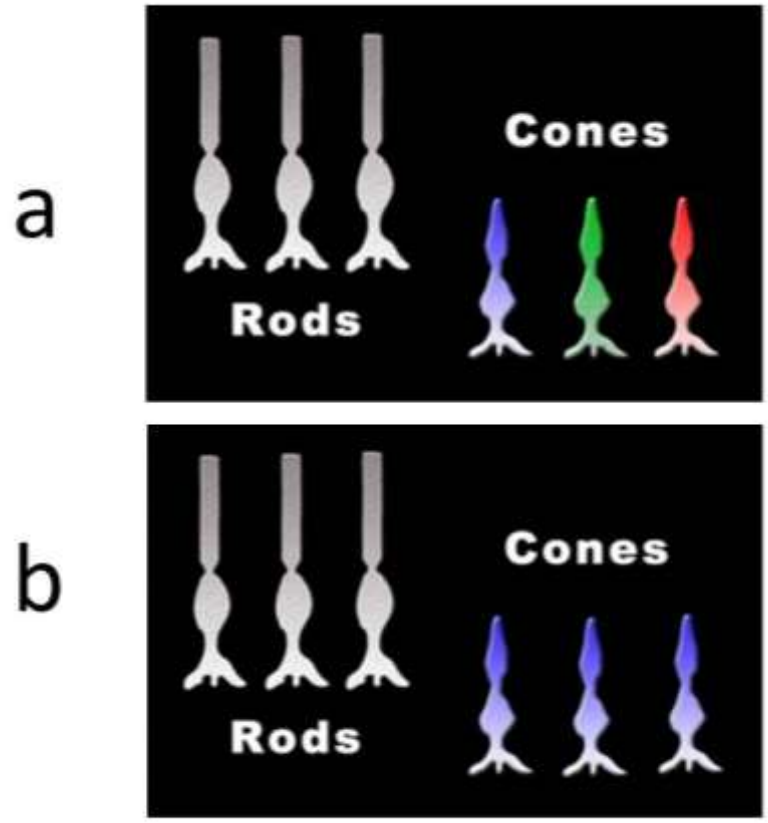


FIGURE 2: SHOWING THE BLUE CONES OF MONOCHROMATS ADAPTED FROM (GOLDSTEIN, 2007)

5.2 PROTANOPIA

Protanopia involves the lack of a long-wavelength sensitive photoreceptor cells. This is around 560 nm and is associated with long wavelength cones (L-cones). This condition makes it difficult for an individual to differentiate between colours that are in the green-red region, which is also manifested as a problem with red-green colour mixes. This is frequently termed as red dichromacy. This means that the wavelength reaching the eye is limited to 492 nm that defines a cyan-like wavelength (Xin Bei et al, 2014) as seen in Figure 3. The brightness of yellow, orange or red is reduced to a normal view, compared to that of the normal eye that defines the brightness from far (Bonilla-Silva, 2013; Catanese, 2011) as seen in Figure 4. The hue difference may not be the strength to them, but they could distinguish between red and yellow based on the lightness and brightness of the colours.

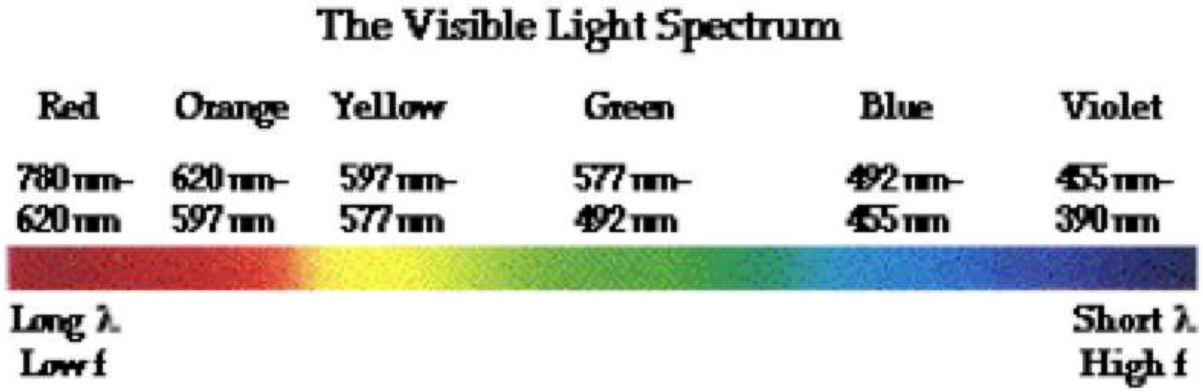


FIGURE 3: SHOWING THE WAVELENGTH ADAPTED FROM (PHYSICSCLASSROOM, 2014)

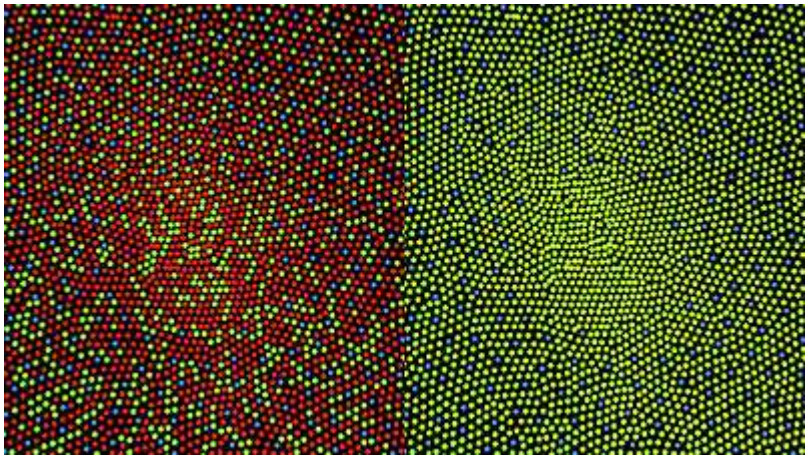


FIGURE 4: SHOWING NORMAL VIEW ON THE LEFT AND PROTANOPIC VIEW ON THE RIGHT ADAPTED FROM (XIN BEI ET AL, 2014)

5.3 DEUTERANOPIA

Deuteranopes lack the ability to distinguish colours in the medium-wavelength range of around 530 nm, which are associated with M-cones that covers the green pigment. This condition shifts the green spectral towards the end of the spectrum resulting in a reduction in the sensitivity to the green light (Norton, et al., 2004). This light insensitivity usually means that shades of green are seen as shades of black. The result is that, Deuteranopes have difficulty differentiating red-green colour mixes (Dunkel, 2013).

5.4 TRITANOPIA

Tritanopia is less common than Protanopia and Deuteranopia. Tritanopia affects individuals who lack the short-wavelength cones, and indicates a mutation of the shades and hues of blues (Potnik & Kouyoumdjian, 2012). This is around 420 nm, which is associated with S-cones.

This is frequently termed as blue-dichromacy (Albany-Ward, 2015). Tritanopes only have the shorter wavelengths in their vision and that means they can only view blue, indigo and a violet spectrum (Ashe, 2014).

5.5 CHROMOSOMAL CVD

With cells, DNA structures known as chromosomes contain all the genetic information needed for the healthy development of an organism. Humans have 23 pairs of chromosomes, with one chromosome from each pair being inherited from the mother, and the other one from the father. The 23rd pair, known as the sex chromosomes, differs between males (XY) and females (XX). The permutations of the mixes of the female to male chromosomes are shown as Figure 5.

Non-CVD female with non-CVD male

XX with XY = XX or XY or XX or XY = XX: XY relationship

Recessive female CVD (where ‘denotes CVD gene) with non-CVD male:

X’X with XY = **X’**X (recessive or carrier female) or **X’**Y (CVD male) or XX (non-CVD female) or XY (non-CVD male) relationship

Dominant female CVD (where ‘denotes CVD gene) with non-CVD male:

X’X’ with XY = **X’**X or **X’**Y or **X’**X or **X’**Y = 2**X’**X (recessive or carrier female) or 2**X’**Y (CVD male) relationship

Dominant female CVD (where ‘denotes CVD gene) with CVD male:

X’X’ with **X’**Y = **X’X’** or **X’**Y or **X’X’** or **X’**Y = 2**X’X’** (dominant CVD female) or 2**X’**Y (CVD male) relationship

Figure 5: The gene mixes of female to male

APPENDIX B: A VALIDATION OF CULP'S RE-COLOURING ALGORITHM AND HUNG'S HATCHING ALGORITHMS

1 INTRODUCTION

Thus far this thesis has focussed on the information conveyed in pie-charts. In reality there are many other forms of diagrammatic information that are also used. Culp in (Culp, 2012) focussed her research on reading spectra maps of the USA and South America. Hung focussed his research on the text where a background change was highlighted in the foreground.

This comparison investigates the benefits that these two post-processing transformation algorithms achieve in their specific contexts.

2 THE VALIDATING OF CULP'S AND HUNG'S ALGORITHMS.

This comparison details and validates Culp's and Hung's work by passing their images (Culp, 2012), (Hung & Hiramatsu, 2013) through HCBEE to ensure that their algorithms do improve information interpretation as they intended and each of the three algorithms are compared for their effectiveness. It must be borne in mind that each algorithm has its benefits but also their pitfalls.

3 COMPARING NORMAL VISION OF SPECTRUM MAP OF THE USA WITH PERSONS WHO SUFFERING WITH DEUTERANOPIA, PROTANOPIA AND TRITANOPIA.

Figure 1 is the same spectrum map of the USA that Culp used in her work (Culp, 2012). It highlights the problems that the different types of CVD would have. All three types of CVD would have difficulty in interpreting the information provided in the original spectrum map. Comparing the normal vision map a) with each of the three different types of CVD Deuteranopia map b), Protanopia map c) and Tritanopia map d) the arrows highlight where there are shades of colours that the CVDt people would have difficulties. Hence, it is highly unlikely that they would be able to interpret correctly the information as intended.

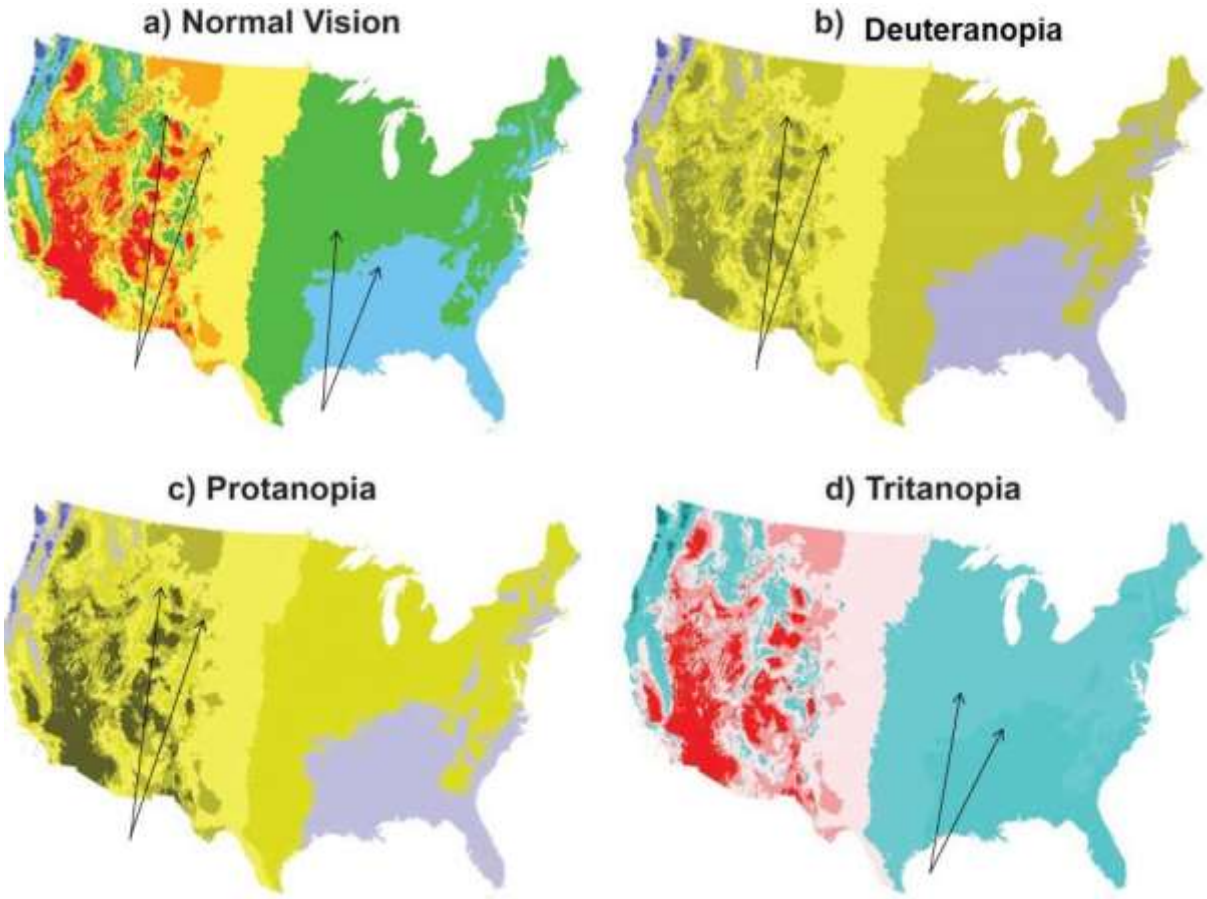


FIGURE 1: CULP'S SPECTRUM MAP OF THE USA

Figure 2 highlights the ROC for b) Deuteranopia and c) Protanopia when compared with normal vision a). Additionally, Figure 3 highlights the ROC for Tritanopia when compared with normal vision.

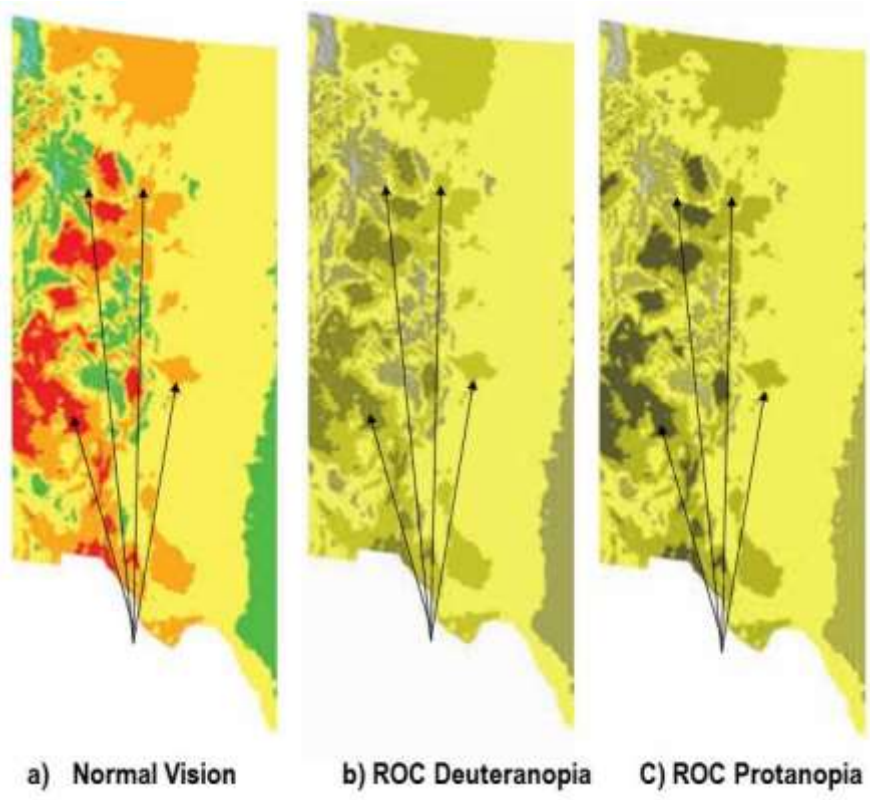


FIGURE 2: ROCS FOR DEUTERANOPIA B) AND PROTANOPIA C)

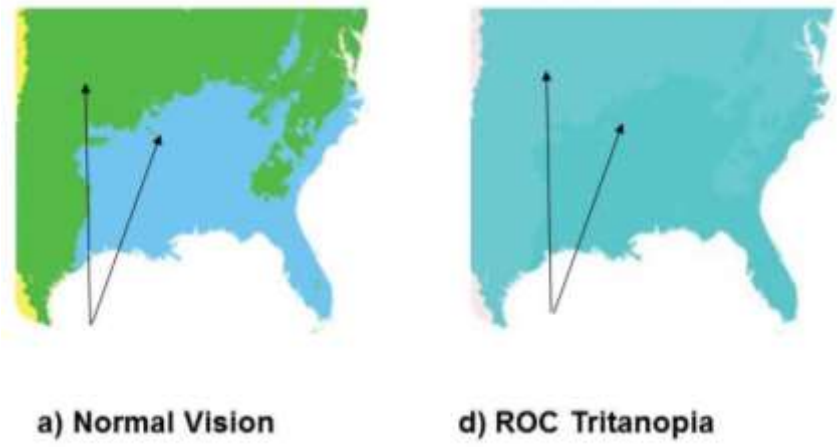


FIGURE 3: ROCS FOR TRITANOPIA D)

4 COMPARING SPECTRUM MAP OF THE USA WITH DEUTERANOPIA, PROTANOPIA AND TRITANOPIA PROBLEM BY USE OF CULP'S ALGORITHM.

Using the same cut outs from Figures 2.and 3, Figure 4 shows the improvements that may be achieved having been post-processed using Culp's Re-colouring Algorithm. There is a marginal improvement for Deuteranopia and Protanopia and there is also a distinctive improvement for Tritanopia. Realistically a reader, say using a tablet, would not be able to identify the ROCs and hence would not be able to cut out the sections as shown.

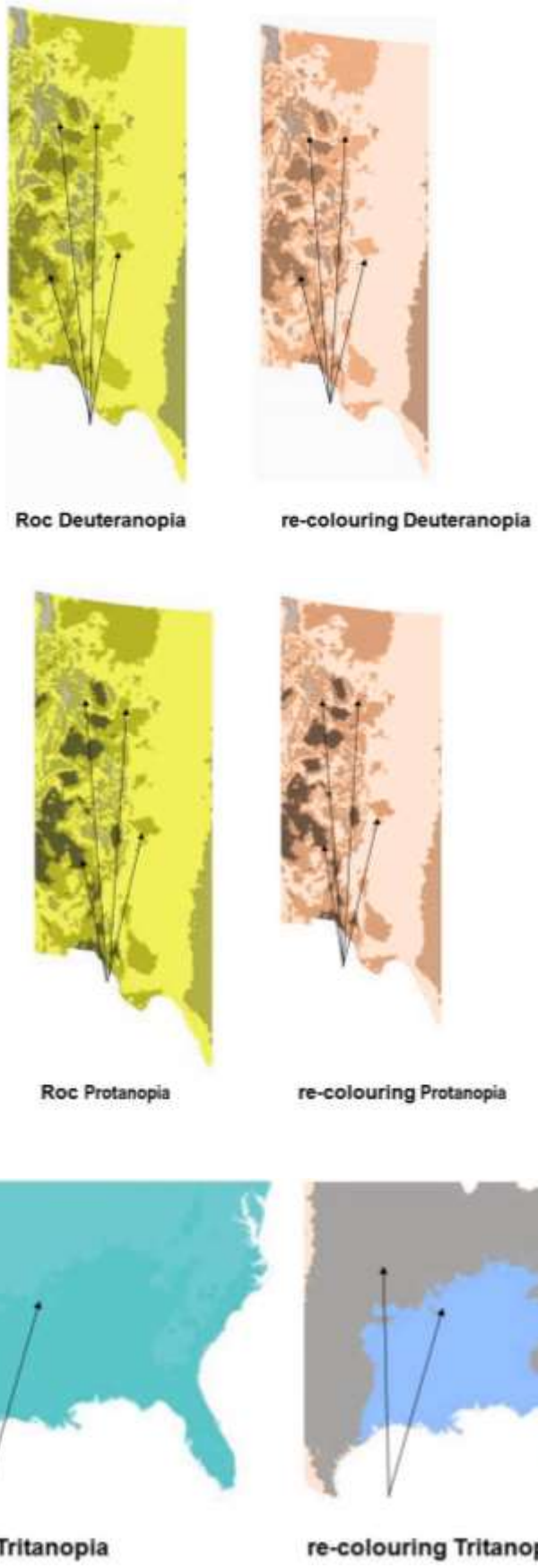


FIGURE 4: ROCS AND CULP'S RE-COLOURING IMPROVEMENTS FOR DEUTERANOPIA, PROTANOPIA AND TRITANOPIA

Figure 5 brings Culp's improvements back together for the complete spectrum map. The left hand side images show how the CVDt would see the original spectrum map and the right hand side images show how the CVDt would see the spectrum map post-processing with Culp's re-colouring algorithm.

This work furnishes a surprising and unexpected result. Culp's Re-colouring Algorithm only shows distinctive improvement for those who are Tritanopia. The expectation was that Culp's Re-colouring Algorithm would show distinctive improvement for all of the three types of CVD under investigation.

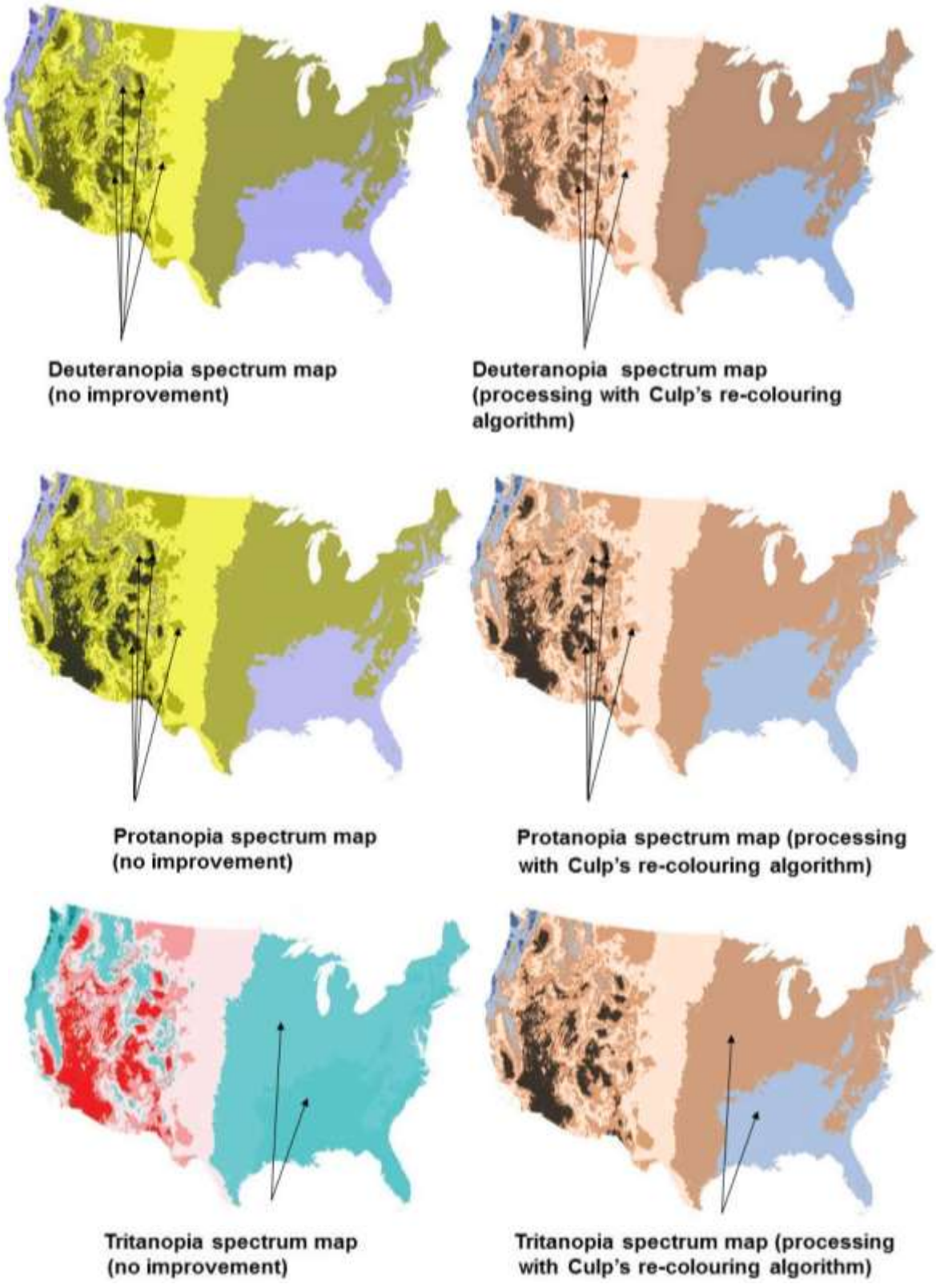


FIGURE 5: CULP'S RE-COLOURING ALGORITHM FOR THE COMPLETE SPECTRUM MAP (PROTANOPIA AND TRITANOPIA)

5 COMPARING NORMAL VISION OF SPECTRUM MAP OF THE USA WITH CULP'S AND HUNG'S IMPROVEMENTS.

Figure 6 shows improvement gained after post-processing with Hung's algorithm but the size of the map has had to be magnified to demonstrate improvement, as shown by the addition of arrows in Figure 7. However, in a realistic situation it is highly unlikely that a reader, say using a tablet, would be able to increase the map size to achieve the benefits of Hung's algorithm.

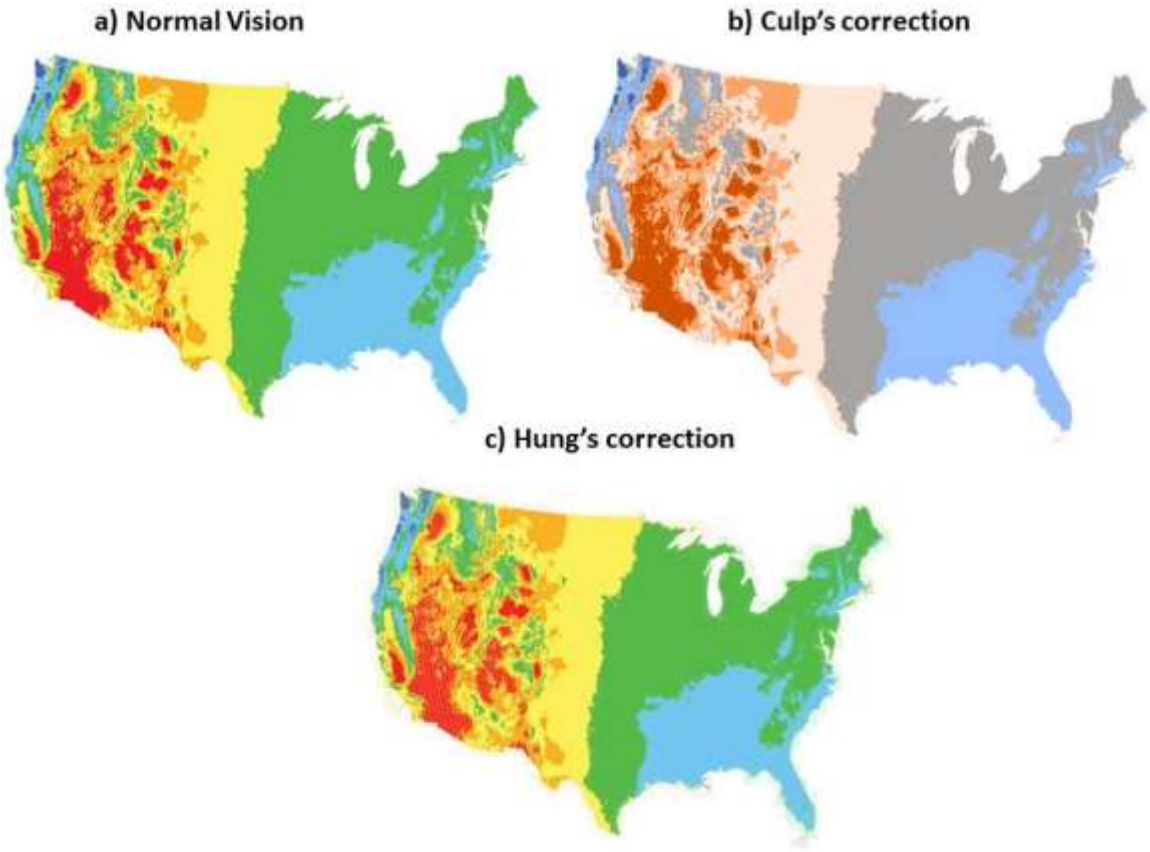


Figure 6: Shows comparison between normal vision spectrum map of the USA with Culp's and Hung's improvements

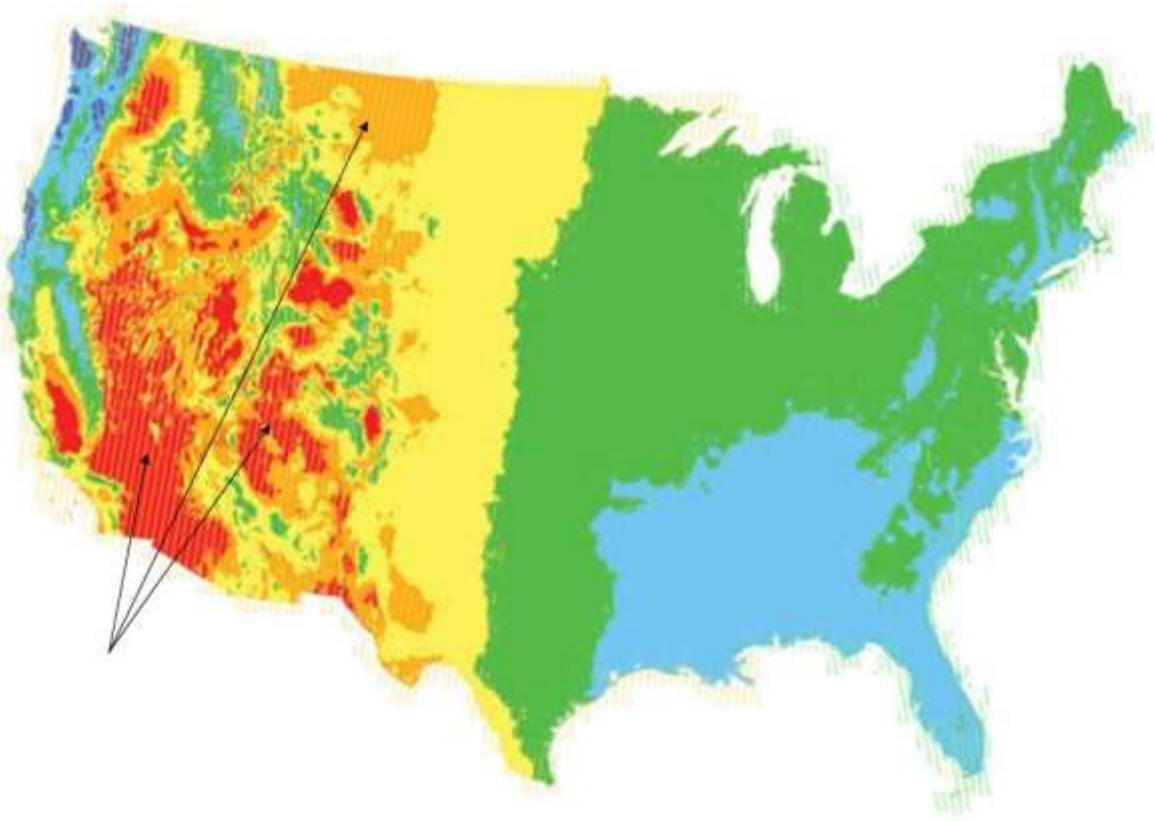


FIGURE 7: SHOWS THE NORMAL VISION OF SPECTRUM MAP OF THE USA WITH HUNG'S ALGORITHM

6 COMPARING CHARACTER TEXT WITH PERSONS WHO SUFFERING WITH DEUTERANOPIA, PROTANOPIA AND TRITANOPIA.

The concept of Hung's hatching algorithm is to shade the background of any given character text, such that the text will be in the foreground and clearly highlighted to the readers. Figure 8: a) is the same image containing the character text that Hung's used in his work. Also in Figure 8): b) shows how those individuals who are Deuteranopia would see the character text within the image, c) the same again, but for those who are Protanopia and d) those who are Tritanopia. Ovals have been added to highlight the ROCs. Those people who are Deuternaopia and Protanopia will have difficulty in noting character text colour changes but those who are Tritanopia will not have any such problem.

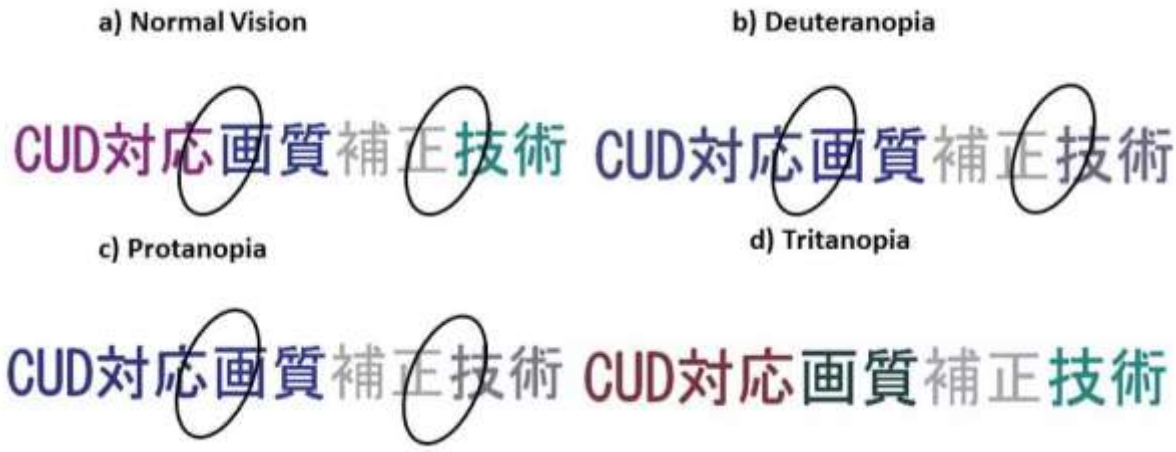


FIGURE8: HUNG'S CHARACTER TEXT

Figure 9 magnifies and separates the two ROCs for those are CVDt b) Deuteranopia and c) Protanopia. As with Figure 8, oval shapes have been added to highlight the ROCs. This exemplifies the problems the CVDt people would have in reading such character text.

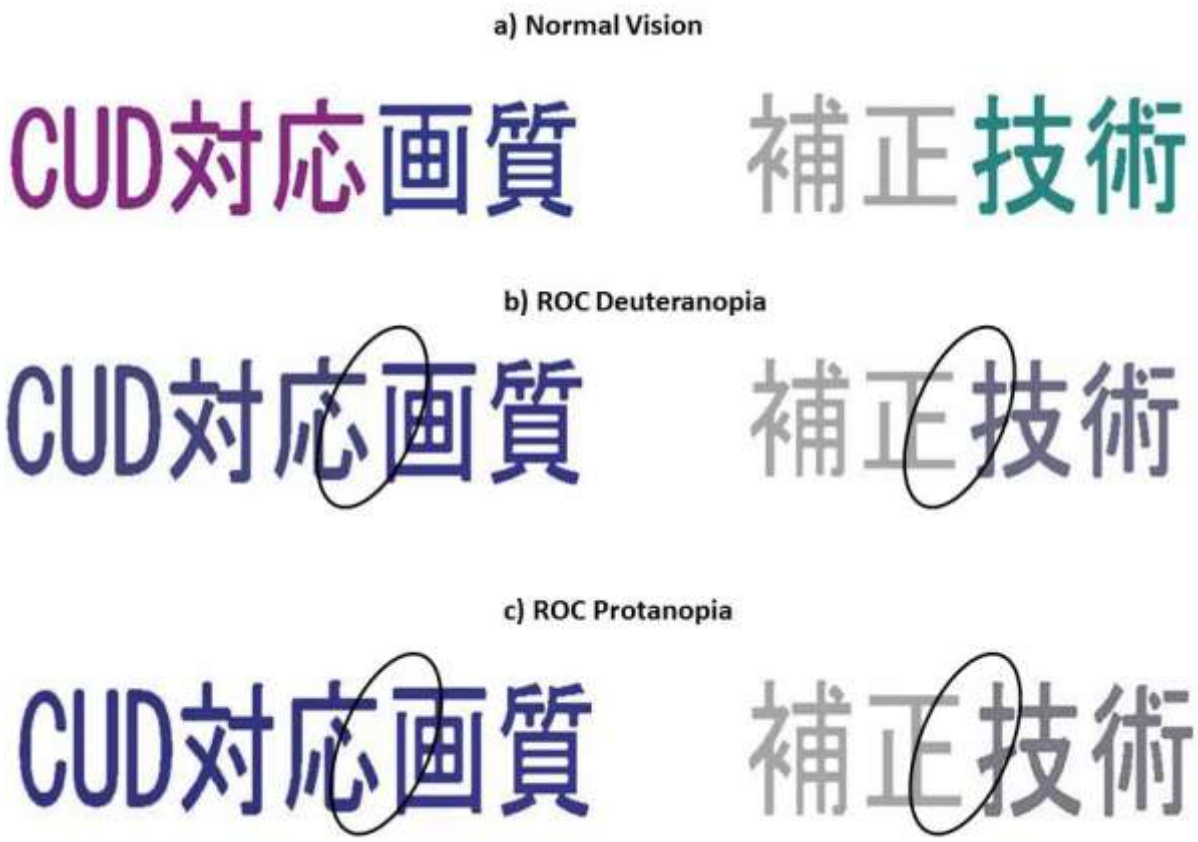


FIGURE 9: ROCS FOR DEUTERANOPIA B) AND PROTANOPIA C)

7 COMPARING NORMAL VISION OF CHARACTER TEXT WITH DEUTERANOPIA AND PROTANOPIA PROBLEMS BY USE OF HUNG'S ALGORITHM.

Figure 10 shows how Hung's hatching algorithm can improve information interpretation. Using the same cut outs from Figure 9 but these times have been post-processed through with Hung's algorithm. The improvements are shown in Figure 10 for Deuteranopia and Protanopia. There is a marginal improvement for Deuteranopia and Protanopia. The expectation was that Hung's algorithm would show distinctive improvement for all of the three types of CVD under investigation. Hence this work shows that the text of a character cannot be used for comparison of any of the improvement algorithms.

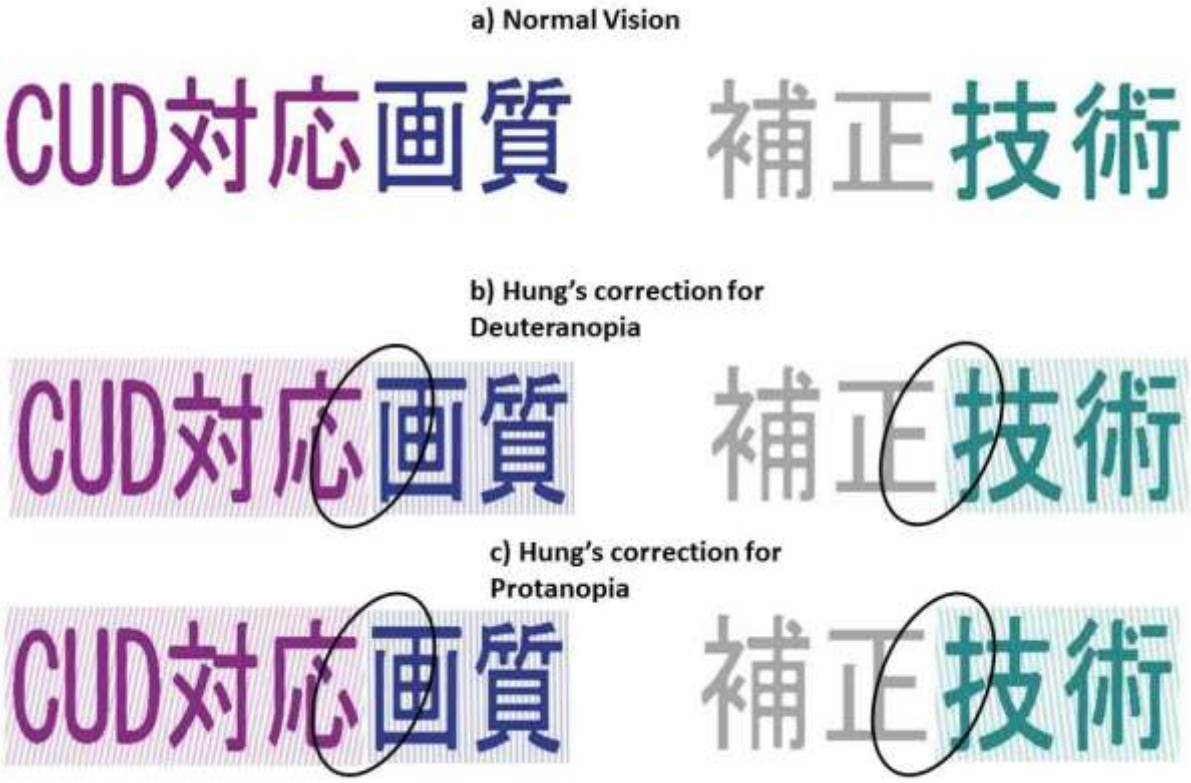


FIGURE 10: HUNG'S HATCHING IMPROVEMENT FOR DEUTERANOPIA AND PROTANOPIA

8 COMPARING NORMAL VISION OF CHARACTER TEXT WITH, CULP'S AND HUNG'S ALGORITHMS.

Figure 11 replicates the figure Hung used in his research (Hung & Hiramatsu, 2013). The Figure highlights the benefits of his algorithm where the inclusion of hatching in an image will aid those who those who are CVDt. However, Figures 11: c) also shows that Culp's Re-colouring algorithm does not provide benefit to the CVD in such a context.

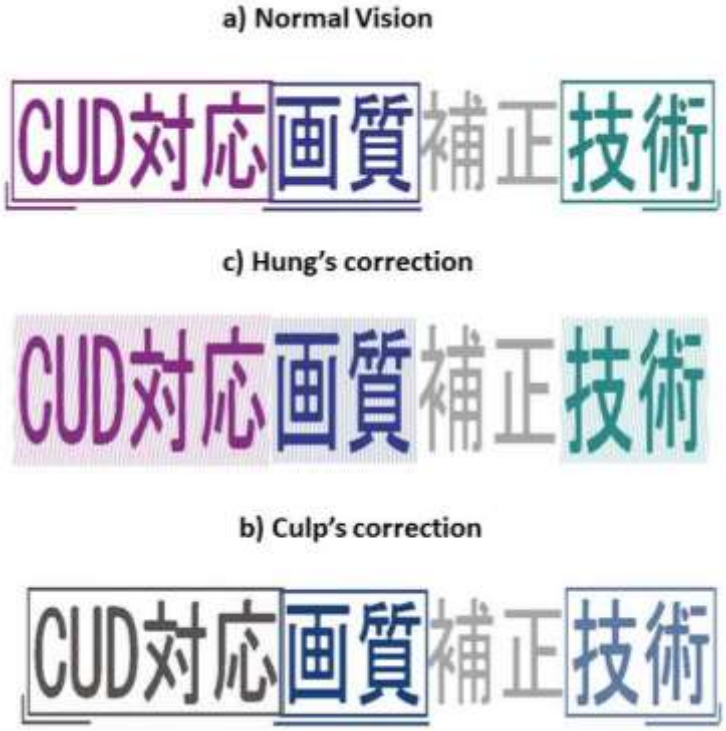


FIGURE 11: SHOWS COMPARISON NORMAL CHARACTER TEXT WITH CULP'S AND HUN'S IMPROVEMENTS

9 CONCLUDING REMARKS

This work shows that both Culp's and Hung's algorithms mainly aid those who are Tritanopia, but only in each of their specific contexts. That is spectra maps for Culp and character text for Hung. Surprisingly, this work shows that Culp's and Hung's algorithms only show marginal improvements for those who are Protanopia or Deuternaopia. However, in both of these cases, benefits can be gained by identifying the ROCs and then magnifying these identifications. The comparisons made highlight that each of the transformation algorithms requires specific contexts to benefit the CVDt.

APPENDIX C: OVERVIEW OF THE RESEARCH APPROACH, RESEARCH STRATEGY, RESEARCH DESIGN AND RESEARCH PROCESS.

1 RESEARCH APPROACH

Research approach relates to the activities that will be carried out to achieve the research aims and objectives (Saunders, M. et al., 2009). Research approach has is divided into three types: the inductive, the deductive and the abductive. The following sub-sections illustrate these approaches in more details.

1.1 INDUCTIVE APPROACH

This approach aims to investigate emerging dimensions which can help to constrict the scope of the research. The inductive approach contributes to the generalisation of the results of the study and the development of new theories. The research process begins with aims, objectives and questions of research that are required (Bernard, H. R., 2011; Goddard, W. and Melville, S., 2004). Inductive research is usually linked with the qualitative method as shown in Figure 1.

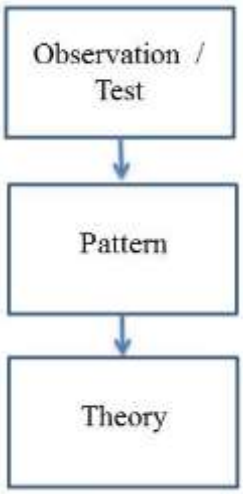


Figure 1: Flow-diagram of the inductive approach

1.2 DEDUCTIVE APPROACH

The approach is used when a researcher has developed a number of hypotheses which need to be accepted or rejected during the research. In addition, the deductive approach examines the validity of the available hypotheses. The deductive approach was used for the present research study, which sought to investigate the emergent aspects of the problem with which it

was concerned, in order to help build the scope of the study (Gulati, P., 2009; Wilson, J., 2014). Deductive approach is usually linked to the quantitative method as shown in Figure 2.

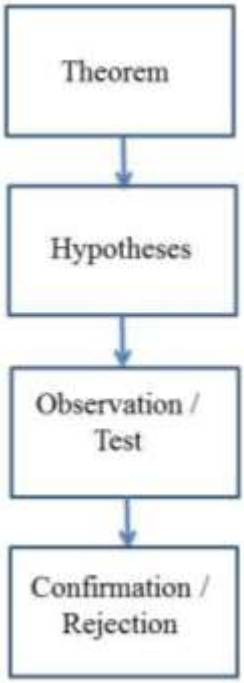


Figure .2: Flow-diagram of d the deductive approach

1.3 ABDUCTIVE APPROACH

Here, the process of research is concerned with puzzles, incomplete observations and explanation of surprising facts, the description of which identifies the research study process (Bell, E. et al., 2018).

Table 1 demonstrates the core differences between deductive, inductive and abductive research approaches with regards to the use of data, the use of logic, the use of theorems and the use of general abilities.

Table 1: Differences between Inductive, Deductive and Abductive research approaches

	Approach		
	Deductive	**Inductive**	**Abductive**
Logic	Used when the bases are real and the conclusions need to be real too.	Used when identified bases are used to produce conclusions which are untested.	Used when identified bases are used to produce conclusions, which are then tested.
Generalisability	From the general form to the specific form.	From the specific form to the general form.	From interfacing between the general form and the specific form.
Use of data	Has to be in the context of the existing theorems. Data collected is used to assess any hypotheses/ propositions.	Data obtained is used to identify patterns, phenomena or themes, as well establishing a theoretical framework.	Data obtained is used to identify patterns or phenomena, and then locate these in the theoretical framework. Also used to analyse the initial data collection via subsequent data collection approaches and so on.
Theorem	Theorem verification	Theorem generation and building	Theorem modification or generation, incorporating existing theorems where applicable. This is done to modify an existing theorem or to establish a new theorem.

2 RESEARCH STRATEGY

Research strategy is a methodology directing research towards its ultimate goal. There is various factors support the research strategy including objectives, research questions, philosophical foundations and current knowledge (Saunders, M. et al., 2009). The basic research purposes are exploratory, descriptive and explanatory, with the possibility of every strategy used for all of those purposes (Yin, R. K., 2017).

Fundamental research is used to develop a new theorem based on the axiom of the proposition of a novel algorithm. On the other hand, applied research is used for the development of a novel algorithm. This study concerned describing of problematic of how

CVD people read day-to-day information, which is a matter of concern. Additionally, applied research aspires to identify solutions to specific research problems. The research in this thesis helps to conceptualise information gained from people who suffer from CVD, providing better interpretation. Furthermore, this research endeavours to fill in gaps of knowledge in this area. Table 2 highlights the major differences between fundamental research and applied research (Saunders, M. et al., 2012).

Table 2: Shows the major differences between fundamental research and applied research

	Fundamental research	**Applied research**
Function	To develop new theorems.	To solve the organisation and the setting of problems.
Purpose	Linked with research methods examination, development, and verification. It is also concerned with tools and procedures of the research methods.	Concerned with information acquired during the setting of the problems and execution of the organisation. It is useful in decision making processes.
Nature	Inductive, accompanying the discoveries of new theorem.	Deductive, retaining some of the theorems as its base.
Other Names	Basic or pure research.	Action research.
Method	Qualitative	Quantitative

3 RESEARCH DESIGN

The purpose of a research design is to identify a general plan that helps the researcher to answer the research questions (Saunders, M. et al., 2012). Research design ensures that any acquired evidence facilitated by the researcher actually does address the specific problem, in an effective manner. Research design is divided into three types: exploratory design, descriptive design and experimental design. The following sub-sections explain each type in more details.

3.1 EXPLORATORY DESIGN

This design of research is used when handling research problems, for which new or past studies have been, conducted (Saunders, M. et al., 2012). It also helps in developing a base for potential future research to support other research designs, (Singh, K., 2007) for instance, experimental research and descriptive research respectively.

Exploratory design could be used in situations where the research problem has not been defined. It helps to determining the problem's nature, exploring research questions. It

follows the inductive approach as well as the qualitative method, and does not aspire to provide final answers, but simply identifies research topics along with changing levels of depth efficiency.

3.2 DESCRIPTIVE DESIGN

Descriptive design is unable to deliver definite conclusions to specific problems being investigated, but instead aids in offering potential answers to associated questions (Ethridge, D. E., 2004). It can be used as a conductor to more quantitative research, with the general overview providing indications which can be useful in understanding and identifying variables that are have worth in testing for quantitatively. Descriptive design was used for the present research study because often helps to provide answers to questions that are related to the specific problem of a research study. It follows the deductive approach as well as the quantitative method and consequently can generate rich data that can lead to significant suggestions. Outcomes from this cannot be used to disprove a hypothesis or to identify an ultimate response.

3.3 EXPERIMENTAL DESIGN

Experimental design is used in situations where the causal relationship time is a priority, there is reliability in the causal relationship, and also the correlation's magnitude is great (Creswell, J. W. and Creswell, J. D., 2017). Control and experimental groups are included in the design, and are measured on similar dependent variables. Over extended periods of time, experimental designs employ more measurements and groups. Real experiments need to have randomisation, manipulation and control. This type of research sustains the capability to conclude the direct causal relation and restrict alternative descriptions in the research. If specific facilities or equipment are required, then this research can become costly. Furthermore, due to technical or ethical reasons, it may be difficult or even not be possible to undertake an experimental design.

4.RESEARCH PROCESS

This process is comprised of sequential steps needed to effectively and efficiently perform a research project. Figure 3 details a flow diagram of this process, which is made up of closely related activities, demonstrated in steps 1 to 7. Activities overlap continuously, as opposed to adhering to a predefined sequence. On occasions, the first step can determine the nature of the last step. If subsequent procedures are not taken into account and consideration in the early stages, challenges may arise, and may even prevent the completion of the study.

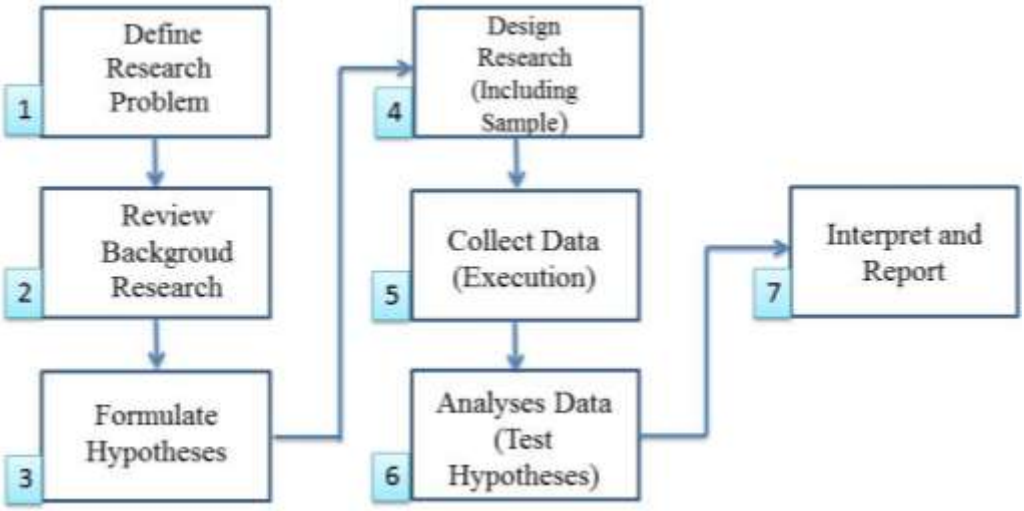


Figure 3: Shows a flow diagram of the research process

The research process in this thesis to conceptualise information gained from people who suffer from CVD. Step number one of the research process defines the research problem (see section 1.3 of chapter 1). The second step investigates related work (see chapter 2). The third step considers and details hypotheses that will be used in the programme of research. In the fourth stage concepts of design are considers and manners of data collection. In the fifth step a survey is undertaken and responses from participants' are gathered. In step 6 any gathered data are analysed statistically such that the hypotheses declared in step 3 can be tested for significance (or not), or validity (or not). Finally, step 7 is used to collate the information gained from the statistical analyses of step 6 in such a manner that the information can be disseminated.

APPENDIX D: ETHICS APPROVAL NOTIFICATION

University of Hertfordshire UH

SCIENCE & TECHNOLOGY ECDA

ETHICS APPROVAL NOTIFICATION

TO Majed Alsafani

CC Colin Egan

FROM Dr Simon Trainis, Science and Technology ECDA Chairman

DATE 19/9/16

Protocol number: **COM/PGR/UH/02073**

Title of study: A survey to investigate the effectiveness of pie charts that use colour to represent data

Your application for ethics approval has been accepted and approved by the ECDA for your School.

This approval is valid:

From: 19/9/16

To: 4/1/17

Please note:

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1. Should you amend any aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit form EC2. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

University of Hertfordshire UH

SCIENCE AND TECHNOLOGY ECDA

ETHICS APPROVAL NOTIFICATION

TO Majed Alsafyani

CC Dr Collin Egan

FROM Dr Simon Trainis, Science and Technology ECDA Chairman

DATE 6/1/17

Protocol number: aCOM/PGR/UH/02073(1)

Title of study: A survey to investigate the effectiveness of pie charts that use colour to represent data

Your application to extend and modify the existing protocol COM/PGR/UH/02073 as detailed below has been accepted and approved by the ECDA for your School.

Modification:

To amend the title of the protocol to the one stated above;

To extend the protocol to the end date stated below.

This approval is valid:

From: 6/1/17

To: 5/3/17

Please note:

Any conditions relating to the original protocol approval remain and must be complied with.

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1 or as detailed in the EC2 request. Should you amend any further aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit a further EC2 request. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

University of Hertfordshire UH

HEALTH SCIENCES ENGINEERING & TECHNOLOGY ECDA

ETHICS APPROVAL NOTIFICATION

TO Majed Alsafyani

CC Dr Mariana Lilley

FROM Dr Simon Trainis, Health ,Sciences, Engineering & Technology ECDA Chair

DATE 08/05/2017

Protocol number: aCOM/PGR/UH/02073(2)

Title of study: A survey to investigate the effectiveness of pie charts that use colour to represent data.

Your application to modify and extend the existing protocol as detailed below has been accepted and approved by the ECDA for your School and includes work undertaken for this study by the named additional workers below:

Modification: Change of supervisor from Dr Colin Egan to Dr Mariana Lilley

This approval is valid:

From: 11/05/2017

To: 11/11/2017

Additional workers: no additional workers named.

Please note:

Any conditions relating to the original protocol approval remain and must be complied with.

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1 or as detailed in the EC2 request. Should you amend any further aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit a further EC2 request. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

University of Hertfordshire UH

HEALTH SCIENCE ENGINEERING & TECHNOLOGY ECDA

ETHICS APPROVAL NOTIFICATION

TO Majed Alsafyani

CC Dr Colin Egan

FROM Dr Simon Trainis, Health, Sciences, Engineering & Technology ECDA Chair

DATE 27th September 2017

Protocol number: aCOM/PGR/UH/02073(3)

Title of study: *A survey to investigate the effectiveness of Images that use colour to represent data.*

Your application to modify and extend the existing protocol as detailed below has been accepted and approved by the ECDA for your School and includes work undertaken for this study by the named additional workers below:

Modification: Revised title of study, Amended /extended dates, Change of supervisor.

This approval is valid:

From: 11/11/2017

To: 11/05/2018

Additional workers: no additional workers named.

Please note:

Any conditions relating to the original protocol approval remain and must be complied with.

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1 or as detailed in the EC2 request. Should you amend any further aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit a further EC2 request. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

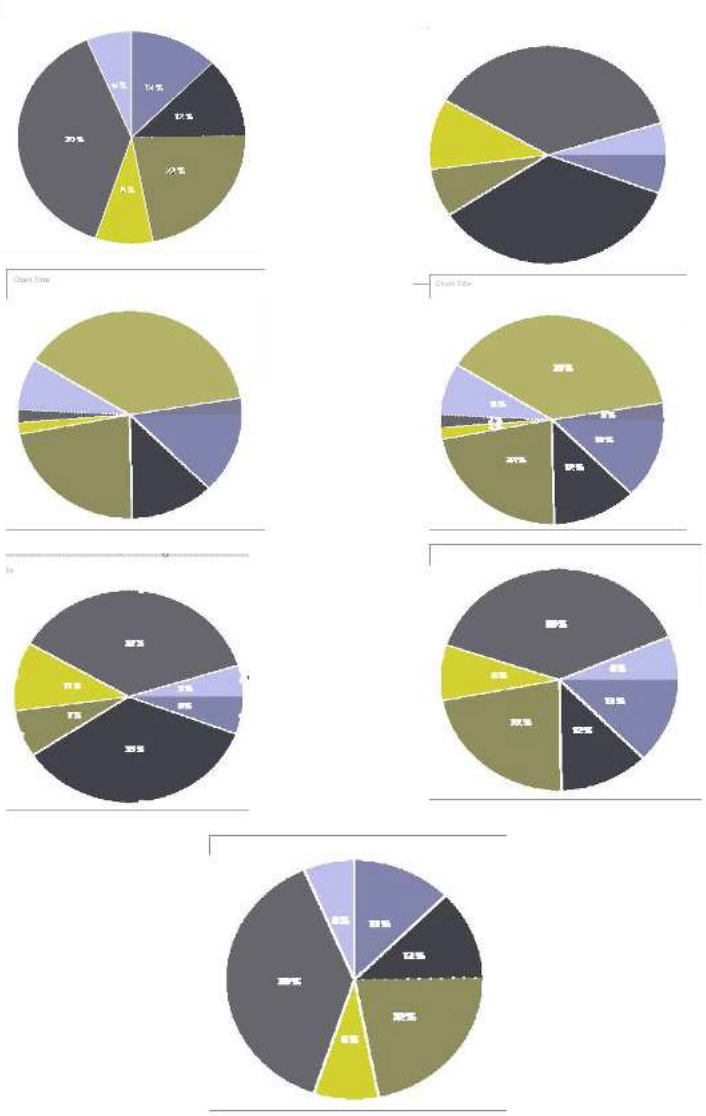
Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

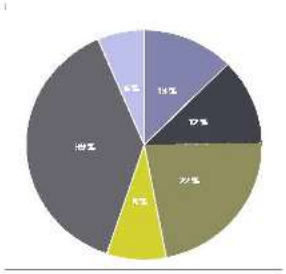
Students must include this Approval Notification with their submission.

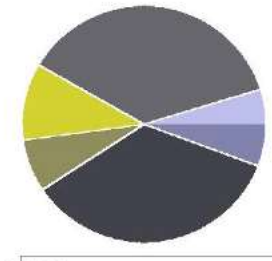
APPENDIX E: A FULL SET OF THE MICROSOFT TUTORIAL RESULTS.

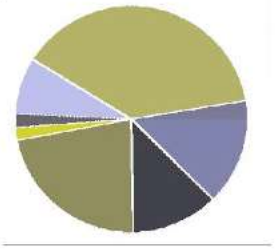
Deuteranopia

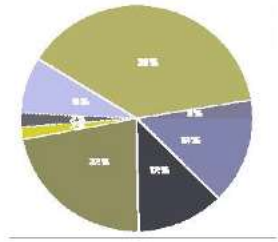


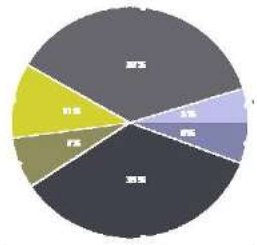
Protanopia

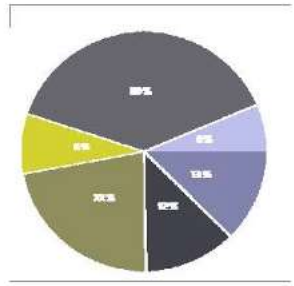


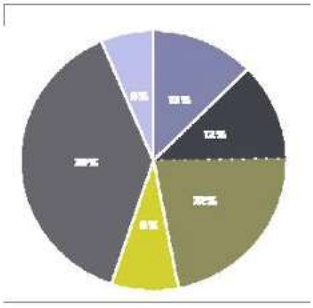




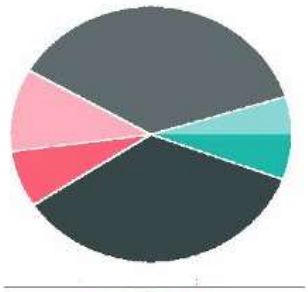


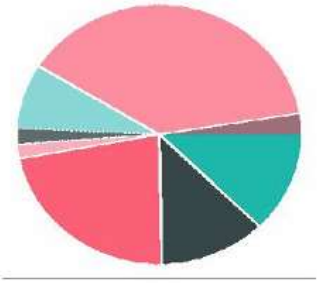


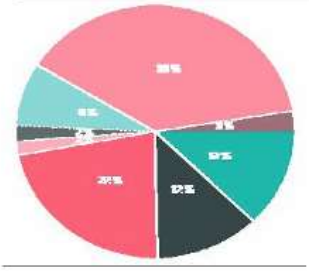


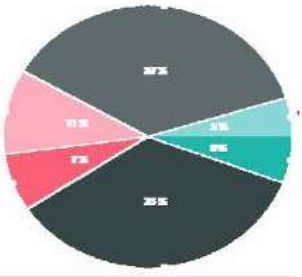


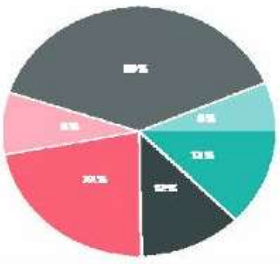
Tritanopia

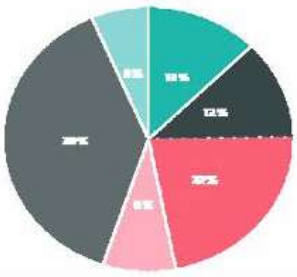












APPENDIX F: THE PAPER THAT PRESENTED AT (EUROPEAN CONFERENCE ON COMPUTER SCIENCE – ROME, OCTOBER, 2016

Is information always informative? Perhaps to you, but is it to the Colour-vision deficient?

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Abstract: - Every day we are surrounded by information which is supplied in many forms and we might be expected to make important decisions from that information. However, it may not be possible for all recipients of the information to make such necessary and informed decisions. In this paper we focus on the difficulties encountered by those who suffer from colour-vision deficiencies. We provide one mechanism of a potential solution to information derived from the frequently used pie-chart which are commonly used by businesses to visually represent (raw) data as information. We use the pie-chart creation tutorial provided by MSDN to highlight how the colour-vision deficient might have difficulties in interpreting information. Our potential solution is an image processing software tool called the HCBEenhanced. HCBEenhanced identifies the actual pie-chart within an image, which we call the Region of Concern (ROC) and any legend provided within the image. HCBEenhanced then inserts a halo around each segment of the pie-chart, which we call the halo-effect of segments. This new pie-chart is then provided as an output file to the user. We demonstrate that those suffering from colour-vision deficiencies, by use of HCBEenhanced, can have significant improvements in the ability to interpret the information that was intended from the original pie-chart.

Key-Words: - **Colour-vision deficient, colourblind, information, data, image, image processing, pie-chart, Microsoft Developer Network (MSDN)**

1 Introduction

Today we are bombarded with information, where information is the meaning that has been applied to data. Data are gathered facts and/or statistics which are collated for analysis and/or for reference. For example, pie-charts and other images are commonly used to show information from gathered (raw) data in a meaningful and graphical manner. But do pie-charts, as images, actually achieve what their creators intended? This is an interesting question and it poses many dilemmas. As authors of this paper we deliberately use the term dilemma as the informative information that pie-charts, as images, are intended to provide may result in a position where difficult choices have to be made and those choices may be desirable or even undesirable.

We consider that it is the pie-charts creators' responsibility to convey the information in a meaningful manner such that those difficult choices that may be made are correct and true [1]. However, if you were colour-vision deficient do you consider that the dilemmas we have highlighted would be exacerbated? Do you think if you were colour-vision deficient you would be in a position to make accurate and true decisions from the intended information provided by a typical pie-chart? Would you be able to process the pie-chart image in the way that the creator intended? Just think, if you did not appreciate that the information you were deriving was not what was intended, you could make severe undesirable choices.

Approximately 1 in 12 males are colourblind and very few females (approximately 1 in 250) are also colourblind. What difficulties do you think they might encounter when interpreting information from pie-charts? Consider, a small business is considered to consist of less than 100 employees and a medium size business is considered to consist of between 100 and 999 employees. Potentially, that means a small business could employ up to approximately 8 male colourblind males, and a medium size business could employ up to 80 colourblind male employees and up to 4 female colourblind employees.

In the remainder of this paper we intend to demonstrate some of the problems that information from typical business pie-charts may cause the

colour-vision deficient in the production of informative decisions. We also propose to demonstrate an image processing software tool which we are developing that may aid the colour-vision deficient to make informative decisions from such business pie-charts. We call our image processing software tool The Hertfordshire colourblind Emulator enhanced (HCBEenhanced), which is an enhanced version of the previously published Hertfordshire colourblind Emulator (HCBE) [2, 3]. We also call our method "the halo-effect of segments". The reason behind our name will be discussed later.

2 Colour-vision deficiency

Although in this paper we are using the terms colour-vision deficient and colourblind interchangeably, the term colour-vision deficient is more accurate. Colourblindness is the total inability to see any colour and colour-vision deficiency is the difficulty or more accurately the inability to distinguish between certain colours [3, 4, 5, 6 and 7].

Colour-vision deficiencies can be manifested in a number of ways including:

- finding it difficult to detect the differences between the colours including reds, oranges, yellows, browns and greens;
- finding it difficult to detect the differences between the colours including blues, greens, and yellows;
- have a difficulty in observing different shades of colours, in particular purple;
- observing colours in a manner which is much duller than they really are;
- mixing reds with blacks or blacks with reds.

There is a number of different types of colour-vision deficiencies and only one of those types can truly be considered as colourblind. In this study we investigate the difficulty encountered by the following colour-vision deficient types: Protanopia, Deuteranopia, Tritanopia and Monochromacy. In our previously work we have investigated the impact of colourblindness in online education of Higher Education [2]. For clarity of this work we provide a short summary of these types of colour-vision deficiencies.

2.1 Protanopia

Protanopia is classified as a two colour phase deficiency (a dichromic defect) and is manifested as red-green colour-vision deficiency, which is caused by a complete lack of retinal photoreceptor cells.

2.2 Deuteranopia

Deuteranopia is similar to protoanopia, in that reds and greens are almost indistinguishable. However, the cause of the condition is different, in that it is the green receptors in the eye that are missing. In the majority of cases the effect very similar to protanopia. Although the contrast between blue and purple seems to be affected to a greater degree by deuteranopia.

2.3 Tritanopia

Tritanopia is manifested with a blue-yellow variation due to the lack of blue photoreceptors. It is not present as frequently as protanopia and deuteranopia.

2.4 Monochromacy

Monochromacy is the complete loss of colour, where colours are visible as shades of grey and is therefore in the accurate sense colourblind. Monochromacy is caused by either defected cones or absence of cones.

3 Microsoft® Pie-Chart Tutorial

To demonstrate the problems the colour-vision deficient may encounter on a daily basis we have chosen to use one of the Microsoft Developer Network (MSDN) Tutorials [8]. The tutorial is provided to teach users how to create informative pie-charts in the Microsoft® Office Suite. The tutorial does not consider the problems that the colour-vision deficient encounter. Hence those who use this tutorial to learn from may quite easily fall into the trap of creating subsequent pie-charts that can be difficult to gain the correct intended meaning from. The tutorial shows users how to create a number of pie-charts of varying complexity, most of which are shown in figs. 1, 2, 3, 4, 5, 6, and 7.

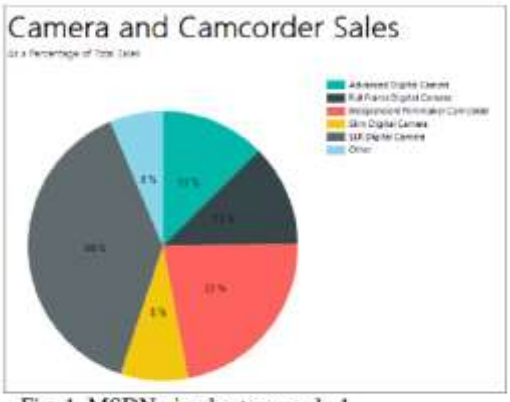

Fig. 1, MSDN pie-chart example 1

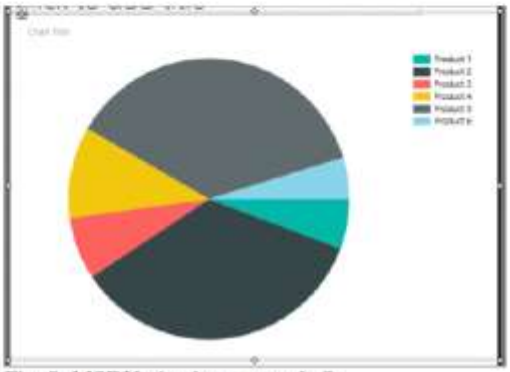

Fig. 2, MSDN pie-chart example 2

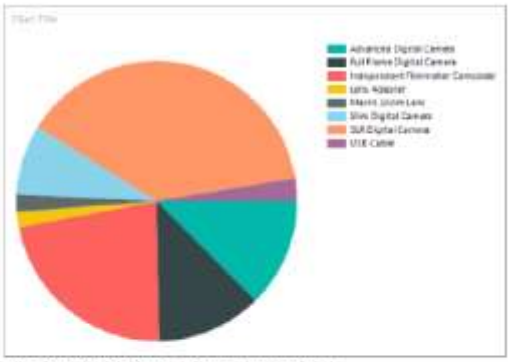

Fig. 3, MSDN pie-chart example 3

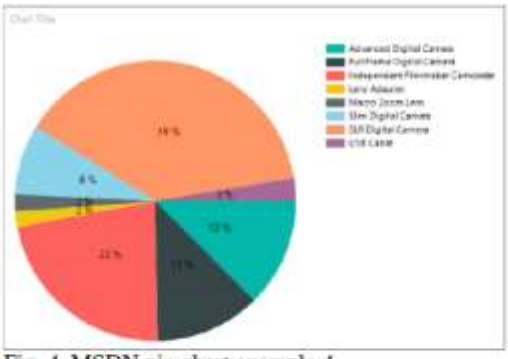

Fig. 4, MSDN pie-chart example 4

Fig. 5, MSDN pie-chart example 5

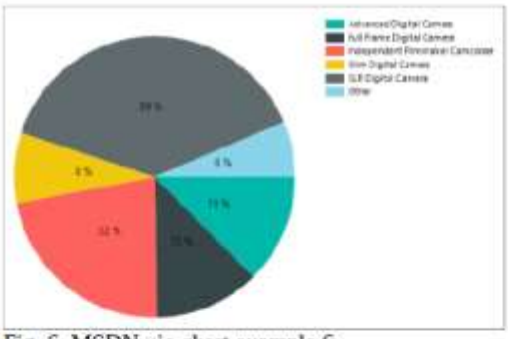

Fig. 6, MSDN pie-chart example 6

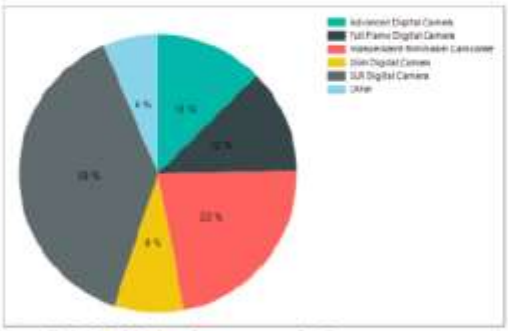

Fig. 7, MSDN pie-chart example 7

3 The Hertfordshire Colourblind Emulator (HCBE)

The Hertfordshire Colourblind Emulator (HCBE) [2 and 3] generates images as they would be seen by the colour-vision deficient. Currently, HCBE relies on the images creators' to make the decision whether the original image conveys the information to the colour-vision deficient as intended or not. In the case that the information is not conveyed as intended then it is the creators' responsibility to make necessary changes to the image such that the information is conveyed as intended [ref equality act]. This could be, for example, by simply changing colour schemes.

HCBE is a software tool that, as input, takes in an image in a number of formats and one of four types of colourblindness selected (protanopia, deuteranopia, tritanopia or monochromacy). That image is then processed pixel by pixel such that if the type of colourblindness is detected then the colour of the pixel undergoing processing is altered to that seen by the selected colour-vision deficiency. Once the input image has completely been processed a new processed image is then output to the user as a Joint Photographic Experts Group (jpeg) file [9].

In subsequent sections of this paper we show enhancements we have been making to HCBE (currently called HCBEenhanced) output .jpeg images that potentially may convey to the colour-vision deficient the meaning that the images' creators originally intended.

3.1 HCBE and the Microsoft® Pie-Chart Tutorial

We have input each of the MSDN pie-chart tutorial's images into HCBE for each of the four types of colourblindness, resulting in 28 altered .jpegs highlighting how the colour-vision deficient would view the pie-charts. In this paper, we only present the output images associated with Deuteranopia (figs. 8, 9, 10, 11, 12, 13, and 14) but we will discuss all of our 28 output files.

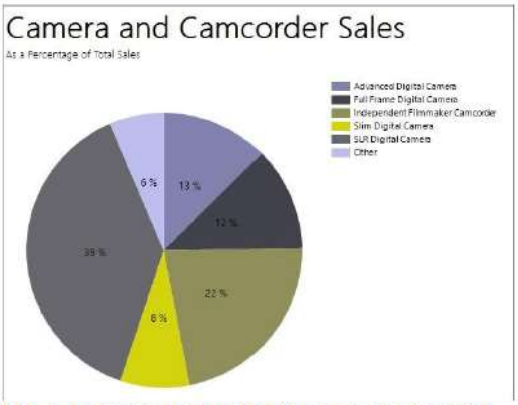

Fig. 8, Deuteranomaly MSDN pie-chart example 1

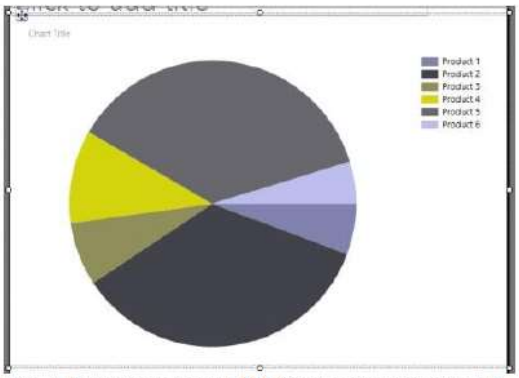

Fig. 9, Deuteranomaly MSDN pie-chart example 2

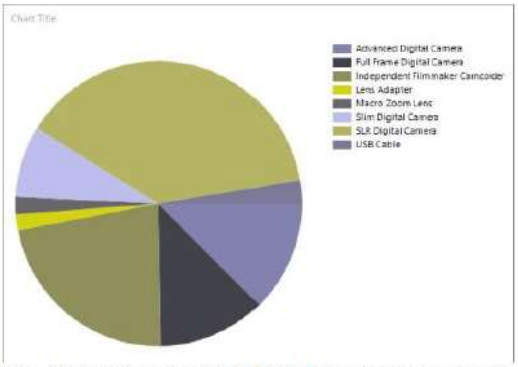

Fig. 10, Deuteranomaly MSDN pie-chart example 3

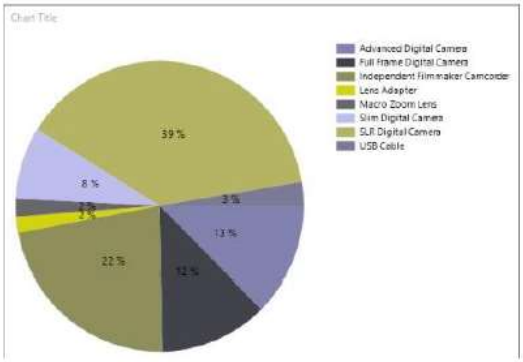

Fig. 11, Deuteranomaly MSDN pie-chart example 4

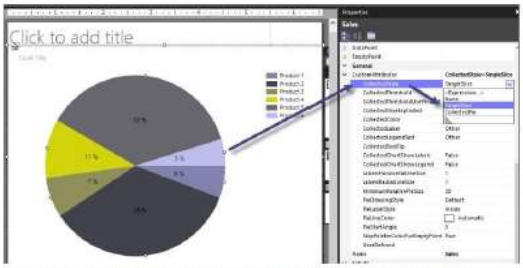

Fig. 12, Deuteranomaly MSDN pie-chart example 5

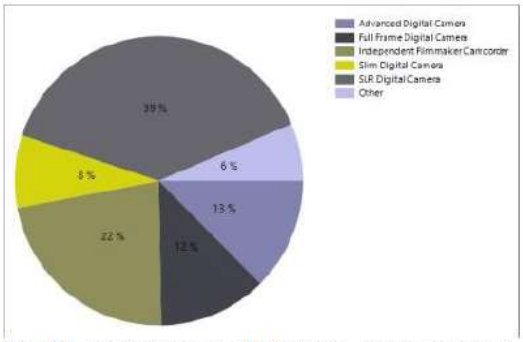

Fig. 13, Deuteranomaly MSDN pie-chart example 6

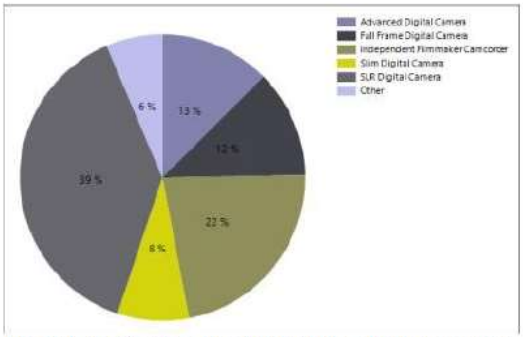

Fig. 14, Deuteranomaly MSDN pie-chart example 7

Comparing fig 1 with fig 8, fig 2 with fig 9, fig 3 with fig 10 and so on to fig 7 with fig 14 demonstrates the problem that those suffering from Deuteranopia suffer. Even though the segments of each pie-chart are visible they are not clearly visible rendering it potentially difficult to comprehend the MSDN tutorial. Our findings were mirrored with the other types of colourblindness that we investigated: Protanopia, Tritanopia and Monochromacy. Even though we do not show the images, the same problems are exhibited in all of the four types of colour-vision deficiencies, in particular (and as expected) those with total colour deficiency (Monochromacy).

4 The Hertfordshire Colourblind Emulator enhanced

Similarly to HCBE the enhanced version is an image processing software tool that, as input, takes in an image in the same number of formats as HCBE and one of the same number of types of colourblindness can be selected for processing.

However, this time the inputted image is first processed to identify the Region Of Concern (ROC). Where we define the ROC to be the areas within an image that will cause those suffering from colour deficiencies would have difficulties in interpreting the information as intended. In these examples the circle within the pie-chart. Once the ROC is identified, HCBEenhanced then processes the image within the ROC and a halo is placed around each segment within the pie-chart. We call this method the halo-effect. We also identify any region where a legend may be provided so that HCBEenhanced also renders the legend in a manner by which the colour-vision deficient can interpret the information as intended.

The halos clearly define the boundaries between the segments of the pie-chart which should render the pie-chart in such a way that those suffering from colour deficiencies can interpret the information as was originally intended. This is shown to the user by an output image post processing.

4.1 HCBEehanced and the Microsoft® Pie-Chart Tutorial

For consistency of comparison figs 15 to 21 show the addition of halo-effect around the segments of the MSDN pie-chart tutorial. As before we show the results of the colour-vision deficient who suffer from Deuteranopia, even though we investigated all types of colourblindness.

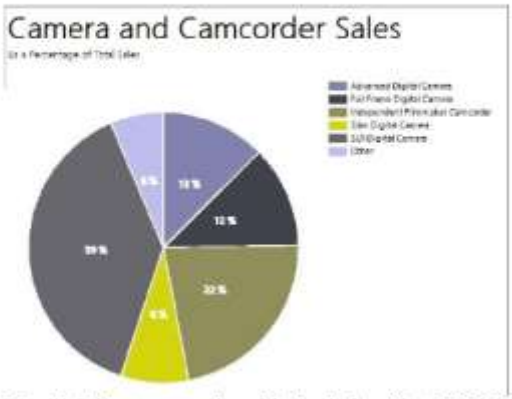

Fig. 15, Deuteranomaly with the halo-effect MSDN pie-chart example 1

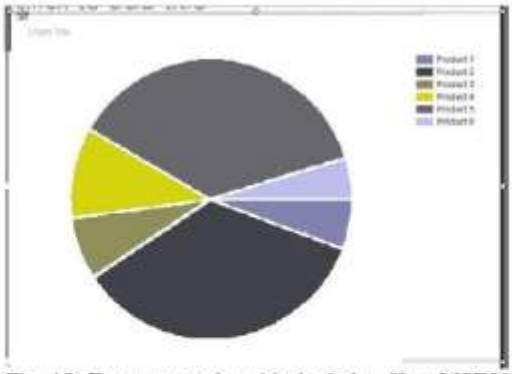

Fig. 16, Deuteranomaly with the halo-effect MSDN pie-chart example 2

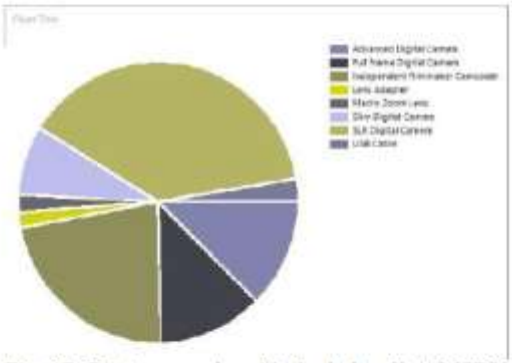

Fig. 17, Deuteranomaly with the halo-effect MSDN pie-chart example 3

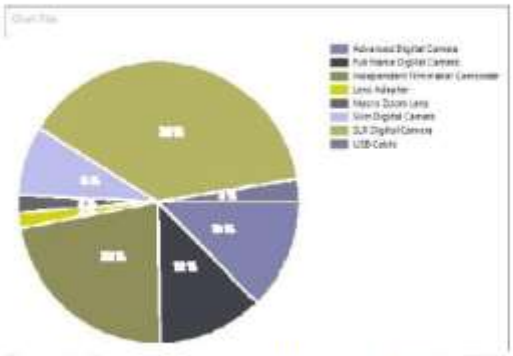

Fig. 18, Deuteranomaly with the halo-effect MSDN pie-chart example 4

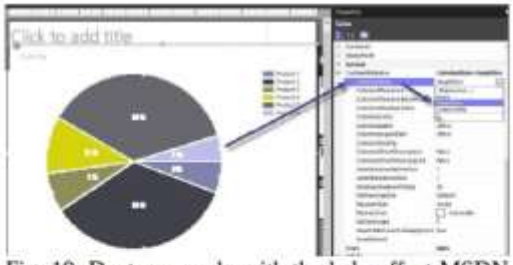

Fig. 19, Deuteranomaly with the halo-effect MSDN pie-chart example 5

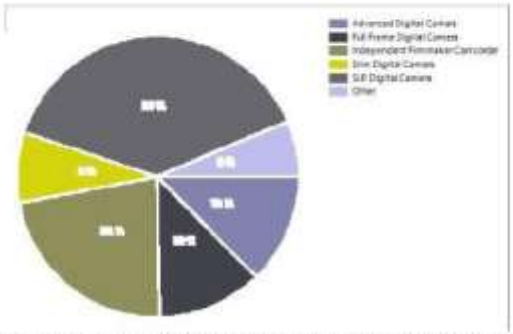

Fig. 20, Deuteranomaly with the halo-effect MSDN pie-chart example 6

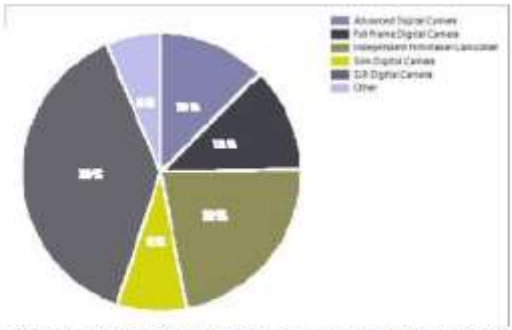

Fig. 21, Deuteranomaly with the halo-effect MSDN

pie-chart example 7

By doing a similar comparisons as before, comparing fig 1 with fig 8 and fig 15, fig 2 with fig 9 and fig 16, fig 3 with fig 10 and fig 17and so on to fig 7 with fig 14 and 21 demonstrates the problem that those suffering from Deuteranopia suffer. However, with the halo-effect we now show that the colour-vision deficient can interpret the original information as intended.

As before, our findings were mirrored with the other types of colourblindness that we investigated: Protanopia, Tritanopia and Monochromacy.

Note that the percentage values shown in some segments of the images are altered to white. This is because we have also surrounded these percentage values with the halo-effect. This means that any problems the colour-vision deficient would have reading the percentage values in the original image are now made visible to the user. Unfortunately, due to size of the images in this paper the percentage values are not clearly shown. However, in the actual output images the percentage values can clearly be identified by the user.

5 Conclusion

In this study we sought to demonstrate how information, as intended, is not always informative in particular for those who suffer from colour-vision deficiency. To highlight this hypothesis we chose to use pie-charts as they are a commonly used visual mechanism to show descriptive or qualitative information. We also chose the MSDN pie-chart tutorial as a publicly available means to show how to provide information in a meaningful and visual manner. However, we also showed that this may not always be as easy at it may seem in particular to those who suffer from colour-vision deficiencies.

We have also shown that by altering the original image then the information as intended can be provided to those suffering colour-vision deficiencies. In this paper, we only show a subset of our results for those suffering from Deuteranopia. Our full set of results mirror what we have shown for Deuteranopia with the three other major types of colourblindness: Protanopia, Tritanopia and Monochromacy.

Our conclusion, therefore, is that by making minor changes to the way information is presented then informative information can be obtained as intended to include those who suffer from the colour-vision deficiencies.

We have introduced the HCBEenhanced as an image processing software tool to achieve this. We consider that it would be better for tutorials such as the MSDN tutorial to consider those who suffer from colour-vision deficiencies, which would mean image processing software tools such as HCBEenhanced would be rendered redundant. Research into this area is also important not only to highlight such problems, but to encourage pie-chart creators to be aware of all different types of users who may view their visual representations. However, until this happens image processing software tools such as HCBEenhanced will be required.

HCBEenhanced is in its infancy in the way to provide potential solutions to the problems of showing how information should be conveyed in pie-charts. Currently, the user would have to have a copy of HCBEenhanced on one of their (non-mobile) desk-top computer systems. The user would then have to obtain an e-copy of the pie-chart in question and input it into HCBEenhanced before viewing the output image. We are already developing a version of HCBEenhanced for use on mobile computer systems such as smart-phones and tablet PCs.

Our research is on-going and we have recently undertaken a survey on colour-vision problems that both the colour-vision deficient suffer and the non-colour-vision deficient suffer. It is too early to release the finding of this study but it will enable us to develop software to enhance the opportunity to interpret information provided in other colour information formats such as the popular ‘traffic light system’ [10]. We propose to continue our work with international collaboration with Saudi Arabia and with individual subjects in the UK.

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APPENDIX G: A FULL SPSS RESULTS FOR THE TWO STUDIES ON (CHAPTER 5)

Study 1: (Hypothesis 1)

Groups * Problematic and Non Problematic Crosstabulation

Count

		Non Problematic	Problematic	Total
	N-CVD	531	0	531
	CVD	28	14	42
Total		559	14	573

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	181.433[a]	1	.000		
Continuity Correction[b]	204.614	1	.000		
Likelihood Ratio	242.589	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	573				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 40.13.

b. Computed only for a 2x2 table

Study 1: (Hypothesis 2)

Groups * Problematic and Non Problematic Crosstabulation

Count

		CVD		
		Non Problematic	Problematic	Total
Groups	Halo	39	3	42
	Original	28	14	42
Total		67	17	83

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.924[a]	1	.003		
Continuity Correction[b]	25.751	1	.000		
Likelihood Ratio	27.151	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	438				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 79.00.

b. Computed only for a 2x2 table

Study 2: (Hypothesis 1)

Groups * Problematic and Non Problematic Crosstabulation

Count

		Non Problematic	Problematic	Total
	N-CVD	111	0	111
	CVD	6	3	9
Total		117	3	120

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	37.949[a]	1	.000		
Continuity Correction[b]	25.506	1	.000		
Likelihood Ratio	16.600	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	120				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is .23.

b. Computed only for a 2x2 table

Study 2: (Hypothesis 2)

Groups * Problematic and None Problematic Crosstabulation

Count

		CVD		
		Non Problematic	Problematic	Total
Groups	Halo	9	0	9
	Original	6	3	9
Total		15	3	18

Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.600[a]	1	.058		
Continuity Correction[b]	1.600	1	.206		
Likelihood Ratio	4.763	1	.029		
Fisher's Exact Test				.206	.103
N of Valid Cases	18				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 1.50.

b. Computed only for a 2x2 table

Study 1: (Hypothesis 1)

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
CVD & N-CVD	Non Problematic	559	0.05	.218	.020
	Problematic	14	1.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CVD & N-CVD	Equal variances assumed	0.71	.000	18.025	571	.000	-.756	.042	-.839	-.674
	Equal variances not assumed			0.15017	467.000	.000	-.756	.020	-.795	-.717

Study 1: (Hypothesis 2)

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	67	1.42	.497	.029
	Problematic	17	1.82	.393	.038

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	0.00	.002	5.328	436	.002	-.257	.048	-.352	-.162
	Equal variances not assumed			5.385	336.344	.001	-.257	.048	-.351	-.163

Study 2: (Hypothesis 1)

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
CVD & N-CVD	Non Problematic	117	.05	.222	.020
	Problematic	3	1.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CVD & N-CVD	Equal variances assumed	.713	.400	7.387	118	.000	-.949	.128	-1.203	-.694
	Equal variances not assumed			46.325	116.000	.000	-.949	.020	-.989	-.908

Study 2: (Hypothesis 2)

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	15	1.40	.507	.131
	Problematic	3	2.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	64.000	.000	2.000	16	.063	-.600	.300	-1.236	.036
	Equal variances not assumed			4.583	14.000	.000	-.600	.131	-.881	-.319

APPENDIX H: A FULL SPSS RESULTS FOR THE THREE STUDIES ON (CHAPTER 6)

(Hypothesis 1)

Problematic and Non Problematic Crosstabulation

Count

		Non Problematic	Problematic	Total
	N-CVD	498	0	498
	CVD	60	30	90
Total		558	30	588

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	174.925[a]	1	.000		
Continuity Correction[b]	168.108	1	.000		
Likelihood Ratio	122.402	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	174.627	1	.000		
N of Valid Cases	588				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.59.

b. Computed only for a 2x2 table

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
CVD & N-CVD	Non Problematic	558	.11	.310	.013
	Problematic	30	1.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CVD & N-CVD	Equal variances assumed	18.627	.000	15.753	586	.000	-.892	.057	-1.004	-.781
	Equal variances not assumed			67.993	557.000	.000	-.892	.013	-.918	-.867

(Hypothesis 2)

Groups * Problematic and None Problematic Crosstabulation

Count

		CVD		
		Non Problematic	Problematic	Total
Groups	Halo	88	2	90
	Original	60	30	90
Total		148	32	180

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	29.797[a]	1	.000		
Continuity Correction[b]	27.707	1	.000		
Likelihood Ratio	34.728	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	29.632	1	.000		
N of Valid Cases	180				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 16.00.

b. Computed only for a 2x2 table

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	148	1.41	.493	.040
	Problematic	32	1.94	.246	.043

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	229.922	.000	5.942	178	.000	-.532	.090	-.709	-.355
	Equal variances not assumed			8.956	93.311	.000	-.532	.059	-.650	-.414

Hatch with Original * None Problematic and Problematic Crosstabulation

Count

		None Problematic and Problematic		
		None Problematic	Problematic	Total
Hatch with Original	Hatch	77	13	90
	Original	60	30	90
Total		137	43	180

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.830[a]	1	.003		
Continuity Correction[b]	7.822	1	.005		
Likelihood Ratio	9.023	1	.003		
Fisher's Exact Test				.005	.002
Linear-by-Linear Association	8.781	1	.003		
N of Valid Cases	180				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 21.50.

b. Computed only for a 2x2 table

Group Statistics

	None Problematic and Problematic	N	Mean	Std. Deviation	Std. Error Mean
Hatch with Original	None Problematic	137	1.44	.498	.043
	Problematic	43	1.70	.465	.071

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Hatch with Original	Equal variances assumed	14.929	.000	3.030	178	.003	-.260	.086	-.429	-.091
	Equal variances not assumed			3.142	74.731	.002	-.260	.083	-.424	-.095

Re-color with Original * None Problematic and Problematic Crosstabulation

Count

		None Problematic and Problematic		
		None Problematic	Problematic	Total
Re-color with Original	Re-color	80	10	90
	Original	60	30	90
Total		140	40	180

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.857[a]	1	.000		
Continuity Correction[b]	11.604	1	.001		
Likelihood Ratio	13.332	1	.000		
Fisher's Exact Test				.001	.000
Linear-by-Linear Association	12.786	1	.000		
N of Valid Cases	180				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 20.00.

b. Computed only for a 2x2 table

Group Statistics

	None Problematic and Problematic	N	Mean	Std. Deviation	Std. Error Mean
Re-color with Original	None Problematic	140	1.43	.497	.042
	Problematic	40	1.75	.439	.069

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Re-color with Original	Equal variances assumed	28.344	.000	3.700	178	.000	-.321	.087	-.493	-.150
	Equal variances not assumed			3.966	70.178	.000	-.321	.081	-.483	-.160

(Hypothesis 3)

Groups * Problematic and None Problematic Crosstabulation

Count

		CVD		
		Non Problematic	Problematic	Total
Groups	Halo	88	2	90
	Hatching	77	13	90
Total		165	15	180

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.800[a]	1	.003		
Continuity Correction[b]	7.273	1	.007		
Likelihood Ratio	9.748	1	.002		
Fisher's Exact Test				.005	.003
Linear-by-Linear Association	8.751	1	.003		
N of Valid Cases	180				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.50.

b. Computed only for a 2x2 table

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	165	1.47	.500	.039
	Problematic	15	1.87	.352	.091

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	156.140	.000	3.025	178	.003	-.400	.132	-.661	-.139
	Equal variances not assumed			4.046	19.565	.001	-.400	.099	-.606	-.194

Groups * Problematic and None Problematic Crosstabulation

Count

		CVD		
		Non Problematic	Problematic	Total
Groups	Halo	88	2	90
	Re-colouring	80	10	90
Total		168	12	180

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.714[a]	1	.017		
Continuity Correction[b]	4.375	1	.036		
Likelihood Ratio	6.203	1	.013		
Fisher's Exact Test				.032	.016
Linear-by-Linear Association	5.683	1	.017		
N of Valid Cases	180				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.00.

b. Computed only for a 2x2 table

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	168	1.48	.501	.039
	Problematic	12	1.83	.389	.112

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	116.597	.000	2.416	178	.017	-.357	.148	-.649	-.065
	Equal variances not assumed			3.006	13.744	.010	-.357	.119	-.612	-.102

(Hypothesis 1)

CVD & N-CVD * Problematic and Non Problematic Crosstabulation

Count

		Problematic and Non Problematic		
		Non Problematic	Problematic	Total
CVD & N-CVD	N-CVD	642	0	642
	CVD	48	24	72
Total		690	24	714

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	221.443[a]	1	.000		
Continuity Correction[b]	211.301	1	.000		
Likelihood Ratio	118.382	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	714				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 2.42.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and Non Problematic	N	Mean	Std. Deviation	Std. Error Mean
CVD & N-CVD	Non Problematic	690	.07	.255	.01
	Problematic	24	1.00	.000	.00

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CVD & N-CVD	Equal variances assumed	8.361	.004	17.891	712	.000	-.930	.052	-1.033	-.828
	Equal variances not assumed			95.997	689.000	.000	-.930	.010	-.949	-.911

(Hypothesis 2)

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Halo	70	2	72
	Original	48	24	72
Total		118	26	144

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	22.717[a]	1	.000		
Continuity Correction[b]	20.699	1	.000		
Likelihood Ratio	26.068	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	144				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 13.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	118	1.41	.493	.045
	Problematic	26	1.92	.272	.053

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	151.838	.000	5.157	142	.000	-.516	.100	-.714	-.318
	Equal variances not assumed			7.374	66.948	.000	-.516	.070	-.656	-.377

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Hatching	56	16	72
	Original	48	24	72
Total		104	40	144

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.215[a]	1	.137		
Continuity Correction[b]	1.696	1	.193		
Likelihood Ratio	2.227	1	.136		
Fisher's Exact Test				.192	.096
N of Valid Cases	144				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 20.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	104	1.46	.501	.049
	Problematic	40	1.60	.496	.078

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	2.219	.139	1.490	142	.139	-.138	.093	-.322	.045
	Equal variances not assumed			1.496	71.421	.139	-.138	.093	-.323	.046

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Re-coloring	64	8	72
	Original	48	24	72
Total		112	32	144

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	10.286[a]	1	.001		
Continuity Correction[b]	9.040	1	.003		
Likelihood Ratio	10.666	1	.001		
Fisher's Exact Test				.002	.001
N of Valid Cases	144				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 16.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	112	1.43	.497	.047
	Problematic	32	1.75	.440	.078

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	22.611	.000	3.305	142	.001	-.321	.097	-.514	-.129
	Equal variances not assumed			3.538	55.672	.001	-.321	.091	-.503	-.139

(Hypothesis 3)

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Halo	70	2	72
	Hatching	56	16	72
Total		126	18	144

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.444[a]	1	.000		
Continuity Correction[b]	10.730	1	.001		
Likelihood Ratio	13.954	1	.000		
Fisher's Exact Test				.001	.000
N of Valid Cases	144				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	126	1.44	.499	.044
	Problematic	18	1.89	.323	.076

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	134.526	.000	3.665	142	.000	-.444	.121	-.684	-.205
	Equal variances not assumed			5.037	30.053	.000	-.444	.088	-.625	-.264

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Halo	70	2	72
	Re-colouring	64	8	72
Total		134	10	144

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.869[a]	1	.049		
Continuity Correction[b]	2.687	1	.101		
Likelihood Ratio	4.124	1	.042		
Fisher's Exact Test				.097	.049
N of Valid Cases	144				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	134	1.48	.501	.043
	Problematic	10	1.80	.422	.133

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	65.841	.000	1.980	142	.050	-.322	.163	-.644	-.001
	Equal variances not assumed			2.300	10.991	.042	-.322	.140	-.631	-.014

(Hypothesis 1)

CVD & N-CVD * Problematic and Non Problematic Crosstabulation

Count

		Problematic and Non Problematic		
		Non Problematic	Problematic	Total
CVD & N-CVD	Non-CVD	597	0	597
	CVD	28	14	42
Total		625	14	639

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	203.458[a]	1	.000		
Continuity Correction[b]	188.200	1	.000		
Likelihood Ratio	81.208	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	639				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is .92.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and Non Problematic	N	Mean	Std. Deviation	Std. Error Mean
CVD & N-CVD	Non Problematic	625	.04	.207	.008
	Problematic	14	1.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CVD & N-CVD	Equal variances assumed	2.882	.090	17.250	637	.000	-.955	.055	-1.064	-.846
	Equal variances not assumed			115.345	624.000	.000	-.955	.008	-.971	-.939

(Hypothesis 2)

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Halo	42	0	42
	Original	28	14	42
Total		70	14	84

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	16.800[a]	1	.000		
Continuity Correction[b]	14.486	1	.000		
Likelihood Ratio	22.227	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	84				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	70	1.40	.493	.059
	Problematic	14	2.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	328.000	.000	4.528	82	.000	-.600	.133	-.864	-.336
	Equal variances not assumed			10.173	69.000	.000	-.600	.059	-.718	-.482

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Hatching	32	10	42
	Original	28	14	42
Total		60	24	84

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.933[a]	1	.334		
Continuity Correction[b]	.525	1	.469		
Likelihood Ratio	.937	1	.333		
Fisher's Exact Test				.469	.235
N of Valid Cases	84				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 12.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	60	1.47	.503	.065
	Problematic	24	1.58	.504	.103

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	.838	.363	.960	82	.340	-.117	.122	-.358	.125
	Equal variances not assumed			.959	42.394	.343	-.117	.122	-.362	.129

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Re-colouring	38	4	42
	Original	28	14	42
Total		66	18	84

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.071[a]	1	.008		
Continuity Correction[b]	5.727	1	.017		
Likelihood Ratio	7.405	1	.007		
Fisher's Exact Test				.015	.008
N of Valid Cases	84				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	66	1.42	.498	.061
	Problematic	18	1.78	.428	.101

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	17.787	.000	2.745	82	.007	-.354	.129	-.610	-.097
	Equal variances not assumed			2.996	30.789	.005	-.354	.118	-.594	-.113

(Hypothesis 3)

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Halo	42	0	42
	Hatching	32	10	42
Total		74	10	84

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.351[a]	1	.001		
Continuity Correction[b]	9.195	1	.002		
Likelihood Ratio	15.218	1	.000		
Fisher's Exact Test				.001	.001
N of Valid Cases	84				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	74	1.43	.499	.058
	Problematic	10	2.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	524.800	.000	3.579	82	.001	-.568	.159	-.883	-.252
	Equal variances not assumed			9.788	73.000	.000	-.568	.058	-.683	-.452

Groups * Problematic and None Problematic Crosstabulation

Count

		Problematic and None Problematic		
		Non Problematic	Problematic	Total
Groups	Halo	42	0	42
	Re-colouring	38	4	42
Total		80	4	84

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.200[a]	1	.040		
Continuity Correction[b]	2.363	1	.124		
Likelihood Ratio	5.745	1	.017		
Fisher's Exact Test				.116	.058
N of Valid Cases	84				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.00.

b. Computed only for a 2x2 table

Group Statistics

	Problematic and None Problematic	N	Mean	Std. Deviation	Std. Error Mean
Groups	Non Problematic	80	1.48	.503	.056
	Problematic	4	2.00	.000	.000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Groups	Equal variances assumed	1558.000	.000	2.077	82	.041	-.525	.253	-1.028	-.022
	Equal variances not assumed			9.344	79.000	.000	-.525	.056	-.637	-.413