MASTER THESIS

in

Universal Design of ICT

May 2015

Colour Contrast Based On WCAG 2.0

Anqi Zhao

Department of Computer Science

Faculty of Technology, Art and Design

OSLO AND AKERSHUS
UNIVERSITY COLLEGE
OF APPLIED SCIENCES

Acknowledgement

First and foremost I would like to express my sincerest gratitude and thanks to my advisor Professor Frode Eika Sandnes, he has been a tremendous mentor for me. His extraordinary talent in all aspects in Universal Design motivates and encourages my research in many ways. His advices on both research as well as on my life have been priceless. I feel so lucky to have him to be my supervisor and I often owe appreciation for his guidance. I would also like to thank my friend Anthony Giannoumis, who gives me priceless help. Also I need to thank my friends, Aillie, Bong Way Kiat Xiangyang and Yang, Yang Yang for their help during my research. Last but not least, I would like to thank all the respondents in the study for their precious feedback and comments.

Abstract

Insufficient contrast between text and the background is a common problem on the web meanwhile very few researchers study the insights of the designers' design thinking process, how they choose the specific colours from all the colours. WCAG 2.0 addresses the contrast problem, but the requirement is hard to understand for most designers. Therefore, some web designers check their designs with contrast checking tools after the design is finished. If the design does not meet the WCAG 2.0 guidelines the designer will have to go back and make adjustments and check contrast again. The gap between the requirements for designers and the sufficient tool assist them need to be filled. To overcome this problem, a cross culture interview was conducted to identify the factors the designer consider and their actual behavior during the design process. Moreover a colour picker tool is developed that allows designers to select WCAG 2.0 compliant colours during the design process thus eliminating the need for post-design colour adjustments. This dissertation aims to help software developer gain a deeper understanding about designers' selections and make it easier to achieve readability on the web.

Keywords: colour contrast; cross-cultural; universal design, WCAG 2.0; web design

Table of Contents

List of Figures and Tables

Introduction

The World Wide Web has profoundly impacted human society during the last 15 years (Agarwal, Veer Arya, & Shashi, 2010). The web becomes an increasingly important resource in many aspects of life such as in business, communication, entertainment, education, health care, etc (Rello, Kanvinde, & Baeza-Yates, 2012). Colour has long played an essential role in web design (Weinman, 2002), colour provides a powerful tool for the web designer, but it may also be counterproductive when not used properly (Widdel & Post, 1992).

Moreover, the web contains numerous text and colour component as its content. Colour can play a critical role in ensuring that attention is paid to important information (Weinman, 2002) in websites. However, the expertise for choosing colours has not kept pace with the opportunities for presenting them (Jefferson & Harvey, 2006), many designers are keen to use different colours, but often the results are not accessible and the risk of inappropriate colours is high due to the some designers lack of colour theory knowledge from education organizations or workplace.

In order to make the text readable, the colour contrast between the text colour and its background colour has to be sufficiently high for viewers access the textual information (Knoblauch, Arditi, & Szlyk, 1991).

Web Content Accessibility Guidelines (WCAG) developed by World Wide Web Consortium (W3C) provides a technical standard for web content accessibility. WCAG 2.0 consists of technology-neutral principles, guidelines, and success criteria that reflect properties of Web content, these guidelines and success criteria can be satisfied in a variety of ways in different Web formats and technologies (Reid & Snow-Weaver, 2008). As the Web evolves, the guidelines can assist technology developers and authors in ensuring that Web content becomes more usable to users in general.

For each guideline, there are success criteria to be tested, which consist of three levels: A (lowest), AA, and AAA (highest) (W3C, 2008). In terms of colour contrast, WCAG 2.0 for level aa (criterion 1.4.3) states that the contrast should have a luminance contrast ratio of at least 4.5:1 for body text and 3:1 for large text. The level aaa criterion recommends a contrast ratio between body text and its background of 7:1 and a contrast ratio for large text of 5:1. But the question is, is this enough to ensure that all website are accessible?

Previous researches use varies methods to evaluate the accessibility of websites in various fields such as education (May & Zhu, 2010), government (Lujan-Mora, Navarrete, & Penafiel, 2014) and commerce, etc. Hanson and Richards Hanson and Richards (2013) examined changes on accessibility indicators over a 14-year period, but they forget to check colour contrast success criteria in WCAG 2.0; Gambino, Pirrone, and Giorgio (2014) through analysis of the Italian public administration website found poor contrast between text and background colour as one of the most frequent accessibility problem. A formal investigation conducted by the Disability Rights Commission (DRC) (Disability Rights Commission, 2004) evaluated 1000 web sites for compliance with the WCAG1.0 (W3C, 1999) check- points. Notable in the results is that “Inappropriate use of colours and poor contrast between content and background” accounts for 59 of the 585 usability problems – that is approximately 10%. In addition, the interview results in this dissertation reveal that at least in China, most website or graphic designers lack of knowledge about the importance of colour contrast.

Even though web designers appreciate the importance of colour and are given standards to follow they may be unable to comply with all the ‘colour rules’ during implementation since they may have insufficient understanding about WCAG 2.0 colour contrast and unsuitable tools assist them. Inappropriate colour selection may lead to insufficient colour contrast and hence bad user experiences for all users and also barriers and inaccessibility for visually impaired users.

However, few studies have investigated designers’ understanding and attitude towards colour contrast and how they use it in the actual website design process. Haddad wrote in “Research and Methodology for Interior Designers” that “Every design is a hypothesis and a practical experiment. Many designers may find it difficult to verbalize design because much of the design process is intuitive and non-conscious, relying on metaphors and implied knowledge rather than explicit and logical thinking” (Haddad, 2014). This represents an important and overlooked topic: even though there is a standard given to designers to follow, do designers can easily implement WCAG 2.0 into their designs? WCAG 2.0 is freely accessible online, but the ratio defined in the guideline can be too technical for designers. Therefore, this dissertation intends to materialize the designers’ thinking process through interviews, to explore to the extent they understand WCAG 2.0 colour contrast and what methods or tools they use to meet the guidelines.

The findings of Rømen and Svanæs (2012) concluded that the applications of WCAG alone is not sufficient to guarantee website accessibility. One possible reason is that it is difficult to cover all the success criteria in one tool,

Further, culture can influence people’s opinion towards colour. Nowadays the World Wide Web is very globalized, designers must consider they are not just design for local audiences but for global audiences, thus culture understanding is therefore important. Very few research studies invesitegated the insight towards colour in websites between Norwegian and Chinese designers. In addition, Norway has introduced a law that effectively requires all websites aimed at the general population to follow WCAG 2.0 while this is not the case in China. This difference can cause the implementation of the WCAG 2.0 distinguished in these two countries, thus these topics above will also be discussed through in-depth interview across these two countries.

This dissertation also presents an overview on of colour contrast by focusing on WCAG 2.0, understanding colour contrast and relevantmathematical definition, experimental research and tools to help non-expert users, expecially website and grapghic designers, to perform better colour selection ensuring colour contrast. Finally, a colour picker tool that provides valid colours with given colour contrast is presented and the author make a purposal for W3C to simplfy the inconprehensible colour contrast passages in WCAG 2.0.

Therefore, this research presents the following two main contributions and the dissertation is thus divided into two parts:

The first part addresses the importance of colour contrast matters and designers understanding of colour contrast. Part I mainly contains a survey of related work and a description of the interviews conducted. By exploring the Norwegian and Chinese designers' thinking process through interviews, the extent to which they understand WCAG 2.0 and details about what methods or tools they use to satisfy the guidelines were acquired. WCAG 2.0 provides specific contrast ratio and contrast checking tools for designers, they help the designers at some level, but it has not fundamentally solved the problem. The contrast analyzer tool tells the designers if the contrast pass or fail the recommendation after the colour selection was conducted, therefore the designers need to compulsory adjust the colours according to the contrast results instead of spontaneous by their decision.

The second part of the dissertation proposes a concrete colour picking prototype that only allow WCAG 2.0 compliant colour combinations to be selected. It assists designers selecting colour combinations that exhibit sufficient contrasts has been presented. Then, usability tests with design students were conducted to assess this tool's efficiency and actual utility. The testing results reveal that this tool significantly help the participant choose colours with sufficient colour contrast.

Part I

Chapter 1

1. Background

1.1 The importance of colour contrast

United Nation define access to information and communication technologies a basic human right (Assembly, 2006). Most information on the web is text content and colour contrast is a vital factor that can influence or even decide the quality of the website content (Jang, Kim, & Yi, 2007). Further, several researches (Heechul & Hyunsuk, 2012; Naiman, 1985) emphasize the fundamentality of colour contrasts in website/interface design. Some researchers conclude that colour trast at least as much impotant as the single colours while some other studies find out the impact and evaluation of a colour combination seems to depend more on the contrasts than on the individual colours (Fridell Anter, 2008). Another study pointed out that low colour contrast is the major reason that casues degradation in readability in websites (Jang et al., 2007).

Moreover, most perceived information on webpages and interfaces are textual content, therefore it is necessary to ensure that end user can access the headings and text information with enough colour contrast.

Text often contributes most information on websites and interfaces, thus if the text content is not readable, the readers will miss important messages the authors attempt to deliver. Colour contrast is a vital factor that can influence or even determine the readability of the content. Further, even people with normal vision cannot perceive all information if the colour contrast is too low, hence people with reduced vision will have bigger accessibility problem when the colour contrast is insufficient. World Health Organization estimated that there are around 285 million people with visual impairment worldwide: 39 million are blind and 246 million have low vision (WHO, 2013).

Lin (2003) experiments suggest that heigher contrast ratios can lead to better visual indentification performance compared to lower contrast ratios. In addtion, for the specific type of screen—TFT-LCD screen, contrast ratio is more important than text colour. If a sufficient contrast ratio was present, text colour did not significantly affect visual performance.

Moreover, the image quality is a crucial factor to evaluate whether a website is user friendly. Choudhury and Medioni (2009) suggested an enhancement technique to compare an image enhancement algorithm is to measure the change in image quality in terms of brightness and contrast. Thus, it suggests colour contrast can directly influence the quality of website content as well.

Contrast has many possible definitions, colors can contrast in hue, value and saturation. Contrast also has different mathematical expressions defined by colour theorists. Such as Michelson contrast (Michelson, 1995), Weber contrast and RMS contrast (Peli, 1990). Thus, for people have no colour knowledge background it is difficult to determine how to use the expressions (Lau & Manager, 1999; Michelson, 1995). Michelson Formula 1 and Weber definition Formula 2:

$$C = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}} \quad (1)$$

In Formula 1, Lmax represents the highest luminance, Lmin stands for lowest luminance.

$$C = \frac{L - L_b}{L_b} \quad (2)$$

In Formula 2, L and L_b represent the luminance of the text and its background respectively. Weber fraction define that local contrast of a single target depends on the surrounding luminance which means that the contrast is inversely proportional to light surround it (Madi & Ziou, 2014). Contrast have been commonly represent the contrast as a ratio of luminance change to mean background luminance (Peli, 1990).

Moreover, if the website and interface designers cannot understand the purpose and calculation of colour contrast, they may create inappropriate colour contrast which result in content unreadable for people with low vision. When the website or graphic designers learn colour theoryduring their design education, they might have few chances to learn about colour contrast.

Further, even they attempt to enhance colour contrast, since they lack of comprehension success criteria and short of useful tools to assist them to address this issue.

1.2 Colour perception

Before discussing Web design and colour contrast, it is important to understand the fundamentals about how the eyes see colours. Colour vision is formed when light passes through lens and falls on the retina. The retina is covered by light-sensitive receptors with different spectral sensitivity (Nathans, Thomas, & Hogness, 1986). Individuals with normal colour vision (NCV) have three types of specialized cells in their retina to help them to perceive colours, which are maximally responsive to three different wavelengths represent the colours red, blue, and green. This is the condition called trichromacy for conveying colour information.

1.2.1 Colour deficiency

However, people with unregular cones will perceive colours differently (Chan, Goh, & Tan, 2014). People with colour vision deficiency (CVD, also called colour blindness) lack of or decreased ability to recognize a certain colour or to perceive colour difference properly under normal lighting conditions (Wong, 2011). Congenital, physical or chemical damage to the eye can cause CVD (Flatla, 2011). Dichromacy is the condition with only two types of cone receptors that means this organism lack of ability to see a specific section of the light spectrum. Monochromatism or achromatism, which allows no color perception at all, which is rare, it means this person will see no colour at all and their world consists of different shades of grey ranging from black to white.

The various types of CVD and their associated incidence rates vary across populations and are shown in Table 1.1 (Hunt & Pointer, 2011) and Figure 1.1.

Table 1.1 CVD types and incidence rates for western races (Hunt & Pointer, 2011)

Medical term	Type	Incidence
Monochromacy	-	0.003%
Dichromacy	Protanopia	1%
	Deuteranopia	1.1%
	Tritanopia	0.002%
Anomalous trichromacy	Protanomaly	1%
	Deuteranomaly	4.9%
	Tritanomaly	-
Total	-	8.005%

Both anomalous trichromacy and dichromacy do not affect other abilities of the vision than color perception, such as visual acuity (visual acuity is the measurement of one's ability to resolve detail) and night vision are unaffected. Thus people with CVD have can easily cope with most everyday situations (Schmitt, Stein, Hampe, & Paulus, 2012).

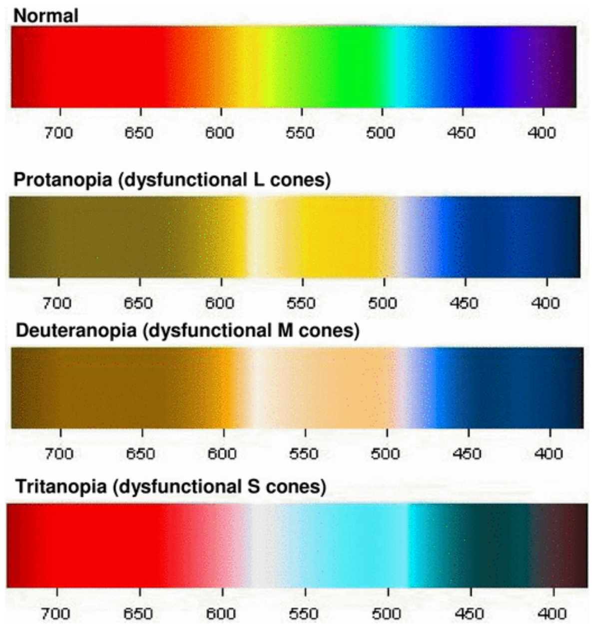


Figure 1.1 Color perception in comparison as spectrum diagram (Wolfmaier, 1999)

Further, colour vision may degrade with age. According to previous research (Nguyen-Tri, Overbury, & Faubert, 2003; Pinckers, 1980), especially in midlife, the risk of acquiring colour vision defects increases due to ocular and systemic changes that may occur.

However, little effort has been put into improving the visual condition for both people with normal vision and people with colour deficiency (Choudhury & Medioni, 2010). By choosing the some certain shades of colour colours, the webpage may appear virtually unreadable to them. For example, people with Red-green colour vision defects decreased the ability to distinguish reds and greens. Since many people have reduced vision, it becomes an urgent and necessary task to ensure that the design of websites and interfaces are accessible.

1.3 WCAG 2.0 colour contrast ratio

Telling designers that colours should be have sufficient colour contrast is not enough; some design principles are needed to guide the design. Web Content Accessibility Guidelines (WCAG) 2.0 has been widely accepted and adopted both as a design guideline (Al-Khalifa & Al-Khalifa, 2011) and as a heuristic in website evaluations. In addition, the number of national evaluations of public websites has included criteria on accessibility from WCAG (Nietzio, Eibegger, Goodwin, & Snaprud, 2012; Rømen & Svanæs, 2008a). Moreover, WCAG 2.0 has been set as the standard in this dissertation.

There are a total of 12 guidelines in WCAG 2.0 and each guideline defines 3 levels of Success Criteria —A, AA and AAA. The three levels are a type of implementation order for authors. Level A is often required and Level AA provisions must also be met in order to achieve Level AAA conformance and all success criteria must be testable. However, unlike WCAG1.0 the requirements groups were called priorities which are critical for some types of disabilities, in WCAG 2.0 they do not imply priority with regard to the needs of users with disabilities (Reid & Snow-Weaver, 2008).

There are two colour contrast Success Criteria 1.4.3 Contrast (Minimum) and 1.4.6 Contrast (Enhanced) in WCAG 2.0 under “Guideline 1.4 Distinguishable: Make it easier for users to see and hear content including separating foreground from background”. 1.4.3 contrast (minimum)/1.4.6 contrast (minimum) require the visual presentation of text and images of text has a contrast ratio of at least 4.5:1/7:1, except Large Text have a contrast ratio of at least 3:1/4.5:1 , incidental and logotypes have no specific contrast requirements. Large text here refers to text with at least 18 point, 14 point bold or font size that would yield equivalent size for Chinese, Japanese and Korean (CJK) fonts(W3C, 2008). Incidental here are text or images of text that are pure decoration, that are not visible to anyone, or that are part of a picture that contains significant other visual content. Logotypes in here are text that is part of a logo or brand (W3C, 2008). The actual size of the character that a user sees changes when author-defined size, the user's display or user-agent settings changed. For many mainstream body text fonts, 14 and 18 point is roughly equivalent to 1.2 and 1.5 em or to 120% or 150% of the default size for body text (W3C, 2008).

The reason W3C chose ratio 4.5:1 is in humans, the average visual acuity of a healthy, emmetropic eye is about 20/16 to 20/12. For people loss vision to approximately 20/40 vision, the contrast ratio of 4.5:1 can compensated their loss contrast sensitivity (Caldwell, Chisholm, Slatin, & Vanderheiden, 2007) and people nearly 80 commonly have possibility have 20/40 vision (Gittings & Fozard, 1986). The contrast ratio of 7:1 was chosen for level AAA was similar with success criteria 1.4.6, that is, for people loss vision to 20/80, this contrast ratio can compensate for the loss. When someone has lower vision than 20/80, they usually need assistive technologies to help them get the information from the content (Caldwell et al., 2007).

Higher colour contrast can indeed increase the readability of the content, however this cannot mean the designers should often choose Success Criteria 1.4.6 since Success Criteria 1.4.6 has request higher contrast than 1.4.3. On the other hand, selecting 7:1 as the contrast ratio imply fewer valid colour combinations. According to Noiwan and Norcio (2006), higher colour contrast not only caused higher degree of readability, but also tend to increase the degree of distraction. Hence, the colour contrast selection should attempt to avoid the distraction as much as possible while keeping the content readable.

Colours that are similar in value, but different in hue are easy to distinguish for people with normal vision, but a person who suffers from severe colour deficiencies lacks the ability to tell them apart. Enough colour contrast can provide information perceived at highest degree by people with moderately low vision (W3C, 2008). Seeing the website in greyscale is a quick way to tell if there is enough contrast.

Jang et al. (2007) explained the Luminosity Contrast Ratio(LCR) definition:

$$LCR = \frac{L_1 + 0.05}{L_2 + 0.05} \qquad (3)$$

$$L = 0.2126 \times R + 0.7152 \times G + 0.0722 \times B \qquad \text{(4) (Rømen \& Svanæs, 2008b)}$$

L1 and L2 denote the higher LCR and the lower LCR respectively. In WCAG 2.0, R, G and B are defined as:

- if Rs_{RGB} <= 0.03928 then R = Rs_{RGB}/12.92 else R = ((Rs_{RGB}+0.055)/1.055) ^ 2.4
- if Gs_{RGB} <= 0.03928 then G = Gs_{RGB}/12.92 else G = ((Gs_{RGB}+0.055)/1.055) ^ 2.4
- if Bs_{RGB} <= 0.03928 then B = Bs_{RGB}/12.92 else B = ((Bs_{RGB}+0.055)/1.055) ^ 2.4

Jang also commented that this guideline is easy to read and presents a quantitative standard rather than mathematic terms. Sandnes (2015a) simplified the two formulations into one, as following:

$$L = \frac{3.27r_1^2 + 11g_1^2 + 1.11b_1^2 + 50,000}{3.27r_2^2 + 11g_2^2 + 1.11b_2^2 + 50,000} \qquad (5)$$

where r_1, g_1, b_1 is the relatively brighter colour, and r_2, g_2, b_2 is the relatively darker colour. It is inconvenient to calculate one of the other valid colours when knowing r_1, g_1, b_1 or r_2, g_2, b_2 and the required colour ratio. Since WCAG 2.0 is technology neutral (Rømen & Svanæs, 2008b)and there many possible technologies available, it does not provide the specific technology to create accessible content. That is, both the 1.4.3 and the 1.4.6 criteria cannot be achieved directly and easily. For example, there is an advise in Advisory Techniques for 1.4.3 – Contrast part, “Using a higher contrast values for lines in diagrams”. ‘Higher contrast’ is too general and abstract for website designers, especially which only have little background in colour theory. Moreover, there are also a lot sufficient technique recommendations that might be difficult for designers who only have graphic art backgrounds. In order to meet all the guidelines, the designers need to go through and check all the requirements WCAG 2.0 has provided, which is not convenient and may make designers miss some of them.

W3C-WAI explains how the formula is calculated:

“Conversion from nonlinear to linear RGB values is based on IEC/4WD 61966-2-1 [IEC-4WD] and on “A Standard Default Colour Space for the Internet - sRGB” [sRGB].

The formula (L1/L2) for contrast is based on [ISO-9241-3] and [ANSI-HFES-100-1988] standards.

The ANSI/HFS 100-1988 standard calls for the contribution from ambient light to be included in the calculation of L1 and L2. The .05 value used is based on Typical Viewing Flare from [IEC-4WD] and the [sRGB] paper by M. Stokes et al."

During the process of finding varies guidelines, the researcher found it hard to to get access the colour contrast success criteria in several standards such as ISO 9241, RFC. WCAG 2.0 is different from most other standards in that it is easy to find web colour design guidelines. For example, ISO 9241-151:2008 (Requirements for displayed colours) English version cost 150 CHF when purchase online in Norway, it is unlikely that most the website designers will access to this standard. In addition, unlike vague anecdotal colour guidelines or tips written in blogs or forums, WCAG 2.0 defines a clear and specific requirement for contrast ratio.

As the last section discussed, people with different type of colour vision deficiencies can affect luminance contrast somewhat. Therefore, in the recommendation, the contrast is calculated in such a way that colour is not a key factor so that people with a colour vision deficit will also have adequate contrast between the text and the background (W3C, 2008).

There is lack of research studies if WCAG 2.0 is over-restriction therefore too simple and rigid to implement in complicated contexts. For instance, the total amount of the text should also impact colour contrast requirement, large amount of text need higher contrast than fewer text context. This flexible criterion can relax the limitation of designers' creativity and innovation.

On the other side, most colour scheme website either take WCAG 2.0 as guideline or discuss colour selection experience without specific contrast ratio. WCAG is profoundly authority and dominate in website design area since it is the only guideline adopted by those websites. However, other areas (e.g., electronic displays and CIE systems) have professional standards to satisfy specific requirements as well. For example, "An adequate contrast of at least 7:1 should be maintained between foreground and background colours to enhance colour perception and perceived image resolution (W3C, 2008)." Certainly, users browse webpages through electronic displays, thus, when it involves multiple fields, the developers need to be careful with choosing the standard for their designs. The possible solution is WCAG 2.0 should be website designers' first concern guideline unless additional requirements are proposed by the customers. Moreover, not all designers have scientific backgrounds, therefore numbers such as 7:1 are hard to comprehend. Therefore, the standard is not helpful even if it is correct and given specific requirements to designers who lack knowledge about colour theory and mathematics.

The most valuable and reliable factor in web design is trained and experienced designers, guidelines and standards cannot replace human factor nor should dominate the design process. Nevertheless, they can be very helpful to achieve better design.

1.4 *Colour Theory*

1.4.1 Colour models

A impotant step to do in colour design is select the colour from a colour model, different design software use different colour models. The main colour model sliders used are RGB colour model, HSV colour model. The deisngers are not neccesary need to know how to mathematically convert colours between different colour spaces, but they should have basic knowledge about how these colour space produce colours.

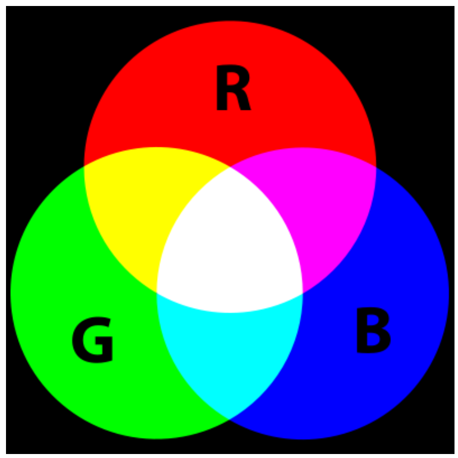


Figure 1.2 RGB colour model1[1]

The RGB space is based on an additive colour model and probably the most commonly used among in computer vision and image processing. This is because both colour images captured by digital cameras and image output devices are based on the RGB primaries, (Tominaga, 2014). Moreover, the RGB colour model is a device-dependent and assigns intensity values within the range from 0 to 255 for each pixel in the image.

RGB images using three colours only which are also known as the three primary colours red (R), green (G) and blue (B) so that they can be mixed at different ratios. In the RGB colour model, brightness is counted and represent by integers. Often, RGB brightness has 256 in each colour (red, green, blue), from number 0, 1, ...to 255. Note that although the highest number is 255, but 0 is also one of the values, thus the total figure is 256. The red, green and blue use 8 bits each, according to the calculation, RGB colour can be combined total of 256 out of approximately 16,780,000 possible colour, that is 256 × 256 × 256 = 16777216. This is also commonly referred to as 16 million colours or ten million colours also known as 24-bit colour (true colour).

[1] Reproduced from http://en.wikipedia.org/wiki/RGB_colour_model

Light-emitting diode (LED) uses electronic circuits to control the blending and diffusion of different colours. All the colours on the computer screen, by which red green and blue colour are mixed according to the different proportions. A group of Red Green Blue is one of the smallest display units. Any colour on the screen can be determined by a set of RGB values to record and expression. Any value between them sets the LED to partial light emission. When the red pixel is set to 0, the LED is turned off. When the red pixel is set to 255, the LED is turned fully on("RGB Color Codes Chart," 2014).

The HSV colour model (Figure 1.3) is cylindrical-coordinate representations of points in an RGB color model. Simple equations are used to convert from RGB to HSV colour. H stands for Hue and S stands for Saturation in all cases. Hue is usually a number between 0 and 360 that represents the angle in the colour wheel (a hue wheel, that is). The B in HSB stands for Brightness and the V in HSV for Value, which are exactly the same: the perception of the ammount of light or power of the source. Both Saturation and Brightness/Value are given as a real number between 0 and 1 or as a percentage.

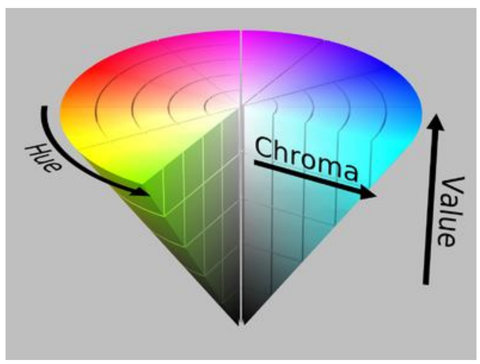


Figure 1.3 HSV colour model[2]

Although RGB corresponds directly to the hardware and it is usually the easiest for a programmer to implement (Schwarz, Cowan, & Beatty, 1987), it is not very human-friendly and "natural" since a human cannot easily reason using all the codes in RGB colour space. After Schwarz, Cowan and Beatty done experiments comparing five colour models, they found that RGB model was the most rapid, but inaccurate model. In the experiments, subject without apprehension of RGB model, they learn very quickly reach the best performance toward RGB model while they need one hour toward other colour models (Schwarz et al., 1987).

HSL and HSV colour models were more convenient for users to specify colours in graphic software (Douglas & Kirkpatrick, 1999). In addition, S. Douglas and Kirkpatrick (1996) proposed that there is widespread belief that HSV are more "natural" and consequently more usable than other colour

[2] Reproduced from http://en.wikipedia.org/wiki/HSL_and_HSV

models from previous research. For instance, Foley, Dam, Feiner, and Hughes (1995, p. 590) declare that RGB is a hardware-oriented colour model while the HSV model is more user-oriented and intuitive for artists.

Many design prototype need to be printed in papers such as posters or do user testing. Hence CMYK is another important colour model designers need to know since it is used in print. According to Wikipedia, “The CMYK colour model is a subtractive colour model used in colour printing. CMYK refers to the four inks used in some colour printing: cyan, magenta, yellow, and key (black). The "K" in CMYK stands for key because in four-colour printing, cyan, magenta, and yellow printing plates are carefully keyed, or aligned, with the key of the black key plate (Wikipedia, 2014).” Black is added to the model because subtractive primaries cannot produce black, instead it create dark brown (Bann, 2006). Because CMYK is used for printing, often the background will be light colours such as white otherwise the colours will be invisible on dark background. This is also the reason it is called subtractive because inks "subtract" brightness from white.

Unlike RGB and HSV, there is no general conversion formula that converts between RGB and CMYK since they have different gamut. Gamut is the range of colours that can be reproduced by a particular printing process, display device, or set of paints.

Designers firstly seeing their work on screen in RGB model, then the digital version need to be converted to CMYK model before it is sent to the printers. Since the colours on screen cannot exactly match that of print, the designers will face troubles when implement their creativity to paper.

Lab colour theory is built upon the Munsell colour system, the 1948 Hunter colour space, and the 1976 CIE colour space. Unlike RGB and CMYK, Lab is not device-dependent colour model which means the colours are defined independent of their nature of creation or any particular piece of hardware they are displayed on. This colour space is typically used in image editing programs. For example, it is useful for sharpening images and removing artifacts in JPEG images.

Natural Colour System (NCS) is a colour system based on six elementary colours that are difficult to define perceptually in terms of others: white, black, red, yellow, green, and blue (Figure 1.4). Unlike the RGB system or the CMYK system which are both based on reactions of the eye’s colour-receptive cones, NCS colours are processed in the retina’s ganglion cells (RGC). A retinal ganglion cell (RGC) is a type of neuron located near the inner surface of the retina, it is responsible for transferring information from the eye to the brain (Van Buren, 1963).

Figure 1.4 NCS colour system[3]

[3] Reproduced from https://www.refin-ceramic-tiles.com/series/cromie/ncs/

1.4.2 Colour harmony

Colours usually work together, they are strongly influenced by its participation colours in colour aesthetics. When discussing designers' selection, it is therefore essential for designers to consider how colours interact in more complex chromatic compositions (Schloss & Palmer, 2011). In aesthetics, harmonic colours are sets of colours pleasing in terms of human visual perception (Cohen-Or, Sorkine, Gal, Leyvand, & Xu, 2006). In a colour space, harmonic colours are colours that hold a specific relationship by their position within the colour wheel. Over the years, there have been many versions of the colour wheel, the most common one is a wheel based on the RYB (red-yellow-blue) colour model (see Figure 1.5).

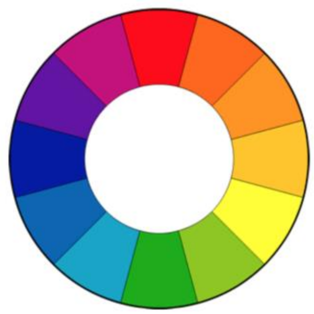


Figure 1.5 Colour wheel based on RYB[4]

Complementary colours (also knows as opposite colours, see Figure 1.6) are colours that hues are opposite each other on the colour wheel such as red and green. Nevertheless, complementary colours are tricky to use in large areas because it can creates a vibrant look especially when used at full saturation. Hence two complementary colours are not recommended as text/background combinations. However, if the designer wants to create some elements that grab readers' attention, then opposite colours are useful to make the element stand out.

Figure 1.6 Complementary colours[4]

[4] Reproduced from http://www.tigercolor.com/color-lab/color-theory/color-harmonies.htm

Analogous colours (see Figure 1.7) are colours where hues are next to each other on the colour wheel. They usually match well and create serene and comfortable designs. Analogous colour schemes often appear in nature and unlike opposite colours, analogous colours do not look too "different" to each other, they are more comfortable and pleasing to the human eyes.

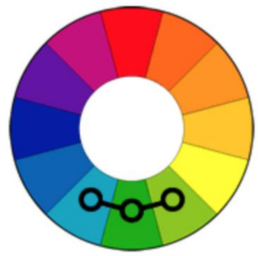


Figure 1.7 Analogous colours[5]

A triadic colour scheme uses colours (see Figure 1.8) that are of even distance from each other on the colour wheel. The triadic scheme is not as contrasting as the complementary scheme, but it looks less vibrant and more harmonious. However, once the designers decide to use triadic colours, they still need to be careful because their hues are relatively close from each other and can potentially lead to people have problems distinguish them.

Figure 1.8 Triadic colours[5]

The monochromatic colour scheme (see Figure 1.9) uses variations in lightness and saturation of a single colour on the colour wheel. Monochromatic colours go well together, they look clean and easy on the eyes. The primary colour can be integrated with neutral colours such as black, white, or gray. However, this scheme lacks colour contrast and it is difficult to highlight the most important elements compare to complementary scheme. This monochromatic colour scheme provides viewers many variations, both obvious and subtle from just one colour.

[5] Reproduced from http://www.tigercolor.com/color-lab/color-theory/color-harmonies.htm

Figure 1.9 Monochromatic colours[6]

1.4.3 Cultural difference

In addition to colour science designers should take account of various interpretation of colour across cultures. Several studies (Noiwan & Norcio, 2006; Tractinsky, 1997) reveal that it is essential to consider cultural diversity in a design process. Further, Noiwan and Norcio (2006) investigated how American and Thai users think and deal with animated graphic colours and they also recommend blue as banner graphics since it helps the viewer remember the banner elements such as banner content. Collazos and Gil (2011) claims it is necessary to take colour into account when applying different needs towards computing systems across different cultures. Overall, interface or website designers need to understand colour appreciation in different cultures and regions since cultural backgrounds could influence people's responses and preferences towards colour.

Few studies have investigated the difference in colour perception across Norway and China. However, based on Table 1.2 we suppose for Norwegian and Chinese have different views and feelings about colours. Thus, even the same colour design within these two cultures might have totally opposite effects. Some research indicate red used as cloth or decoration usually means happiness in China (Cyr, Head, & Larios, 2010), hence Amazon uses blue and orange as corporative colours in all the versions, but the Chinese version is the only one to include red (Collazos & Gil, 2011). However, unnatural colors, such as reds usually cause eye fatigue and this can turn away viewers (Ma, Yao, Wei, & Zhang, 2009). The Colour-Culture Chart below reveals same colours own different meanings in six countries (Thorell & Smith, 1990).

Table 1.1 Different colour meanings in six countries

Culture	Red	Blue	Green	Yellow	White
US	Danger	Masculinity	Safety	Cowardice	Purity
France	Aristocray	Freedom	Criminality	Temporary	Neutrality
		Peace			
Egypt	Death	Virtue	Fertility	Happiness	Joy

[6] Reproduced from http://www.tigercolor.com/color-lab/color-theory/color-harmonies.htm

		Faith Truth	Strength	Prosperity	
India	Life Creativity		Prosperity	Success	Death Purity
Japan	Anger Danger	Villainy	Future Youth Energy	Grace Nobility	Death
China	Happiness	Heavens Clouds	Ming dynasty Heavens Clouds	Birth Wealth Power	Death Purity

Further, a study had done (Cyr et al., 2010) to compare if three colours (grey, blue and yellow) in three different cultures (Germany, Canada, Japan) related to trust, satisfaction and loyalty. Previous studies confirmed that blue was most popular on German websites, while grey was the colour most often appearing on American websites. Japanese are known to prefer brighter colours such as yellow. During the investigation, they used a multi-method approach to gather the data. The results suggests that the most appealing colour for Canadians is grey, that the most trusted colour for German is blue and that yellow is the significantly most disliked across the three cultures. The results suggest that the favorable colour in realm and in electronic display may have different impacts for viewers. In addition, the influence of colour appeal on satisfaction or trust will not be moderated by culture.

Cultures have penetrated in every society. In the book “Cultures and Organizations: Software of the Mind”, the author elaborate the cultural differences or diversity between nations from different dimensions, based on empirical researches (Hoftede, Hofstede, & Minkov, 2010).

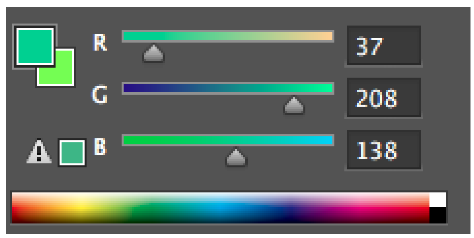
Unfortunately, there is a gap in assesses the different aestheticism towards colour between Norwegian and Chinese. In fact, general cultural studies in HCI are limited (Noiwan & Norcio, 2006). Thus, a cross culture interview between Chinese and Norwegian designer was conducted to fill the gap. Further, based on the previous studies mentioned earlier and shared feelings among people in these two countries were used in purpose a hypothesis:

Norwegian and Chinese potentially represent two different attitudes towards the meaning of colour in website/interface and its relationships to overall impression.

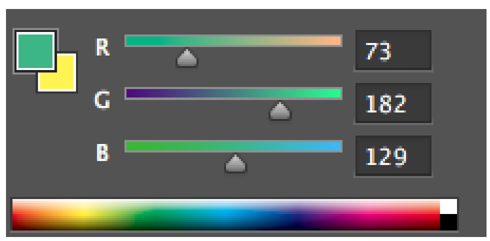
1.5 Colour selection tools limitations

There are many design software used by the website or graphic designers, such as Adobe Photoshop, Adobe Illustrator, Corel Paintshop Photo, etc. But the main question is, are those tools appropriate for professional designers (Dow, Saponas, Li, & Landay, 2006)? Some designers consider computers helpful in creating graphic designs while others against it actually give help on graphic design since it actually limits people's imagination and creativity. The following are some mainstream design or colour contrast assist tools:

Adobe Photoshop is a raster-based program creating or editing an image with dots. It developed by Adobe Systems for photo editing. Figure 10 presents one of the colour selection feature in Adobe CC:



a



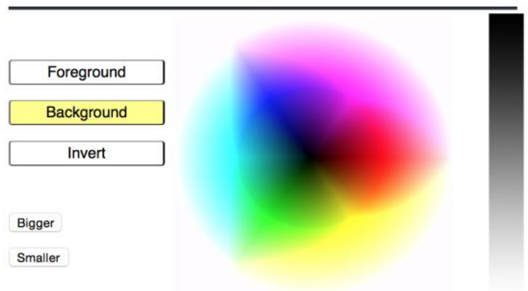
b

Figure 1.10 Colour selection feature in Adobe CC

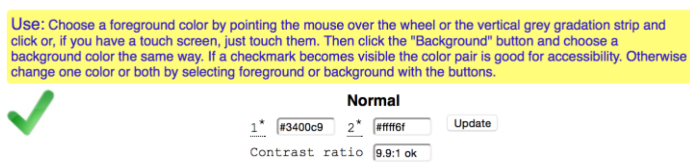
Apparently, the RGB letters demonstrate Photoshop uses the RGB colour model for chosing colours by adjusting the intensity of red, green and blue on the colour sliders. The foreground colour is (37, 208, 138), the background colour is (0, 231, 3). When the colour contrast analyser is used to check the ratio, it was 1.5:1. In Figure 1.9 b, the foreground colour in RGB is (73, 182, 129), the background colour is (255, 246, 3). The triangle with exclamation mark disappears and the contrast ratio is 2.22:1. This does not even meet the minimal success criteria. There is an exclamation mark inside a triangle (Figure 1.10a). In fact, the warning means the colour cannot be printed on papers. However, the researcher's own encounter with Adobe CC was the impression that the explanation mark was a indication of two colours not providing enough colour contrast.

In order to ensure that the colours are consistent with standard colour contrast, numerous evaluation tools which assist the designers in their effort to create accessible websites have been proposed (Mereuţă, Aupetit, & Slimane, 2012). This dissertation also investigate how other implementations of WCAG 2.0 colour contrast tools address the issues mentioned above and attempt identify potential shortcomings and possible solutions. Most of the tools are designed for colour contrast analysis or checking, thus these types of tools make the designers check the contrast after the design phase. The following are some of the colour tools provided by the international community The World Wide Web Consortium (W3C) which developed WCAG 2.0.

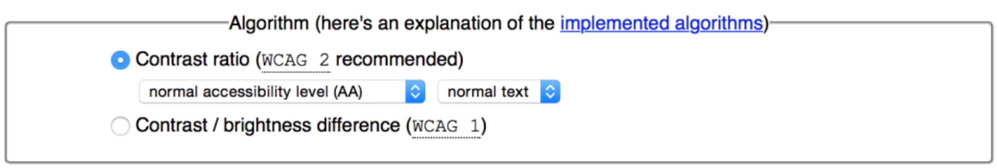
A. Accessibility Colour Wheel[7]



a



b



c

Figure 1.11 Interface of Accessibility Colour Wheel. a) Colour Wheel, b) contrast ratio results, c) different algorithm of contrast ratio

Accessibility Colour Wheel is a tool (Figure 1.11) created by Giacomo Mazzocato, it enable the user to evaluate the readability, experiment and rapidly envisage the appearance of colour schemes bymoving the mouse around the colour wheel. However if the users find the colour scheme difficult to read, they still need try again to find other colours that can pass the contrast standard.

B. Colour Contrast Visualiser[8]

---

[7] http://gmazzocato.altervista.org/colorwheel/wheel.php

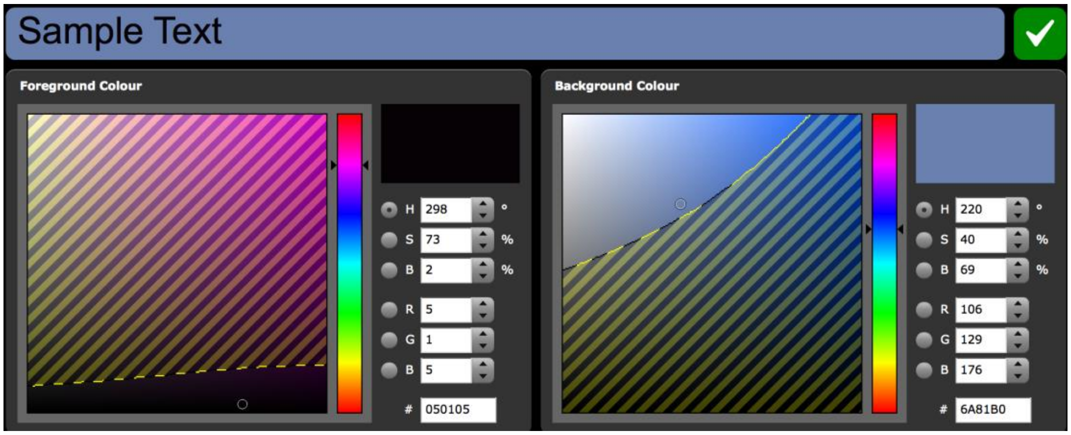


Figure 1.12 Colour Contrast Visualiser

This tool Colour Contrast Visualiser tool (Figure 1.12) created by Thomas Hooper provides visualizes appropriate colour combinations. The user pick the first colour in one palette and the colours in non-scribe area from another palette can exhibit sufficient contrast. Nevertheless, it sets 5:1 as the standard contrast ratio, but lacks of present the different levels requirements defined by WCAG 2.0. Therefore the colour schemes adopted from this tool are likely to fail to adhere to WCAG 2.0 contrast standards for normal text for level AAA and provide less colour choices for large text.

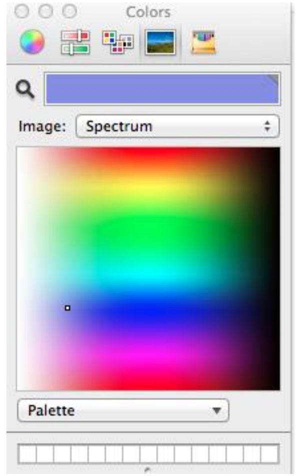
C. Colour Contrast Analyser[9]

This native application developed by Cédric Trévisan can run on a computer running without any external support. This tool allows users to evaluate the colour visibility and contrast of foreground/background colour combinations. It also presents an initial pass/fail assessment against WCAG 2.0 colour contrast success criteria. The first step is to get the ratio and chose the foreground and background colour as showed in Figure 1.13. Then, it will automatically calculate the colour/brightness difference and luminosity contrast ratio to check whether the result of the ratio fits the criteria.

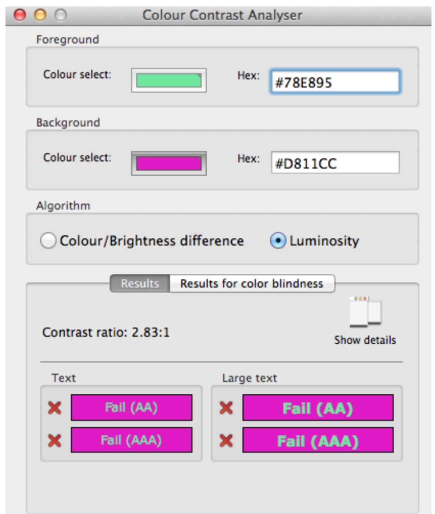
---

[8] http://www.stainlessvision.com/blog/projects/colour-contrast-visualiser

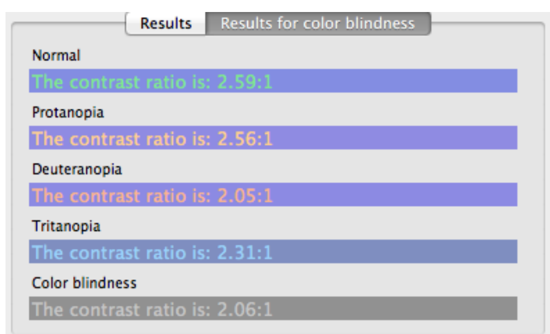
[9] http://www.paciellogroup.com/resources/contrastanalyser/



a



b



c

Figure 1.13 a) Select the foreground/background colour, b) The result shows that the contrast ratio test failed, c) A presentation of the colour contrast ratio results for different colour blindness.

This application is a typical representation of a post-design approach (Sandnes, 2015a) which means it is used after the design was done, not at the same time. This may lead to repeated and unnecessary repeated contrast checking since it does provide a real colour picking function. In some cases, the colour contrast can be perceived by people without colour blindness, but not for people have. For instance, greens and reds will be diffcult to distinguish for organism with Red-green colour vision defects.

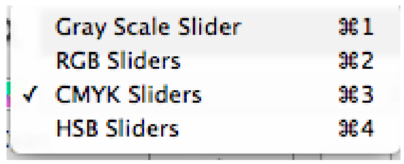


Figure 1.14 The choices of different colour model sliders

The advantage of this tool is it provides designers with multiple colour sliders as shown in Figure 1.14. The users can select the slider according to their preferences and habits.

According to (Douglas & Kirkpatrick, 1999), simplified function and interface was preferred. However, this colour picker has colour/brightness difference and results for colour blindness features which might lead to confusion especially for inexperienced users.

D. Colour Contrast Check[10]

W3C offers several online contrast ratio analyze tools which have similar functions as the tool 'Colour Contrast Analyser'. From the interview results in the latter section, this tool is mostly used among Norwegian website designers.

As showed in Figure 1.15 this online analyser present both RGB and HSV colour model sliders.

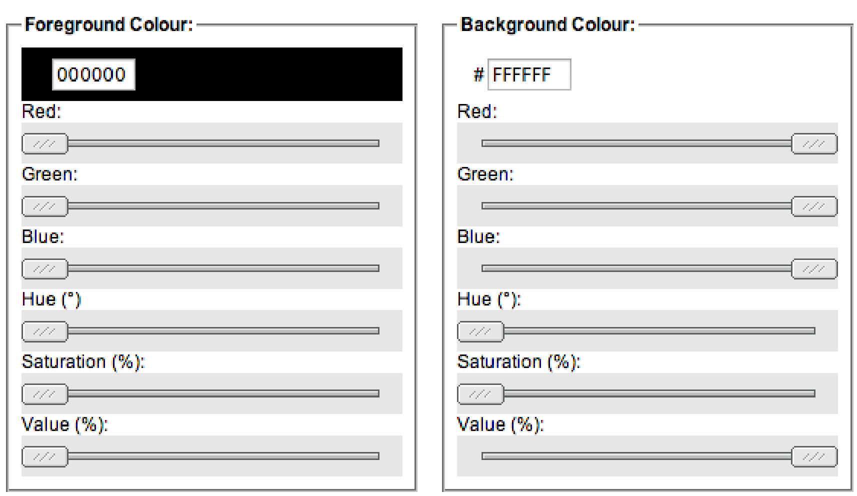


Figure 1.15 Another way to select foreground/background colours

[10] http://snook.ca/technical/colour_contrast/colour.html#fg=33FF33,bg=333333

Dragging the button from left to right to change colours is more compatible with human colour perception since it uses Hue, Saturation and Value. Another disadvantage of online contrast anlysers is that they require access to the internet. Similarly, they are also post-design tools.

As discussed in the previous sections, although these types of tools can solve some problems they are still ineffective since they are used after the design is done. In this study, a colour picker tool ‘colour picker for designers’ based on WCAG 2.0 is proposed. The difference between this tool and other colour picker tools is that it helps to select the colour during the design process. When the designers select the first colour, the tool will automatic calculate the corresponding colour based on the 4.5:1 colour contrast ratio.

1.6 Website design guidelines

In order to make a accessble design in terms of colours, it is important for designers to look to examples and references on the web (Weinman, 2002). For instance, Google published Google Design[11], a design guideline to build experiences that surprise and enlighten users. However, even the contrast between the heading and its background colour on Google Design homepage fails to pass the minimum success criteria requirement (see Figure 1.16).

Figure 1.16 Google Design headline

The contrast of the Google Design heading and its background colour is 2.61:1, which is below the minimum limit of 3:1. The main title at the homepage of Google Design even failed the minimum requirements, level A for large text. Similarly, Apple also made a guide document called “iOS Human Interface Guidelines”. Unlike Google, Apple try to impress the viewers with vivid colours and Apple use white with Grey heading and black body text (Figure 1.17).

[11] http://www.google.com/design/

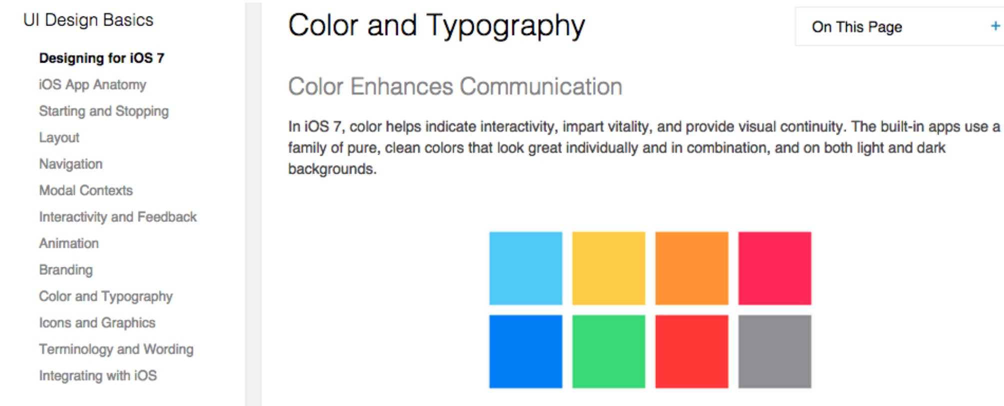


Figure 1.17 Designing for iOS 7

The popularity and usage of WCAG 2.0 among Chinese designers is relatively low. Conversely, the public knows and trusts Google, once Google published a guideline to help users synthesizes the classic principles of good design according to its introduction. There is a speculation that the designers naturally believe that the Google Guideline is a safe choice, represent timely design and generally accepted by the public. As a consequence, Web and UI (User Interface) designer, also other designers, might learn from and reference Google Guideline. Since Google has such tremendous influence while their guidelines do not successfully pass the contrast standard, the consequence is that all the graphic designers that follow this guideline as a standard will also fail to provide sufficient contrast.

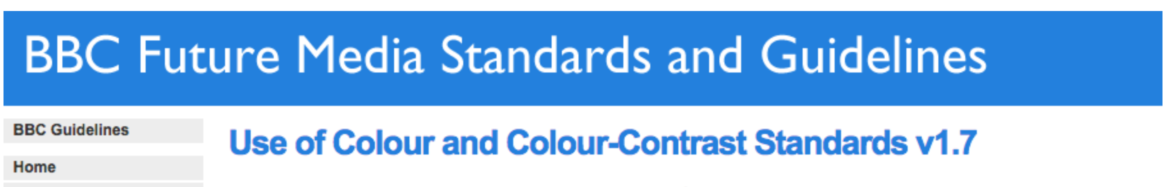


Figure 1.18 BBC standards

BBC (British Broadcasting Corporation) established a series of guidelines to lead those undertaking or consider to undertake work for them as a supplier, to gain better performance.

It is worth noting that BBC uses blue both as the background colour and as foreground colour (Figure 1.18), picking colour from the screen and testing with Contrast Analyser indicate the colour contrast ratio for the biggest heading is 4.04:1, which successfully pass the Level AA (large Text), but fail to pass the Level AAA (large text). According to the interviewed designers that voiced negative opinions toward WCAG 2.0 colour contrast guidelines, Google might selects a blue the designers would prefer.

A survey could be implemented to compare the two blue colours and which one the viewers preferred. It is considered permissible to speculate some colours such as the ones Google choose for the headline background catch people's eye at first sight, but might fail to remain attraction in longer time. Conversely, BBC’s colours probably keep the interviewer’s eye stay longer than the lower contrast colour combination. Unlike Google, BBC states that the colour contrast must be WCAG AA-compliant.

1.7 Other factors influencing colour contrast

Some extraneous factors may have impact on colour contrast. Previous research has investigated these topics, but they are not the main issue in this dissertation. Thus, these uncertain factors will only be briefly discussed.

Quality of the display variation can lead to different presentation of the colour contrast. Currently, LCD, AMOLED, OLED and Retina are the most popular types of displays. Different displays have different quality and visual performance, because of the different technology used. Luminance and contrast ratio are two measurements to estimate the performance of a display, because it can influence the presentation of colours.

OLED displays have a shorter brightness lifespan than some LCD displays, which means the screen might be half bright after having been used for some years. Young individuals who replace their mobile phones every two years this brightness reduction situation have less impact than on the elderly who replace their handsets less often. However, with age comes reduced vision and the elderly may need higher colour contrast. Thus, old OLED displays will affect the visual performance of colour contrast. In addition, very few study investigate how variety qualities of different types of screen display the colours, however, if the user know which screen has higher or lower luminance, they can adjust the colour to improve the visual performance. Moreover, Pölönen, Salmimaa, and Häkkinen (2011) found that:

“It is well known that a large difference between the display luminance and the illumination level of the environment can impair the visibility of the display, leading to sensations of discomfort or transient adaptation effects from fixating back and forth between two luminance levels.”

Both of the variables, display luminance and illumination level of the environment, are hard to control. However, as the technology of screen display developed, the deficiency will be fixed in the future, it can minimize the contrast lost caused by varying screen quality.

Variation of devices such as projectors or small screen devices such as mobile devices also influence the perception of colour contrast. Projectors increasing appear in multiple areas and situations, but since the projectors explored in bigger display screen and space, the device and real viewing conditions such as ambient light will affect the displayed content. Under bright conditions the displayed content may be presented with attenuated contrast (Madi & Ziou, 2014). The reason is the spectral characteristics of a light source and a surface reflectance cause the measurement of object colours and colour contrast to be biased towards the color of the light source (Heechul & Hyunsuk, 2012).That is, even if the designer configure the contrast ratio according to WCAG 2.0, when the projectors or viewing conditions changed, the colours still cannot be perceived by some users.

Similarly, there are Web users who face challenges because of device limitations, for instance small size screens, due to most of the Web pages in existence today were designed for desktop PCs (Yu, Xing, Wei-Ying, & Hong-Jiang, 2005). The influence of variables screen size has been mainly investigated on the sense of physical presence (Dagonneau, Martin, & Cosquer, 2014), that is what size does people fell confortable when hold it in hand, but less attention has been paid to how the size of the screen can influence the sense in terms of colour contrast.

There could be three hypotheses regarding colour contrasts on variables screen size: a) screen size is associate with colour contrast, b) colour contrast ratio become smaller as the screen size reduced, c) colour contrast ratio becomes larger as the screen size is enlarged. If either of the hypothesis b or c was supported by researches, the web designers or developers need to consider the screen size factor when they select colours.

Some written languages can also cause the same colour contrast distinctive from other written languages. For example, written Chinese is quite different to Latin languages based on an alphabet or a compact syllable. Instead, Chinese uses symbol as characters, each character components either depict objects or represent abstract notion (Wieger & Davrout, 1965). Often one Chinese character consists of two or more components are combined to form more complex characters, using a variety of different principles. In short, Chinese characters save more written space than other languages. For example, the character" 籭 (pronunciation: shi) " has many components crowed in one square, but complex English character sequences such as "internationalization" uses more space thus the readers have enough space left to recognize the word. Nevertheless, to ensure that the character *"籭"* can be clearly recognized, it needs to be lager. For CJK language, (CJK is a collective term for the Chinese, Japanese, and Korean languages) designers need to adjust the font size of the textual content.

Chapter 2

2 Method

Few studies have examined designers' understanding with colour contrast and the design process of selecting colour. Actually, the website/graphic designer also has the demand for help with colour contrast selection and requirements for their design tools. In order to investigate how designers understand and use colour contrast, and to fill the gap in evaluate aestheticism between Chinese and Norwegian designer, interviews were the chosen method in this study. Eight interviews with designers were planned (D1 to D8), lasting on average half an hour.

The main goal of these interviews were to determine how the designers reason around colour contrast and why. The findings can provide a deeper understanding about designers' thinking process around colour contrast and help the organization which makes standards such as W3C to improve WCAG 2.0 and make it easier and more efficient for designers to use.

This leads to the following research questions (RQs):

RQ1: How do designers understand colour and colour contrast?

RQ2: To what extent do the designers understand and can apply the formula to calculate contrast ratio in WCAG 2.0?

RQ3: How do designers choose colours? What is their process of reasoning?

In order to find out the answer of the RQ 3, the designers were asked to design a website/interface for a travel company and pet stuff website, they need to select colours for headings, foreground (text), background. During their design process, ask them what they are doing, why they choose the specific colour, do they have other possibilities.

The data was collected using a semi-structured interview technique. Since the author previously had limited interview experiences, a pilot interview was conducted for practice to check the flaw and improve the interview.

The designers are also encouraged to discuss wider aspects of colour design as they felt appropriate. As a result of the interview, suggestion to overcome these potential deficiencies can be implemented in the new colour picker tool.

2.1 Participants

The sample of this research consisted of eight participation. Four Norwegian and four Chinese designers volunteered to take part in this study. Norwegian and Chinese have totally different cultures and very few studies focus on comparing this topic. Further, different colour knowledge background, even language and mathematics education can influence designers' thoughts towards colour contrast. For example, in WCAG 2.0, W3C W3C (2008) explained key term large scale (text) as “with at least 18 point or 14 point bold or font size that would yield equivalent size for Chinese, Japanese and Korean (CJK) fonts” imply that because of the specialization of CJK fonts, these languages may have different visual performance presenting colour contrast compare to other languages. For example, 18 point font size of Norwegian and Chinese might display slightly different colour contrast to human eyes. But this is a speculation and need further validation.

The participants from China include one male and three females. Their ages are between 24-29 years and all of them have bachelor degrees in graphic design, computer science or architecture. The Norwegian respondents aged from 26 to 48 years and they were all male, they had backgrounds from communication, graphic design and computer science. Two of them work in the same design company.

2.2 Interview procedure

The interviews were structured into two sections and lasted about half an hour. First, designers answered the interview questions, second they performed a design task. All the designers needed to decide the colour combination in the design task and explain the reason they chose them. A case study approach was used in this study since it helps investigate to the designer’ thinking process. It intends to collect understandings from different designers about colour contrast and how they choose colours. In addition, to ensure the validity of the research, the opinions that appear in the dissertation were directly cited from the participants. Participants with different education backgrounds, ages, genders and different workplaces were selected to guarantee the diversity of the sample. Participants own diverse backgrounds or ages, they might hold different opinion about WCAG 2.0 and colours, this can ensure the collect the information as much as possible. The interview questions were prepared to answer the research questions. All the interviews were recorded and subsequently transcribed into text. Consent for recording the participants were acquired and the recordings were deleted after the transcriptions.

A challenge with interview is to determine what to ask, how to ask it, and who to ask. Fundamentally, the research questions were decided, “how designers understand colour and colour contrast?” and “how designer choose colours? What is their thinking process?” Therefore, all the sub-question were asked in order seek the answer of research questions. As mentioned in (Lazar, Feng, & Hochheiser, 2010, p. 179), interview has this shortcoming :participants recall what they remember, this is not actually what happened. The interview guide was changed for the Norwegian designers after the first interviews with Chinese designers were completed, as follows:

From these interviews, the researcher noticed more question should be asked to address what are they thinking when they select colours? What are their considerations and which factors subconscious influence of their choices?

A combination of interviews along with direct observation in this study was intended to provide more appropriate measurements (Lazar et al., 2010, p. 149) and give explanation to observed behaviors.

The observation started from the beginning of the design process. However, the interview still carried on because this was more nature and realistic when the designer did not aware they were being observed. In addition, the design thinking process was instant formed when the designers made the decision, it is better to gather the answer while designer sitting in front of a computer and actually using the tool to do the colour selection. As Lazar suggested, “these observations will be helpful to understand the relationship between what interviewees say and what they do (Lazar et al., 2010).” In this case, the designers may say they do consider colour contrast as an important factor when making choices, but they might select colours that do not have enough colour contrast ratio; or they claim they know colour models, but they failed to choose the appropriate colours in order to get higher contrast when adjusting colours based on RGB colour model.

Chapter 3

3 Results and interpretation

3.1 WCAG 2.0 and Colour contrast ratio calculation

Before the researcher introduced WCAG 2.0 to the participants, all of the Chinese designers thought that there is no such standard for colour contrast, because they believed that the appropriate colour contrast was based on individual preferences. Where some users prefer higher colour contrast others prefer lower contrast. One of the Chinese participants noted (freely translated from Chinese):

“I don't have a clear and precise definition of colour contrast. I think it is decided by mainly light and shade of the whole interface. By adjusting the contrast we can make single colour more highlighted or two colours more consistent. There is some way to compare contrast in mathematics, such as using RGB.”

Moreover, none of the Chinese designers had heard of WCAG 2.0 meanwhile all of the Norwegian designers know and have experience with WCAG 2.0. In addition, although China completed drafting their Web accessibility standards in 2007 and has based them on WCAG 2.0 (Reid & Snow-Weaver, 2008), they have not provided a Chinese translation of how to meet and understanding of WCAG 2.0 guidelines in technical recommendations. Thus, even if the Chinese designers know and willing to implement WCAG 2.0, they have to face another challenge caused by language barriers.

All Norwegian designers know and have some experience with implementing WCAG 2.0, because the regulations mandates that all websites must meet its minimum accessibility standard in Norway. Norway has published a law that requires all websites to be universally designed otherwise whomever negligently acting in violation of this law maybe ordered to pay restitution to the aggrieved party.

After the four Chinese designers were introduced to WCAG 2.0 and the 4.5:1 colour contrast ratio, three of four Chinese participants thought it was not worth changing the design to meet the standard since the website was not planned to be used for everyone. Adjusting the design would cost extra time and effort. Apparently the Chinese designers lack the awareness of accessibility and universal design. Two of four Norwegian designers believe occasionally that by following the standard the web design becomes less attractive.

For instance, one participant mentioned they used to make a website for a standardization organization, and they certainly has to follow the most strict standards. That means they need to meet all requirements of WCAG 2.0 Level AAA. The designer believe this definitely make the design not as beautiful as designs with lower contrast colours, because the participant thought higher contrast colours looked old-fashioned and not fresh. The participant also claimed colour combinations with higher contrast of course can be used well and look nice, but he think softer and lighter colours look better together.

However, an interesting observation is that when showed the colour contrast ratio calculation, all of the interviewed Chinese participants are willing to explain how to calculate contras ratio step by step and three of them are following the correct calculation process.

Among the four Norwegian designers, only one of them is willing to look at and explain the calculation in detail, the other participants think it is too difficult to understand the calculation process. One Norwegian designer claimed he uses online tools to check if the colour contrast meets the standards, however, he admitted he is not familiar with how to calculate the WCAG 2.0 contrast ratio. When the researcher showed the formula to him, he immediately responded he cannot understand and explain the formulas.

Chinese in general are known for good math ability. International surveys such as the Trends in Mathematics and Science Study (Table 3.1) have placed 8th-grade students in Singapore, Taipei, Hong Kong near the top. The average score in Norway is 475, lower than the TIMSS scale average which may explain this phenomenon. In addition, there was balance between mathematics achievement growth and decline among countries. Of the countries participants with comparable data spanning 1995 or 1999 to 2011, Taipei, Hong Kong and Korea had increased achievement and Norway had decreased achievement (Mullis, Martin, Foy, & Arora, 2012).

Chinese, Japanese, Korean and Turkish use simpler number words and express math concepts more clearly than English, making it easier for small children to learn counting and arithmetic operations. Although mainland China did not participate in this survey, we can speculate that the Chinese perform similar on mathematical tasks to those in the neighboring regions.

Table 2.1 Average mathematics scores of 8th-grade students, by education system: 2011 (Mullis et al., 2012)

Education system	Average score	Rank
TIMSS scale average	500	
South Korea	613	1
Singapore	611	2
Taipei	609	3
Hong Kong	586	4
Norway	475	20

In short, Chinese designers show resistance towards colour contrast requirement from WCAG 2.0 while Norwegian designers aware they must comply with the guidelines in their designs. On the contrary, three of the Norwegian designers tend to avoid understand and explain the contrast formulae while all of the Chinese designers shows more interest in the computations.

3.2 Design trends

An interesting obersevation is that all of the Chinese designers talked about the current design trends, they mentioned it is important to follow the current trends such as popular fonts, colours and layouts. Participant W mentioned that fresh colours are now very popular and has been widely used on websites. He also emphasized to keep the design style consistent with the operating systems such Android and IOS especially on mobile devices.

Unfortunately, the first sign of the Google Design Guideline failed in colour contrast WCAG success criteria 1.4.3. Moreover, this participant strongly underlined the importance of maintain the consistent visual style with Android and IOS, thus web designers adopted Google Design Guideline using similar or even same colour combinations are very likely creating a colour scheme with weak colour contrast.

Another Chinese designer B specifically claimed grey text with white background makes a clean presentation style to viewers.

Similarly, one of the Norwegian designers also mentioned design trends. He explained it by using an example colour orange, which is more popular now than the last five or seven years. He believed in the last 5 years, a lot of brand logos are using orange as their colours, maybe not main colour, but at least as an additional colour.

3.3 Cultural influence

All the four Chinese designers chose colour such as green or blue for the travel agency website and warm colours such as yellow or pink for the pet companies. However, the reasons for chosing the same scheme varies. Participant W analyzed he chose green or blue because there are many existing Chinese travel websites using cold colours (see Figure 3.1, 3.2) and their designs may potentially influence his decision. When he was thinking about selecting colours for the travel agency, he subconsciously associated colour schemes from these websites. Another participant Z explained she chose blue and green because these colours can be accepted by most public. Participant T with seven years of design experience also chose blue and green as the main colour, because they are more pure and natural and represent cleanliness and tidiness. She categories websites into different types, when she used to design for political website, the context and small pictures appears most frequently. For websites such as art exhibitions, they may have pure big image without any text as background, and the colour they pursue show stronger company culture, the better. For the travel agency, the goal is to highlight the pictures of the travelling, meanwhile the context should account less places.

Figure 3.1 Homepage of qyer.com, a popular website for backpacking

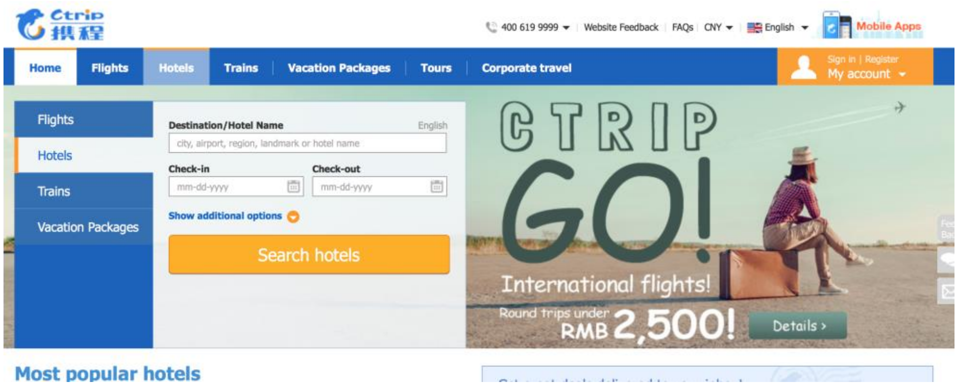


Figure 3.2 Homepage of ctrip.com, a mainland China-based travel agency

One Norwegian participant chose warm colours such as orange for the travel company as he explained that people from cold area such as Norway might prefer warm places as travel destinations. In addition, he mentioned existing travel agencies often use warm colours.

The remaining Norwegian designers insisted they cannot make decisions without preliminary research on popular colours among target customers. For instance, when asked to choose colour for the travel company, one of the designers deny to rashly determine the selection, he responded it depends on what is the travel company intend to tell the customer. If it is a travel company attempt to tell the customer how they offer the cheapest flight to China then some colours maybe help the company get this association. But, if the company want to provide customers the most amazing place on earth and top class service, without consider how much it costs, the most important thing is to give clients a fantastic experience, then maybe they will use some other colours. This participant thus believed it is not possible to pick one colour for all travel companies, because they also have different types of business strategies. In other words, the colours were not actually chosen by any individual designers, but depend on customers' preferences.

However, the interview results do not support that Norwegian and Chinese potentially represent two different attitudes towards the meaning of colour in website/interface and its relationships to overall impression. The sample from the interview is too small to make a generalized conclusion.

3.4 Customer design profile

Both Chinese and Norwegian designers mentioned design profile or menu profile. A design profile or menu profile is a document provided by clients, it often contains the information about logo design, branding advice design company brochures, packaging and web site, etc. The profile is often designed by branding agency, whether for an existing company looking to 'freshen up' their corporate branding, or a start up business.

Customers' needs and demands profoundly impact the designer's choices. All of the interviewed designers in both countries emphasized the importance of satisfying the customer. Therefore, the designers need to keep the correlation of the design profile and also meet WCAG 2.0 standard.

Another designer mentioned the external company hired by HiOA tested the new logo on the people working in the school and it is very important to make the people in the organization to accept the design. Interestingly, the main target group is not potential students or employees, but people already studying or working at HiOA. Therefore, the nature of the company or organization decided the target customer group. The logo is the core of the whole design profile menu, such as shown in Figure 8, the more inside of the circles, the factor is more important and stable in order to keep the consistency of the brand. On the other hand, the more outside of the circles, the factors are more flexible and changeable.

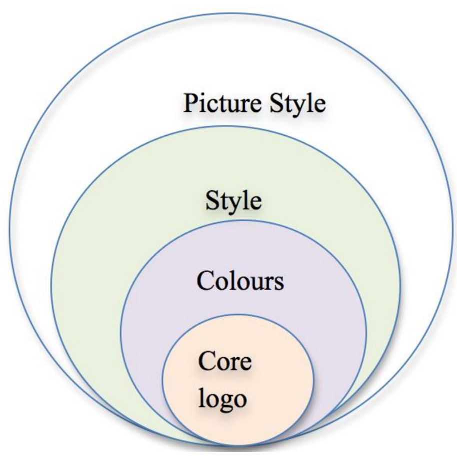


Figure 3.3 Factors influencing graphic design

Another example is shown in Figure 3.4. In recent years, an increasing percentage of universities set a particular colour as a basic element in the website to reflect their profile.

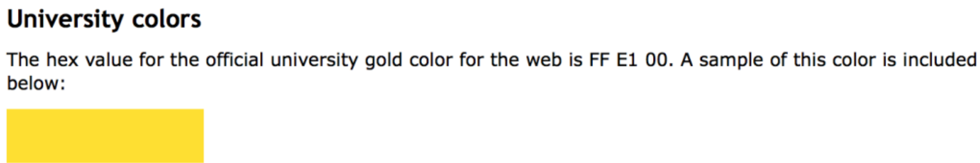


Figure 3.4 Official gold colour for University of IOWA

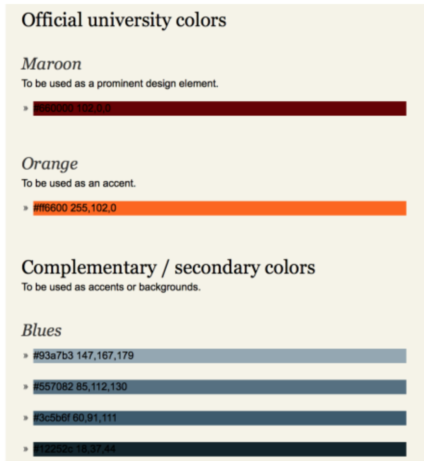


Figure 3.5 Official colours for University Relations

Some organizations provide primary and secondary palettes for related designers to select (see Figure 3.5). Suppose at the beginning of creating the website, the website or graphic designers already consider WCAG 2.0 when deciding the palettes, then latter when designers use these colour combinations directly might save time to satisfy both colour standards and customers' demands. Nevertheless, if at the beginning, the designers of websites missed the chance to take WCAG 2.0 colour contrast success criteria into account, all the following design is likely to not meet the standard.

Compared to the WCAG 2.0 standard that is only based on a general ratio, these two before mentioned organizations instead provide designers with a limited colour scheme to use. It makes the colour selection process easier and faster to implement, for example, in Figure 3.15a and Figure 3.15b, present the two primary and six secondary colours provided by University of Norte Dame.

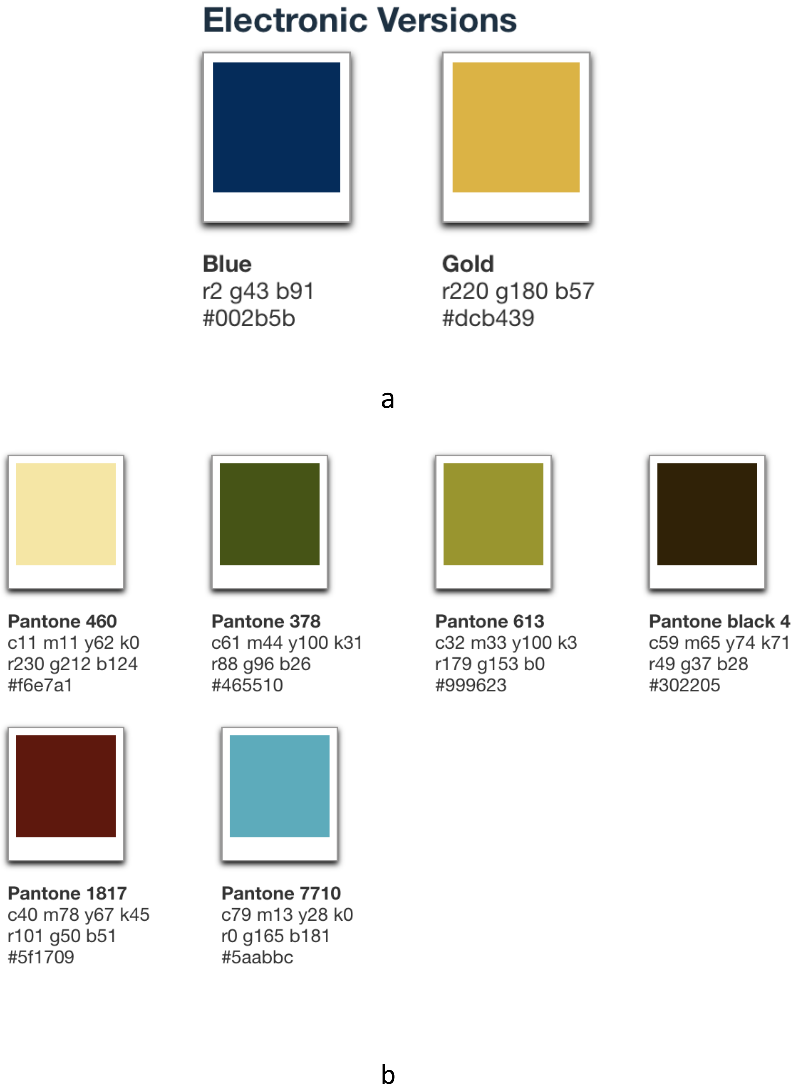


Figure 3.6 a) Primary colours of University of Norte Dame, b) Secondary Colours of University of Norte Dame

Table 3.2 Contrast ratio of the colours combinations

Colour Combination (R,G,B,)	Test Level AA	Text Level AAA	Large Level AA	Large Level AAA
1. (2,43,91) vs (220,180,57)	Pass	Pass	Pass	Pass
2. (2,43,91) vs (246,231,161)	Pass	Pass	Pass	Pass
3. (2,43,91) vs (153,150,35)	Pass	Fail	Pass	Pass
4. (2,43,91) vs (90,171,188)	Pass	Fail	Pass	Pass

5. (220,180,57) vs (70,85,16)	Fail	Fail	Pass	Fail
6.(220,180,57)vs(153,150,35)	Fail	Fail	Fail	Fail
7. (220,180,57) vs (48,34,5)	Pass	Pass	Pass	Pass
8. (220,180,57) vs (95,23,9)	Pass	Fail	Pass	Pass
9.(220,180,57)vs(90,171,188)	Fail	Fail	Fail	Fail

Imagine the designers get the design profile and try to combine the different colours, what results in term of colour contrast will acquired? The author first look and check the colour combinations from the 2 primary and 6 secondary colours using visual inspection, then pick out the combinations (one from primary colours, one from secondary colours) which thought could pass the colour contrast success criteria and then examined the pair using Colour Contrast Analyser. Table 3.2 illustrates the results of contrast ratio when these colours are combined with each other.

There are 9 of 12 (2 primary colours*6 secondary=12) colour combinations that author suppose them could pass at least one colour contrast success criteria. However, the results show two (number 6,9) of the nine combinations pass both levels for text and large text while another two (number 6,9) failed on all criteria. Further, websites used for providing information such as university, government and other organizations' websites, keep the consistency of colour by providing secondary colours that can help reflect the organizations' brand in tone and style or even ass breadth and depth to the overall look and feel (Dame, 2015). Moreover, personal understanding of colour contrast differs from each designer which means that the colour combination choices will vary. Therefore, a tool that only provides all the colour combinations from selected colours that pass the guidelines can help save time and effort.

3.5 Other findings

All of the Chinese more or less use Photoshop for their work. Only one said that it is difficult to use the colour selection function in Photoshop, because it fails to provide the instant effect to help the designer see the difference between very similar colours.

Another Chinese participant stated "I can only accept all the good and bad part of the software, I cannot wish for any change, when it updated or changed, I will follow and adapt to it." This issue is complicated to explain. It can attribute to culture influence, individual personality, personal experience. All these factors might influence why someone is much more willing to give advice and critics on software they use than others.

The Chinese senior designer with seven years of experience is clearer about which colour is needed than the junior designer. Designers who lack practical knowledge and skill tend to seek help from the colour matching website or colour schemes recommended online.

Photoshop provides a gamut warning when the colour lies outside of the printers can display. The real question is what the designer should do once they identify them. If the design is going to be in print, then the colour should be adapted to ensure it can be properly printed.

The designers can figure out how to adjust the colours to meet the standard after they failed. Either they enhance the background colour saturation or reduce the background lightness. Then, they felt the design lost the fresh and clean appeal. Another noticeable observation is at the reselect colour process, the designers seemed to forget their original design plan. Instead of designers initiative to select colours with sufficient colour contrast, it turned out that they are compulsory in finding colours that adhere to WCAG. Chinese designers expressed that colours that meet colour contrasts limits break their independent creative thinking and design process. This dilemma suggests that the tool proposed in this dissertation is an important contribution to website design.

Among the Chinese group, three designers with relatively limited working experience think if they do consider colour contrast as an important factor in design, it would make the design ugly. However, the senior designer holds a more cautious opinion about this. She thought the designers are capable of keeping the balance between following the guidelines and maintaining the aesthetics.

3.6 Limitations of the interview

Two different languages were used during the interviews. The interviewer communicated with the Chinese and Norwegian designers in Chinese and English, respectively. Chinese is the mother language of the interviewer, but some technical terms is not well accepted or understood in Chinese. Hence during the interview of the Chinese designers, it was challenging to accurately describe some issues and design scenarios. When Norwegian designers were being questioned, both the interviewer and interviewee use a second language to communicate and it is a potential source of reduced accuracy and efficiency. The pilot interview was attempting to reduce the chances of this situation happening.

The interviews of the Chinese designers and the Norwegian designers did not occur at the same period due to the author’s schedule. Moreover, the researcher’s interview skills and experience improved with each interview. Consequently, the earlier interviews held in China, have more defects than the interview of the Norwegian designers. This deficiency may be the cause of a bias in the results.

Another issue is individuals within a country differ from each other to a certain extent (Collazos & Gil, 2011) especially China is a large country and have numerous subcultures. However only eight designers in total participated in the interviews, thus the results of the interview only present the individual or small group of people’s opinions.

Further, analysis of open-ended responses is challenging and important since it needs time and skills to separate the good and useful answer from “bad answer” (Lazar et al., 2010).

Chapter 4

4 Discussion

Obviously, the Chinese designers' lack of knowledge about the importance and definition of colour contrast, also how colour contrast ratio can ensure that people with different level of visual impairment can read text. It is not difficult to learn or get skills to estimate how much the contrast ratio it is thanks to existence of many colour contrast analysis tools with WCAG 2.0 support. During the design education, one should stress the importance of colour contrast and introduce WCAG 2.0.

Though the Chinese designers have limited knowledge about WCAG 2.0, they do reference colour schemes from other websites or companies. For example, big companies such as Google or Apple will influence their design styles, includes colour, font and hatching effects, etc. Moreover many websites posts poplar design trends online. For instance, there is an article discussing about "7 Web Design Trends to Look Out for in 2014"[12] on the website justcreative.com, a design portfolio and blog running by Jacob Cass. In the colour section, this blog suggest placid blue, violet tulip, hemlock, sand, paloma, cayenne, freesia, celosia orange, radiant orchid, dazzling blue with HSL value as fashion colours in 2014.

Figure 4.1 Colours suggested in justcreative.com[12]

[12] Reproduced from http://justcreative.com/2014/01/21/2014-web-design-trends/

Check to see if the colour contrast between these colours as background with white text as shown in the Figure 4.1 are shown in the Table 4.1.

Table 4.1 Colour contrast ratio of the website recommendation

Colour combination	Colour Contrast ratio	Large Text	Normal Text
Placid Blue vs White	1.69:1	Failed	Failed
Violet Tulip vs White	2.85:1	Failed	Failed
Hemlock Greenvs White	1.76:1	Failed	Failed
Paloma Grey vs White	2.17:1	Failed	Failed
Sand Brown vs White	2.00:1	Failed	Failed
Freesia Yellow vs White	1.41:1	Failed	Failed
Cayenne Red vs White	3.25:1	Pass	Failed
Celosia Orange vs White	2.67:1	Failed	Failed
Radiant Orchid vs White	3.66:1	Pass	Failed
Dazzling Blue vs White	5.54:1	Pass	Pass

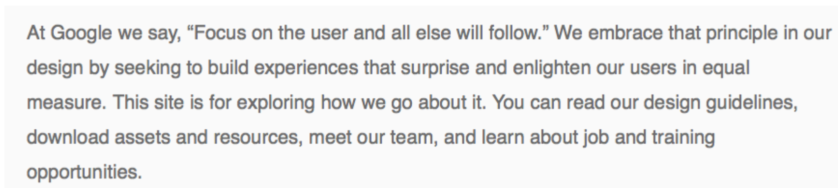
Only one colour combination, dazzling blue and white pass success criteria 1.4.3 Contrast (Minimum). Meanwhile, two other combinations, Cayenne Red and Radiant Orchid with white text pass the criteria for large text. The rest of the colours combinations need different text colours to satisfy the guideline. It is likely that thousands of website recommend thousands of colour schemes, they might suggest inappropriate foreground colour with background colour combinations. The reason leads to this might be 1) the importance and knowledge of colour contrast is not recognized; 2) WCAG 2.0 is not widely known and implemented.

Another problem is that the screen quality varies. Take the colour violet tulip as example, Coloursnapper-a tool to find out the colour of any pixel on the screen-find out the result of hex value of the violet tulip is slightly different from the Figure 4.1 provide, it gives the hex of violet tulip AACCE5 (Figure 20). Under this circumstance, the contrast ratio is 1.68:1, 0.01 lower than the original. In extreme cases, the varying screen qualities may lead to totally different colour contrasts.

Figure 4.2 Coloursnapper catch the violet tulip

Brooks and Bullet (1987) think good designs that accessible to everyone can be acquired by following good practices instead of poor ones, certainly in the premise of they do follow good practices. Nevertheless, the designers might follow poor designs (such as Figure 4.1 shows) in the Internet as well.

Another trend is in recent years, it appears that dark grey have become a popular choice for text colour to replace pure black, however this is only a suspicion and need further validation. Figure 4.3 shows an example of using grey as text colour from Google Design website.



At Google we say, “Focus on the user and all else will follow.” We embrace that principle in our design by seeking to build experiences that surprise and enlighten our users in equal measure. This site is for exploring how we go about it. You can read our design guidelines, download assets and resources, meet our team, and learn about job and training opportunities.

Figure 4.3 Text on Google Design

Standards

Benefits of International Standards
Certification
Management system standards
ISO 26000 - Social responsibility
ISO 31000 - Risk management
ISO 4217 - Currency codes
ISO 8601 - Time and date format
ISO 639 - Language codes
ISO 3166 - Country codes
Education about standards

Figure 4.4 ISO homepage

In RGB, with the exception of black (0,0,0) and white (255,255,255), if the red, green and blue components equals, it is defined as grey. Which colour is the most popular text colour for a majority of websites? One intelligent guess would be black (0,0,0), and it is the most simple and safe choice in term of black text with white background is the maximum contrast in any colour system. But sometimes too high contrast between design elements might give an unsettled and messy impression.

Site	Domain	Alexa traffic rank (June 2014)[2]	Google Display Network Ad Planner	Type
Google	google.com	1	[Note 1][Note 2]	Search
Facebook	facebook.com	2	1	Social networking
YouTube	youtube.com	3	2	Video sharing
Yahoo!	yahoo.com	4	3	Search
Baidu	baidu.com	5	8	Search
Wikipedia	wikipedia.org	6	6	Reference
Tencent QQ	qq.com	7	10	Portal
Taobao	taobao.com	8	14	Commerce
Twitter	twitter.com	9	15	Microblogging / Instant messaging / Social media
Windows Live	live.com	10	4	Portal and search engine

Figure 4.5 List of most popular websites

Table 4.2 Test colours and background colours in the top ten popular websites

Site	Main headline Colour	Text Colour	Background
Google	(0,0,0)	(125,125,125)	(255,255,255)
Facebook	(20,24,34)	(20,24,34)	(255,255,255)
Youtube	(0,124,192)	(95,95,95)	(255,255,255)
Yahoo	(49,84,220)	(95,95,95)	(255,255,255)
Baidu	(1,23,195)	(51,51,51)	(255,255,255)
Wikipedia	(0,0,0)	(37,37,73)	(255,255,255)
Tecent QQ	(0,117,186)	(44,55,85)	(255,255,255)
Taobao	(0,0,0)	(119,119,119)	(255,255,255)
Twitter	(41,47,51)	(41,47,51)	(255,255,255)

As the Table 4.2 shows, four varies grey were used in five website.

None of the top ten website text colours for content is black (0,0,0) while their backgrounds are all white (255,255,255). Apparently the all foreground colours are the darker than background colours. Usability guidelines (Leavitt & Shneiderman, 2006) suggest to use black text on a plain, high-contrast background as it elicited reliably faster reading performance than medium-textured background.

W3C created the WCAG 2.0 colour contrast success criteria based on ISO-9241-3 and ANSI-HFES-100-1988. Due to this dissertation’s argument is discussed under WCAG 2.0 is the standard, even though the designers regard colour contrast as an profound important element in their design, the 4.5:1 the interviewed Chinese designers think colour contrast ratio standard might decrease their creativities. However, maybe WCAG 2.0 is too strict, apparently the Chinese designers lack of the awareness of accessibility or universal design.

Senior designers are clearer about which colours they need to use than that is for junior designers. The junior designers typically seek help from colour matching websites.

Chinese designers learn to reference the ready-design colour combination probably on the basis of culture influence, Chinese value and respect teachers, predecessors. On the other hand, interviewed Norwegians tend to have more confidence about their creative ability. Nevertheless, the young Norwegian generation seem like to break the rules, hence they tend to innovate mostly by themselves. Interestingly, Chinese designers collective show resistance to guideline WCAG 2.0 meanwhile Norwegian designers are more willing to accept and follow it (Hoftede et al., 2010).

In the design industry, customers are not only the person who use the product, but also the first party who purchase the design itself. Therefore, in practical projects, to avoid design rework and improves efficiency designers need to communicate with clients and understand their requirements first, and then propose several design draft for client's conformation (Ma et al., 2009). Customers’ needs and demands certainly impact the designer’s colour selection. Nevertheless, the phrase “customer is god” does not literally mean that the designers must obey every wish.

Since design is such an objective subject, individual has diversely opinion towards the same design. Occasionally, client rejects the design over and over just because the design failed to impress them or the customer simply did not feel right. However, irrespective of the industry the designers work in, numerous guidelines in different industries exist to guarantee the product is reliable. For instance, ISO 9000 provides standards for companies and organizations to ensure the product meet user requirements. Similarly, WCAG 2.0 provides the companies and guidelines from different organizations and tools to improve quality of the product. Hence, product designers come out with a design that conforms to the regulations.

According to the interviews of Chinese designers, neither the designers nor the first party know

WCAG 2.0, even if the designer know the guideline, the customer who own the design certainly has the right to say no and demand changes. Here comes the key problem, how to balance the implementation of the standard and “customer is god”? It is the designers’ responsibility to inform the first party that enough colour contrast can ensure that most users receive the information from the website. In countries that has mandated WCAG by law such as Norway, the government has the right to inspect and instruct the website at any time (exceptions not included), this makes it easier for the designers to persuade clients to follow WCAG to avoid punishment from government. Further, as more users gain good experience and satisfaction from the website, more profits will be earned by the clients.

If the design is going to be in print, then the colour should be adapted to ensure it can survive printing. Photoshop gives gamut warning when the colour lies outside of what printers can display. The real question is what the designer should do once they identify them.

The reason all Chinese designers choose blue or green for the travel company design may be because China is a rapidly developing country, due to the pressures of work and life caused by huge populations, Chinese tend to travel for relaxation and rest. On the contrary, adventure tours might be the paradise for Norwegian and red or orange could be the first choice. Another explanation is Norwegians prefer warm colours on holiday sites because they want to travel to a warm place that is different to the cold Norway.

Therefore, the colour selection is adapted to their travel preferences.

After the interview with the Norwegians, the following conclusion is made.

One Norwegian designer complained they only learned half an hour about colour contrast during the whole two years of design study, but they are now required to design colours that meet standard such as WCAG. This is a challenge for them as beginners, requirements other than colour contrast in WCAG made this situation even worse.

Once the contrast ratio failed to achieve the requirements, either the designers enhance the background colour saturation or reduce the background lightness. Then they felt that the design has lost the fresh and clean appeal. Another noticeable observation is at the reselect colour process, the designers seemed forget their original design intention. Instead of them initiative design a colour which meet the guideline, it turned out they are forced to find a colour can be approved by WCAG. In a way, consider colours that meet colour contrast limits their independent creative thinking and design processes. This dilemma supports the need for the tool proposed in this dissertation and that it is profoundly important to the website design industry.

One may guess that senior designers have more experiences and knowledge about how to adjust the colours without compromise too much on the original conceptual design. Whether dealing with clients or guidelines, the experienced designers have more confidence and skills to satisfy both than juniordesigners. Designers that just enter into the design industry lack experience and skills as they are challenged by clients queries and new standards. Consequently, one may speculate that they are inclined to subconsciously reject and resist potential obstacles. Since WCAG is mandated by law in Norway, Norwegian website designer should know better about the importance of colour contrast and accept it more easily. Moreover, culture could impact on this issue as well, as previously addressed, Generally, the Chinese are relatively conservative compared to innovative Norwegians when designing, hence maybe this is the reason why the interviewed Chinese designers hold more conservative opinion on WCAG.

According to a PDI (power distance index) survey across France, Germany and Great Britain, in fact that less-educated, low–status employees in various western countries hold more “authoritarian ” values than their higher-status compatriots had already been described by sociologists (Hofstede, 1991).

Moreover, in the book “Cultures and Organizations: Software of the Mind”, the authors revealed several index in different countries and regions to measure the values in comparative research on culture. It uses a statistical analysis of the answers on questions about the values of similar IBM employees in different countries revealed common problems.

The first one is inequality in society (the power distance index for 76 countries and regions based on three items in the IBM database plus extensions):

Table 4.3 Inequality in society (Hoftede et al., 2010)

Rank	Country	Index
12-14	China	80
69-70	Norway	31

In societies with large power distances such as China tend to hold the value that the powerful should have privileges in the meantime Norwegian believe everybody should have equal rights (Geert Hofstede, 2010). This difference may make it understandable why the Chinese designer think it is not necessary to follow the colour contrast guideline on account of the website is not designed for everyone anyway.

Table 4.4 shows the cultural dimension of individualism in society (individualism Index Values for 76 countries and regions based on factor score from 14 items in the IBM database plus extensions(Hoftede et al., 2010)):

Table 4.4 Individualism in society (Hoftede et al., 2010)

Rank	Country	Index
17-18	Norway	69
58-63	China	20

The higher index, the more individualistic the culture is. According to their theory, China is typical on the collectivist side. In individualist societies, everyone is expected to have a private opinion, hence people can speak out their minds loudly without hesitating. In China, group determination is more important than individual values. This theory may possible explain the logic the Chinese designer said she do not have any opinion about the design software she used, because she is not capable to change the software in any circumstances.

Table 4.5 present the cultural dimension of masculinity-femininity in society (Masculinity Index Values for 76 countries and regions based on factor score from 14 items in the IBM database plus extensions(Hoftede et al., 2010)):

Table 4.5. Masculinity-Femininity in society (Hoftede et al., 2010)

Rank	Country	Index
11-13	China	66
75	Norway	8

Resolution of conflicts in femininity society such as Norway, is to compromise and negotiate, thus it requires little effort to solve the problem when there is argument between the designers and clients. In Chinese culture, people resolve conflicts by letting the strongest win.

Table 4.6 reveals the cultural dimension of avoidance of uncertainty in society (Uncertainty Avoidance Index Values for 76 countries and regions based on three items in the IBM database plus extensions(Hoftede et al., 2010)):

Table 4.6 Avoidance of uncertainty in society (Hoftede et al., 2010)

Rank	Country	Index
59	Norway	50
70-71	China	30

Norway and China both have relatively weak uncertainty avoidance, which indicate if not strictly necessary, there should be no more rules in these two societies. Also, this is the closest rank Norway and China share among the indexes.

Table 4.7 shows the culture dimensions of long- and short-term orientation (Long-term Orientation Index Values for 93 countries and regions based on factor scores from three items in the world values survey (Hoftede et al., 2010)):

Table 4.7 Long- and short-term orientation (Hoftede et al., 2010)

Rank	Country	Index
4	China	87
57-58	Norway	35

China acquired very high index value at long-term orientation and Chinese have better performance at mathematics of fourteen-year-olds. Meanwhile same age Norwegian teenagers show no special skills for mathematics due to they put less effort on mathematics. This difference may be the reason why Norwegians seemed to reject attempts to understand the formula when showed the calculation of colour contrast. On the other hand, Chinese designers who have either technical background or artistic background showed more confidence at explaining the calculation.

Subjective well-being (Indulgence Versus Restraint Index scores for 93 countries and regions based on factor scores from the three items in the world values survey (Hoftede et al., 2010)):

Table 4.8 Subjective well-being (Hoftede et al., 2010)

Rank	Country	Index
31	Norway	55
75	China	24

Compare to China, Norway is a relatively indulgent society. One key difference of the two countries is Norwegian hold higher optimism and Chinese are more pessimistic.

Except tolerance of ambiguity in society, Norway and China ranked significantly difference on inequality, individualism, masculinity-Femininity, song- and short-term orientation and Subjective well-being in society. The minimum discrepancy appeared at the tolerance of ambiguity in society, which the two countries result in twenty differences ranks, obviously distinction between the two cultures in the remain indices. Each index difference may affect the difference value to Chinese and Norwegian designers. Therefore, the following are the possible explanations to the observed differences:

Table 4.9. Possible explanation of the interview results between Norwegian and Chinese designers

Difference between the Chinese and Norwegian designers	Involved Measuring Values
It is interesting to notice that all of the Chinese designers talked about the current design trend, they mentioned it is popular to make design variety rules. Big companies such as Google or Apple will influence the style of the design, includes colour, hatching effect, etc. Chinese held more authoritarian values than Norwegian, they	Inequality; Individualism; Long- and short-term orientation;

trust big companies such as Google, as a Chinese myself, my logic towards this matter is Google is profoundly successful in business, hence it has features catch the users and I should follow them to ensure my design can be accepted by as many people as possible.	
Currently, dark grey might be the popular choice for text colour.	Individualism;
Only one said that it is difficult to use the colour selection in Photoshop, because it don't provide the instant effect to help the designer see the difference between very similar colours.	Inequality;
One said" I can only adjust to the software, I cannot wish for any change, when it updated or changed, I will follow and adapt to it."	Inequality; Individualism; Tolerance of ambiguity;
After they were told that the 4.5:1 colour contrast ratio can ensure that most people see the text content, 3 of them thought it was not worth changing the design to meet the 4.5:1 standard since the website was not for everyone. Since China is a collective society, they consider freedom to adopt their own approach to the job is not crucial as Norwegian consider. They feel safe and perform batter when following the mainstream methods, thus they need more time and effort to accept a not widely recognized standards, let alone it is the first time they heard of WCAG 2.0.	Tolerance of ambiguity; Subjective well-being; Masculinity-Femininity
For senior designers it is clearer about which colour they need to use than that is a junior designer. The junior designers seek help from the colour matching website.	Inequality;
Customers' need and demand impact the designer's colour selection.	Inequality; Long- and short-term orientation;
They all choose green or blue for travel agencies, warm colours such as yellow or pink for pet companies.	Inequality; Individualism; Long- and short-term orientation; Subjective well-being
Senior designers are clearer about which colours they need to use than that is for junior designers. The junior designers typically seek help from colour matching websites.	Inequality;

PART II

Chapter 5

5 Colour picker prototype

Probably, the most common method for colour selection is to use a direct-manipulation colour selection tool called a colour picker (Douglas & Kirkpatrick, 1999). It has been argued that the WCAG 2.0 contrast requirements should be incorporated into the design tools such that low contrast colour combinations are avoided (Sandnes, 2015b). Currently, the existing colour contrast analysis tools discussed previously in this dissertation provide checking features to assist designers test the sufficiency of the contrast. What if the tool skip the checking process and just give the designers valid colour combinations with the required contrast? Therefore in this dissertation, a colour picker tool id described which objective is to help designers perform better when choosing colours based on contrast without checking. Another solution proposed in later section is to enhance the comprehensible of colour contrast section in WCAG 2.0.

5.1 Design phase

The main function of the colour picker tool is that it allows designers to select WCAG 2.0 compliant colours during the design process thus eliminating the need for post-design colour adjustments. Web developers commonly work with hardware oriented RGB (red, green, blue) representations as used in HTML (Sandnes & Zhao, 2015b), thus the RGB colour model was adopted to present the colours. HSB representation (hue, saturation, brightness) was widely used among web designers, however Douglas and Kirkpatrick (1999) pointed out that visual feedback is more important than the actual colour model used. Therefore in this paper HSB was not chosen to be the colour representation.

First, the tool displays the RGB colours, the user selects the first colour freely from all available colours, the RGB values of the chosen colour is also displayed along with the colour. Douglas and Krikpatrick (Douglas & Kirkpatrick, 1999) attempted to compare the user interface accuracy and time used between RGB and HSV colour model. The results indicate that position + effect interface can help users locate the specify colour on accuracy. Further, they also recommended to create explicit and simplified colour selection strategies for inexperienced users.

Next step is chose the different levels of the standard, subsequently, only colours that meet the chosen contrast level are presented and able to be selected. In addition to being a design tool, it also provides a colour scheme filter where only colours that belong to the chosen scheme will be displayed. In order to help the user visualize how the two colours work together, the tool offer two display areas that shows examples of the two colours as foreground and background colour, respectively, and vice versa. The reset feature enables the user to reset the selections and start from the beginning.

Further, since Chinese designers lack experience with implementing WCAG 2.0 into their design, they are not the suitable target group to participate in the design of the picker tool.

On the other hand, according to the interview results, Norwegian designers are familiar with intergrade colour contrast check tools at the final stage of the design phase, they may potentially fall into the traditional design circle (see Figure 5.1) once they get used to with contrast analyzer tools. Since this tool is intended to explore the usefulness new design concepts, no web-designers were involved throughout the design process of this tool. Since the most important concept in 'User centered design' (UCD) is that users are involved one way or another (Abras, Maloney-Krichmar, & Preece, 2004). The prototype in this dissertation is not a product for business reason, it is trying to explore a new knowledge that the designers are not familiar with. Hence, this picker tool is not developed using a user-centered method, but it is intend to help the designers save time and effort on colour selection in terms of meet contrast standards.

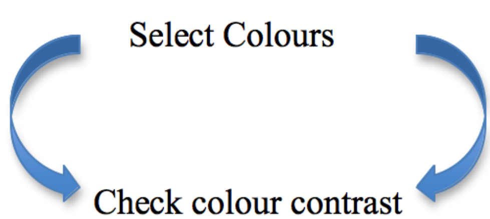


Figure 5.1 Traditional design circle based on checking colour contrast

5.2 Colour picker Sketch

WCAG 2.0 has two colour contrast success criteria, minimal and enhanced, based on the two levels the sketch designed into different features to meet Level AA and Level AAA.

Unlike the colour contrast analyzer tool which make the designers check contrast ratio after the colour selection is done, this tool provides users with the valid colour combinations with the given colour contrast. Figure 5.2 is the sketch of the interface of colour picker. All colours in the RGB colour model were presented in the little squares. Each square is a unit that displays colours in this order: from left to right the red is added; from top to bottom the colour is green is added and in this square the blue is the same intensity. The blue component is gradually increased between the squares next to each other. Once the user chose one colour from the squares and select which WCAG success criteria they intend to achieve, then the left colours presented are those colours can provide enough colour contrast correspond to the chosen colour at the beginning.

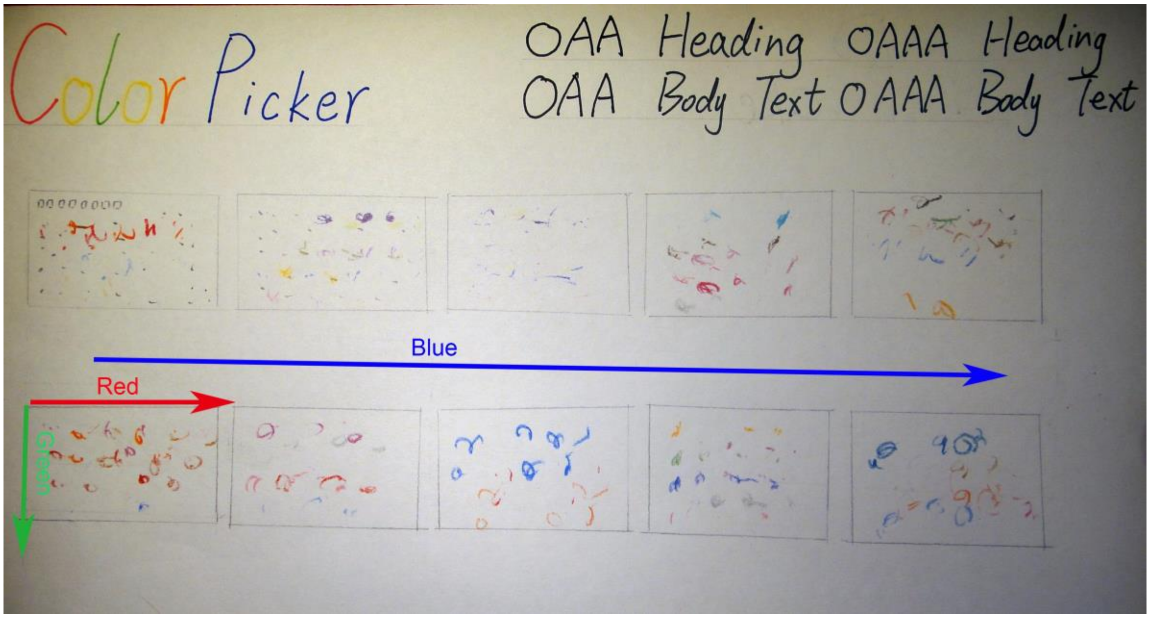


Figure 5.2 Interface of colour picker. The blue, red and green lines and arrow show the order to display colours

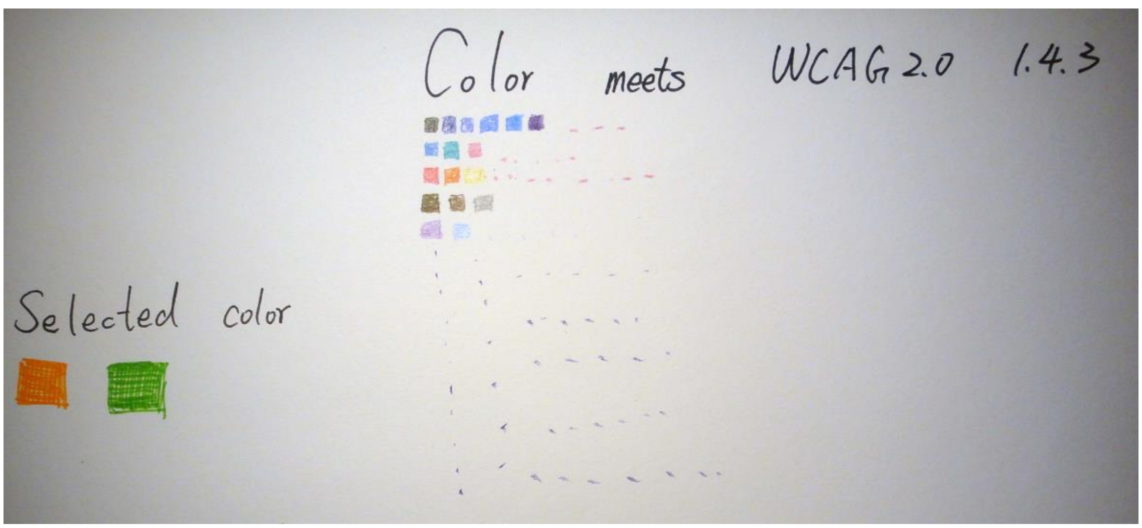


Figure 5.3 Only valid colours meet WCAG 2.0 display

Under this feature (Figure 5.3), the left area of Figure 8 is the selected colours presentation. The right area removes the colours that do not meet the success criteria and only left the colours meet the requirement.

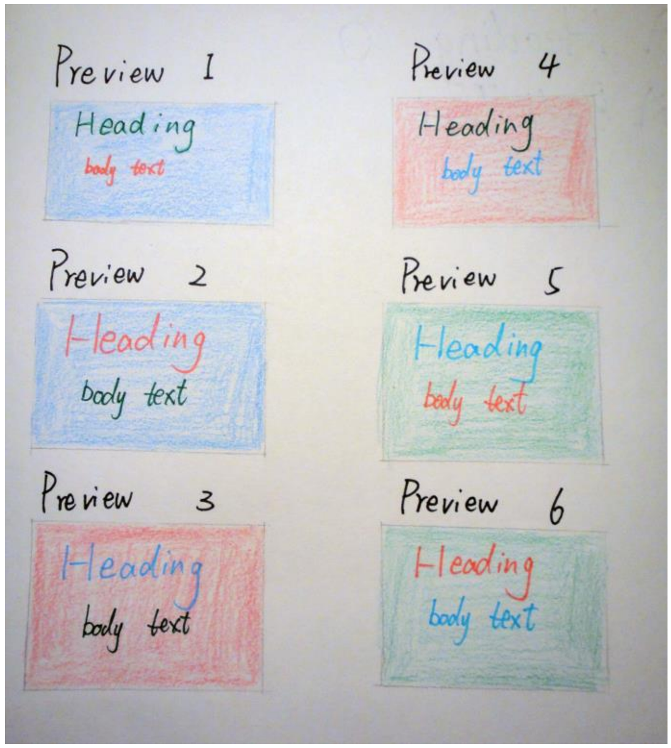


Figure 5.4 The preview feature

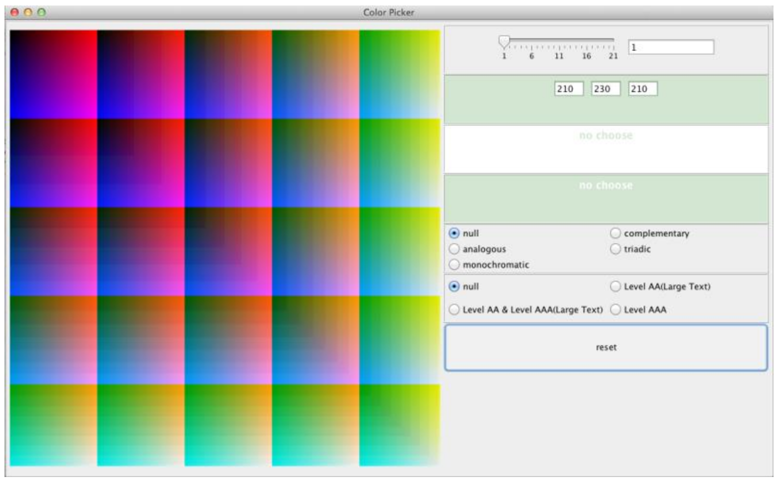
The colour picker does the colour permutation and combination. Figure 5.4 shows how colour picker present the colour combinations when the user chose three colours, blue, pink and mint. First, two previews use blue as background colour, then mint and pink as the heading and body text colour each time. Preview 3 and 4 set pink as the background colour while preview 5 and 6 use mint. This feature can clarify the variations of the three colours combination and make the visual performance vivid to the users.

Figure 5.2 to 5.4 are just three basic functions in the colour picker tool, there are more features such as colour scheme suggestions. However, these addition features were carefully designed to avoid it restricting the designers' thoughts. The features and functions were designed first, but the interface of this tool is not determined at this stage.

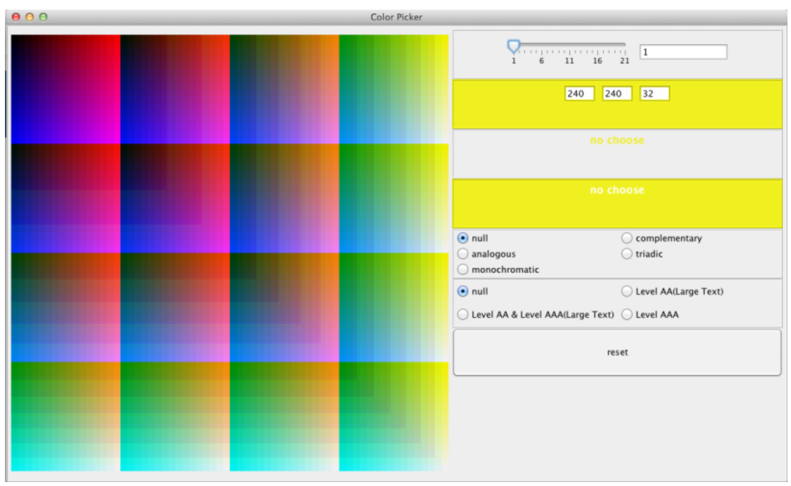
5.3 Colour picker Prototype

An interactive prototype colour picker tool based on the colour picker sketch was developed in JAVA. First, the tool displays a representation of the entire RGB colour space. According to a study by Douglas and Krikpatrick (Douglas & Kirkpatrick, 1999) , they suggested that a particular colour model used may be a less important factor than visual feedback and design of the interface in improving the usability of a colour selection interface.

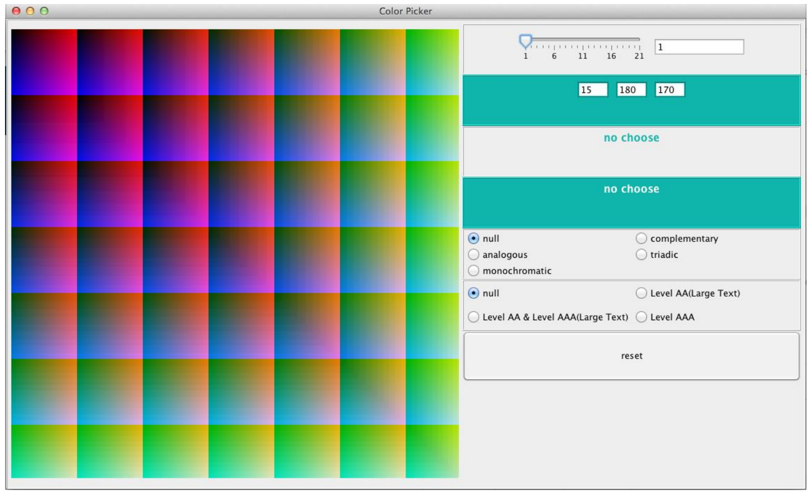
For simplicity and make things visible, the prototype employs the hardware oriented RGB colour space, where the cube is projected to the display real estate as slices of the red-green colour plane for various levels of the blue component. Hence, the representation is a grid of red-green colour planes (Sandnes & Zhao, 2015b). Since not all colours are displayed from the colour space, the colour picker tool can be switched to three version of colour representation to meet different needs (see Fig.5.5 (a)(b)(c)). Setting the variable “whatnumber”(see Appendix D) to 1,2,3 can change to correspondence interface of the colour representation. The entire colour space represented using red-green plane slices for different levels of blue.



a



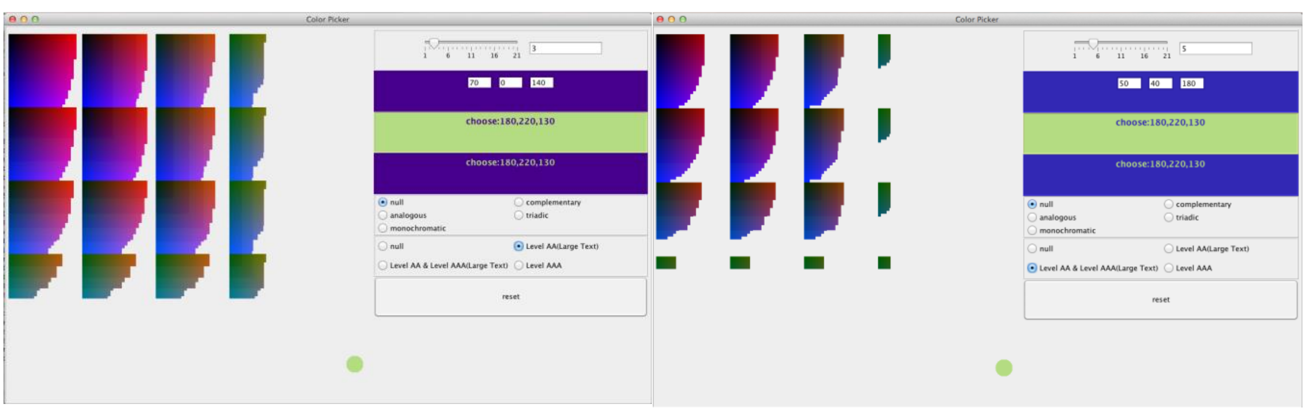
b



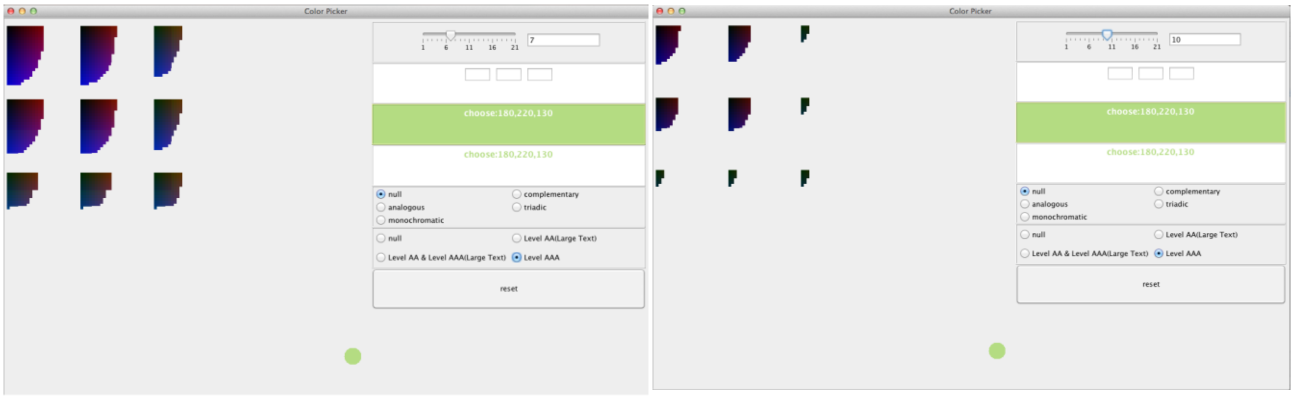
c

Figure 5.5 Three versions of display RGB space colours.
Interval of a) 10 RGB values b) 16 RGB values c) 5 RGB values

When the variable “wahtnumber” equals 1, in each colour grid, from left to right each colour increases in steps of 10 red values (Figure 5.5a), from top to bottom each colour increases in steps of 10 blue values. As variable “whatnumber” equals 2 or 3, the increase is 16 or 5 values (red, blue) respectively. Green values increase based on different grids.



a b

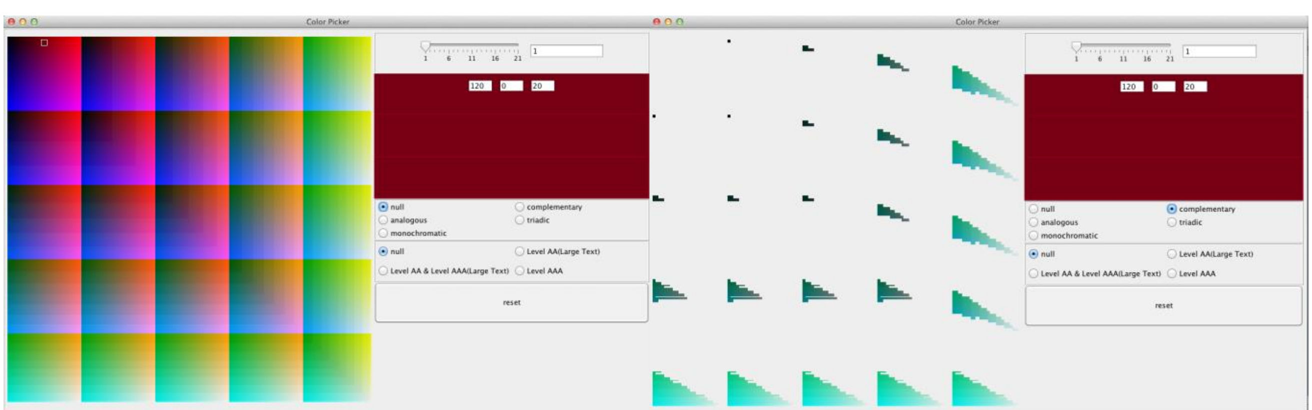


c d

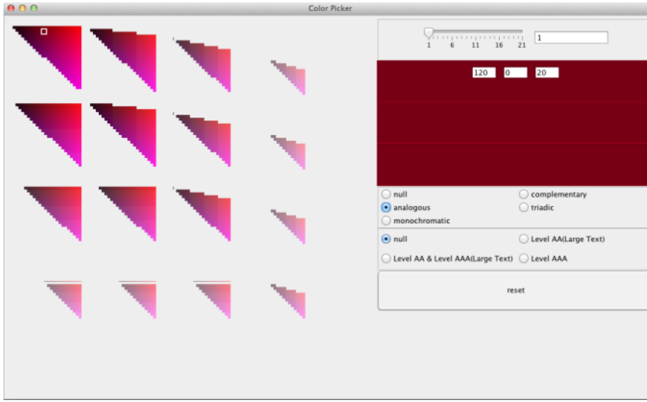
Figure 5.6 Varying contrast level: Valid colours after selecting a light green a) with contrast level 3 (aa headings), b) with contrast level 4.5 (aa body text), c) with contrast level 7 (aaa body text) and, d) with contrast level 10

Once the user selects a colour in the colour space the chosen colour is highlighted with a little square and the RGB values of the colour is shown in the three test fields. Moreover, all the colours that do not adhere to the chosen contrast level are disabled and only valid colours are displayed.

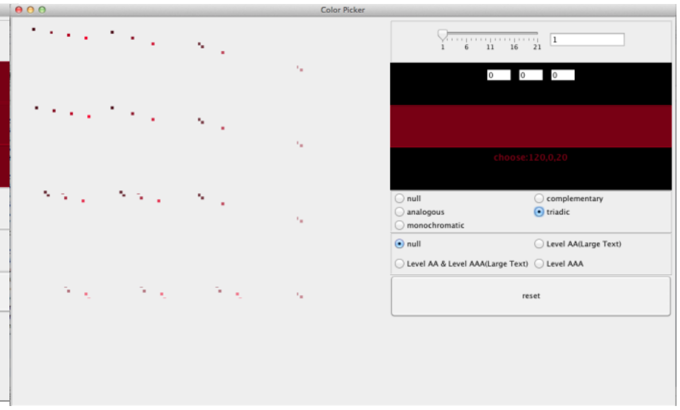
There are two ways to set the contrast level, either by using contrast slider or choosing the three specific WCAG 2.0 level radio button directly, that is level aa for heading (3:1), level aa for body text (4.5:1), level aaa for headings (4.5:1) and level aaa (7:1) for body text (Sandnes & Zhao, 2015b). Since the highest colour contrast ratio is between black and white and the lowest figure is between the same colour that is 21:1 and 1:1, the range of the slider is 1 to 21. Further the colour contrast ratio of level aa for body text and level aaa for headings are both 4.5:1. The decision was therefore made to combine these two standards together into one button. The effects of selecting different contrast levels are illustrated in Figures. 5.7 a, b, c and d.



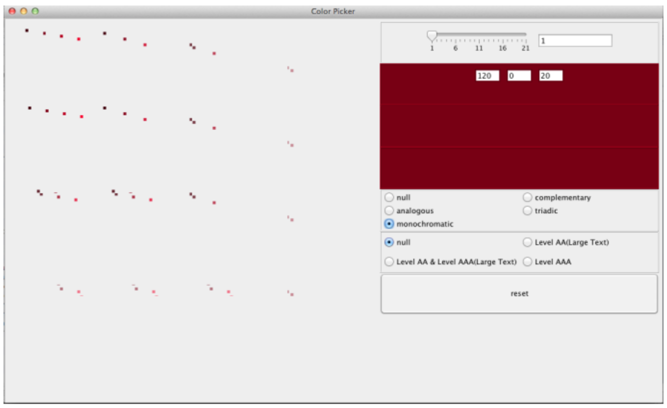
a b



c



d



e

Figure 5.7 Colour harmonies: a) Fist select a dark red values (120, 0, 20), Valid colours after selecting a dark red with contrast level b) with a analogue colour harmony 3, c) with a monochrome colour harmony, d) with a complimentary colour harmony, e) with a triadic colour harmony

There are certain colours that look better together, while other colours looks uncomfortable or even painful to human eyes. Due to this reason designers are frequently employ colour harmonies in their designs such as monochromatic colours, analogous colours, complementary colours, triadic colours, split complementary, etc. The colour harmony filters are demonstrated in Figures 5.7 (Sandnes & Zhao, 2015b).

Colour systems of primary, secondary, tertiary, complimentary, tertiary and analogous are important reference points in graphic design, but often lack practical application. Once the designers start to know colour schemes, paying attention to contrast in colour schemes is what allows a designer to create a hierarchy of information (Weinman, 2002).

Hence the tool also provided a colour harmony filter that allows designers to immediately see all the contrast compliant colours with a specific colour contrast. This further limited the colour space and gives the designer an even smaller palette to choose from and hopefully leads to more rapid design process, because fewer colours are valid (Sandnes & Zhao, 2015b).The colour harmony filters work with given colour contrast are demonstrated in Figure 5.7, all the valid colours based on the first light green colour values (100, 190, 100). According to Itten and Van Haagens (Itten & Van Haagen, 1973) research, they were one of the first to define and identify colour wheel relations between hues. The colour wheel is divided in twelve sections. Some colour combinations that are considered especially pleasing are called colour harmonies or colour chords and they consist of two or more colours with a fixed relation in the colour wheel.

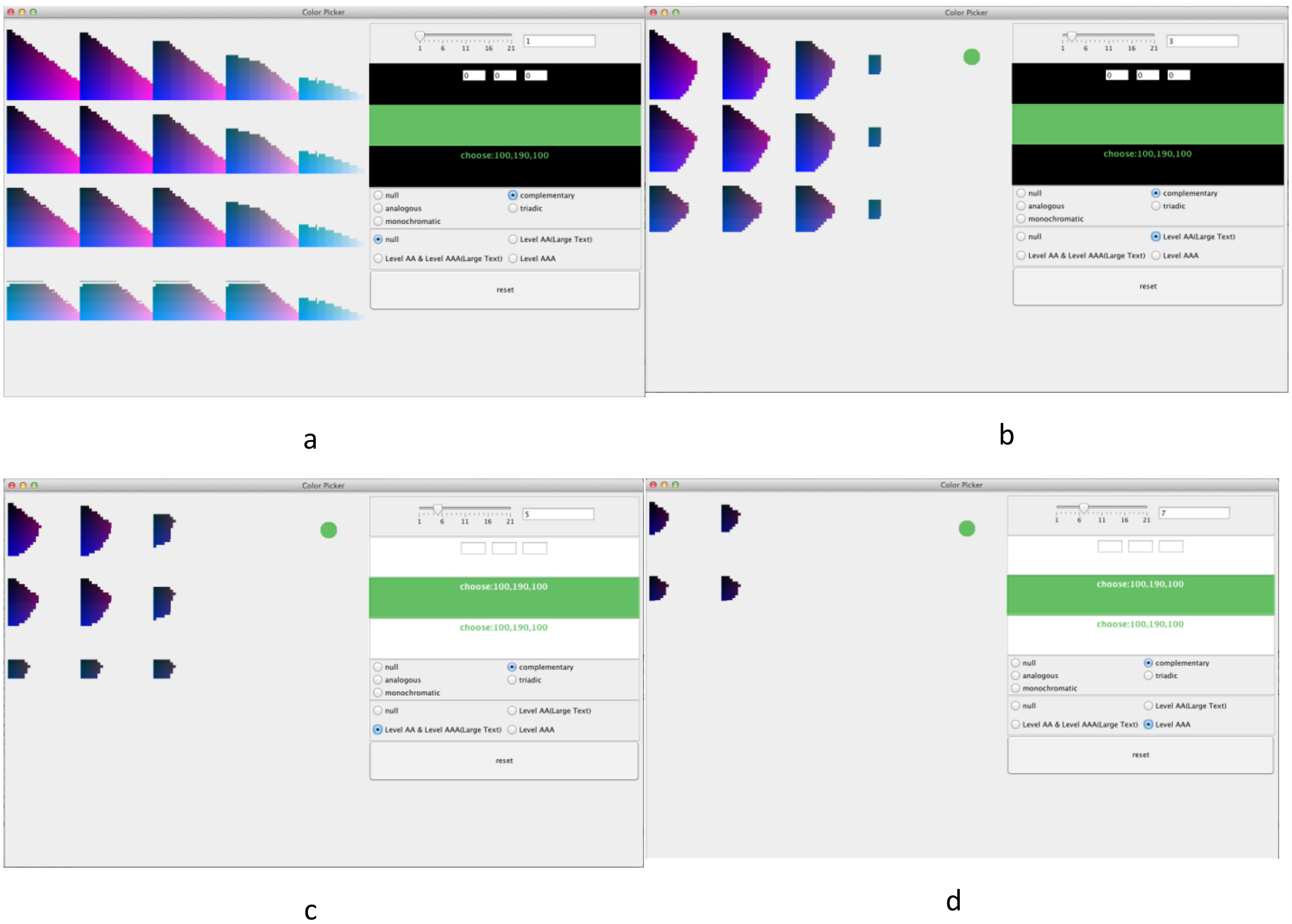


Figure 5.8 Complementary colours with different colour contrast. Valid colours with a complementary colour harmony after selecting a light green a) without contrast level, b) with contrast level 3, c) with contrast level 4.5, d) with contrast level 7

Complementary colours are colours where hues are on the opposite side of each other on the colour wheel such as red and green, which means they are 180 degrees from each other. From Figure 5.8a, without any contrast requirement, the opposite colours of the chosen green (100, 190, 100) are some blue-pinkish colours. As the contrast requirements get higher, the set of valid colours become smaller. After clicking the button for Level AAA for body text, only some dark purple colours can be selected in terms of meet the standard.

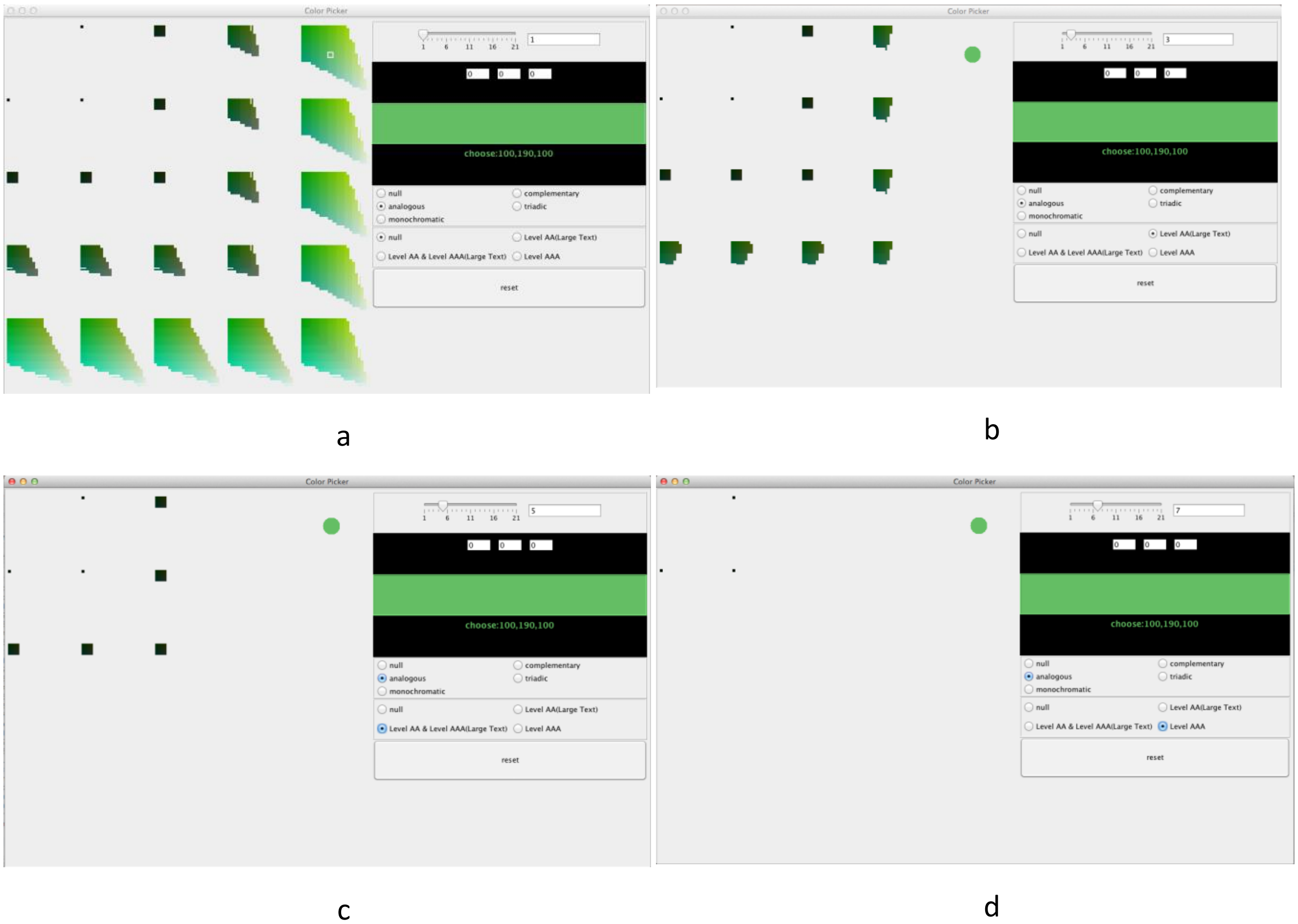
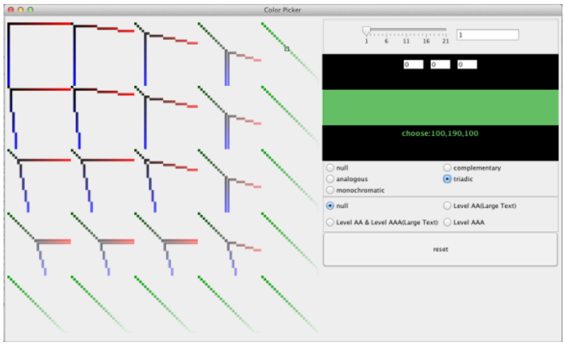
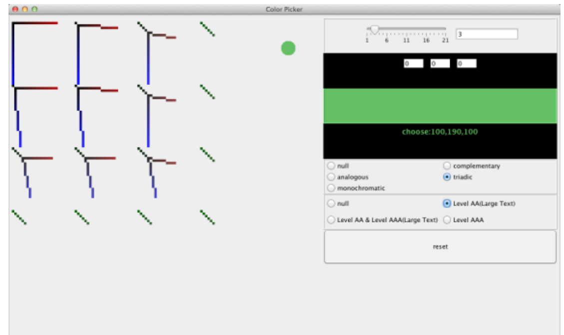


Figure 5.9 Analogous colours with different colour contrast. Valid colours with a analogous colour harmony after selecting a light green, a) without contrast level, b) with contrast level 3 c) with contrast level 4.5 d) with contrast level 7

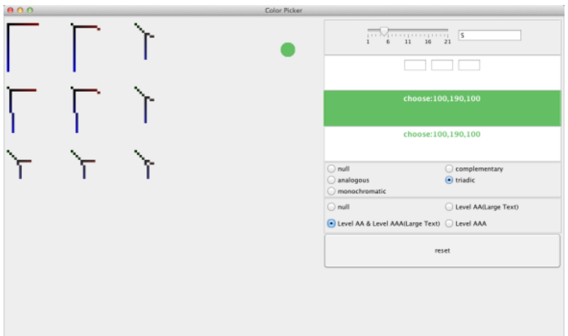
Analogous colours are colours where the hues are next to each other on the colour wheel, in this colou picker tool mean they are within 15 degree from each other. Figure 5.9a shows the analogous colours of the chosen green without contrast constraints, apparently they all share similarities at their root.



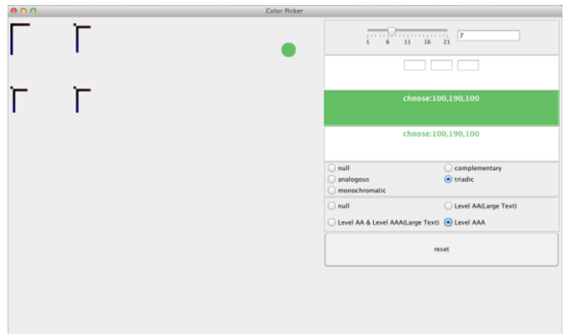
a



b



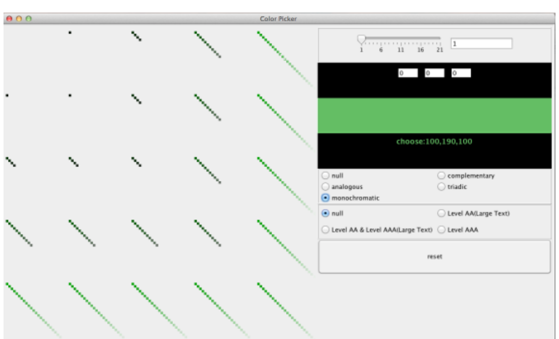
c



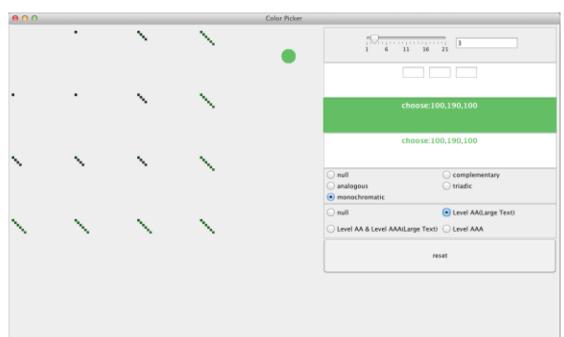
d

Figure 5.10 Triadic colours with different colour contrast. Valid colours with a triadic colour harmony after selecting a light green a) without contrast level, b) with contrast level 3, c) with contrast level 4.5, d) with contrast level 7

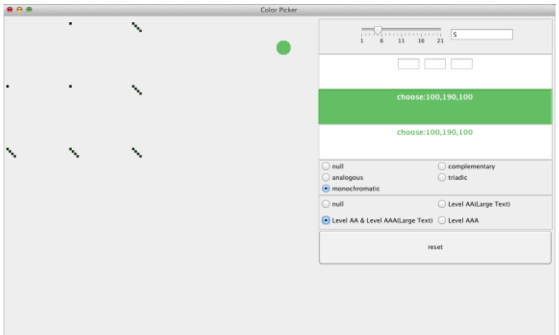
A triadic colour scheme uses colours that are of evenly distance from each other on the colour wheel, which means they are 120 degree from each other (Figure 5.10).



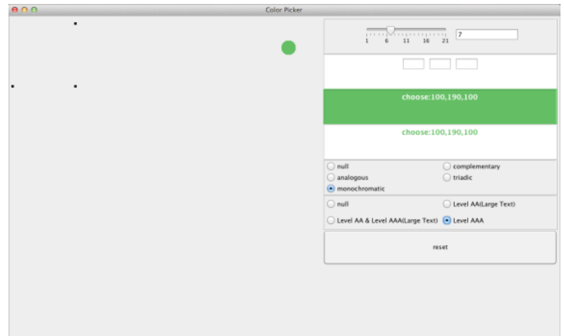
a



b



c



d

Figure 5.11 Monochromatic colours with different colour contrast. Valid colours with a monochromatic colour harmony after selecting a light green, a) without contrast level b) with contrast level 3, c) with contrast level 4.5, d) with contrast level 7

The monochromatic colour scheme uses variations in lightness and saturation of a single colour on the colour wheel, which means they share the same hues from the basic colour wheel and repeating it in various tints, shades and tones. In Figure 5.11a, the same light green has been selected. The monochromatic colours of this chosen colour share same hue, thus they are all greenish colours.

5.4 Other possible solutions

It is difficult for beginners to learn web accessibility and make implementations only through reading the guidelines and following them in the development process (Al-Khalifa & Al-Khalifa, 2011). Providing higher education facilities for web designers and web developers follwing WCAG 2.0 can help the designers who just begin work in websites understand and implemant the standard quickly and correctly. More countries have embraced the idea of requiring websites to comply with WCAG 2.0 as law, a trend towards integrating the need for Web Accessibility in the legislation can be recognized (Ortner & Miesenberger, 2005).

As it is expected that web designers and web developers will follow WCAG 2.0, the need for experts and curriculum in the field of Web Accessibility will increase. Thus, to help the designers and developers perform better at colour selection in terms of colour contrast, both education organizations and business companies should offer education in the field of Web Accessibility to increase the designers' awareness and abilities. For instance, Ortner and Miesenberger (2005) made a proposal of a curriculum to meet the need of web accessibility education. They divided the courses into six modules contains and each module contains appropriate lectures. This gives the designers and developers a chance to gradually get familiar with accessibility issue before their actual implementation.

Another possible solution could be to rewriting the colour contrast ratio formulation to readable text. By turning the formula into words may enhance designers' understanding and confidence is another way to help the designers have better performance in selecting colours. Even though the designers get assistance by the tools, they may still lack knowledge about the principles to choose colours based on WCAG 2.0. Thus, the fundamental way to tackle this issue is to improve the designers' ability to chose colours by supporting them to more easily understand the explanation of the WCAG 2.0 success criteria. Unfortunately, WCAG 2.0 is written in an incomprehensible manner. In (Law, Jaeger, & McKay, 2010), the researchers cited from several articles online (Clark, 2006) to support the opinion that WCAG is not easily used:

"If you ever set aside two hours of your life to read a previous ''draft'' of WCAG 2, you were probably baffled and/or infuriated."

"Take a look at WCAG 2 and you'll come up with your own checklist of malapropisms and incomprehensible passages. In fact, so much of WCAG 2 is so hard to understand, and almost impossible to apply to real-world websites, that WCAG 2 is no better than its predecessor in one respect—both documents flunk their own guidelines for clear and simple writing (Clark, 2006)."

There are also other articles that criticize that weird terms used in WCAG 2.0 because W3C intended to cover all possible technologies (Hearnshaw, 2011). In understanding success criteria 1.4.3 and 1.4.6, incomprehensible passages also appears several times such as:

"Note 5: The 18 and 14 point sizes for roman texts are taken from the minimum size for large print (14pt) and the larger standard font size (18pt). For other fonts such as CJK languages, the "equivalent" sizes would be the minimum large print size used for those languages and the next larger standard large print size (W3C, 2008)."

So far, all the respondents asked by researcher to read this note lost the meaning and got confuse. Effort should be put into transfer not only the colour contrast ratio formula to words, but also make the colour contrast explanation in WCAG more comprehensible and simpler to understand.

Chapter 6

6 Method

To validate the sufficiency of the tool, end-user involvement is necessary. The interview results indicated a lack of awareness of accessibility among interviewed Chinese designers and Norwegian designers forget to check the colour contrast at the early design phase. To estimate if this tool can be seamlessly integrated into web designers current flow and routines and assess usability of the tool, usability tests with design students were conducted.

6.1 Participants

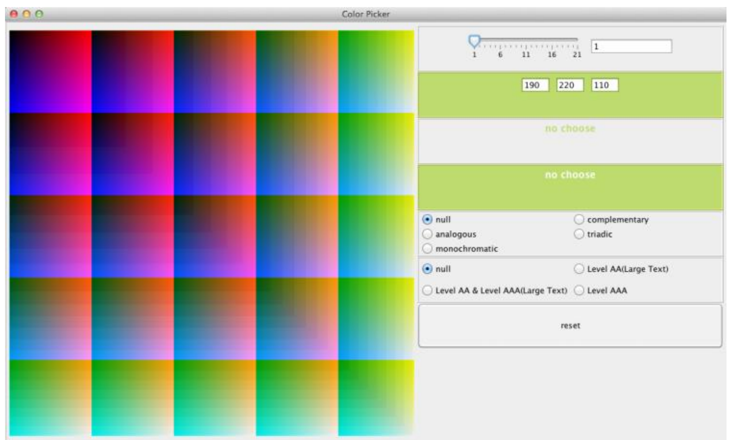
In total there were six designers with various experience. They are all majoring in product design at Oslo and Akershus University College of Applied Sciences and participated voluntarily. Neither age nor gender was explicitly asked in the interview, but participants were observed to range from around 19 to 50 years of age and 4 of them were female. None of them reported systematic knowledge about colour theory and are not familiar with website design. However, due to their lack of technical background, their opinions about colour contrast or WCAG 2.0 might be different from professional website designers and website developers who are used to colour contrast check tools. Finally, participants were tested if they had normal colour vision.

6.2 User testing

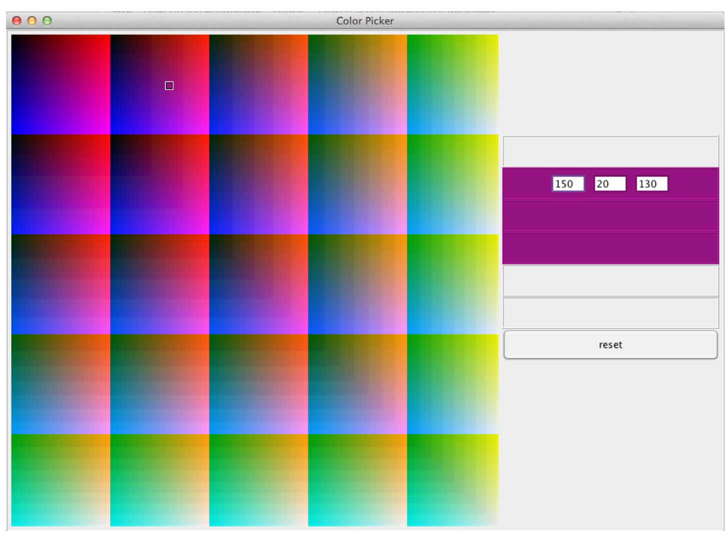
Further, user testing was conducting with product design students in order to assess the usability of the tool, improve the quality of the interface and, eventually, obtain the user experience. The experiment is also designed to reveal designers' behavior in colour selection and the perceptions during their designing thinking process. Initially, the target groups were computer students and product design students at HiOA. Due to the time limitation, eventually six product design students completed the testing. The prototype WCAG colour picker tool was evaluated by six designers in individual talk aloud design sessions and compared to an ordinary non-WCAG colour picker tool with the same colour layout. The participants were asked to adhere to the WCAG 2.0 guidelines in their designs. The ordinary colour picker tool did not constrain the choice of colours and the participants were therefore asked to use a contrast calculator together with the non-WCAG tool. In this way an attempt was made to simulate the current practice in a controlled environment. To minimize learning effects, the participants were told to use the two tools in random sequence to select colours for two websites.

In-depth interviews were deployed during testing to explore in detail the respondent's own perceptions and accounts. However, the interviews are more informal, conversational interviews in order to remain as open and adaptable as possible to the interviewee's nature and priorities. Before the testing begin, interviewees were explained the background of the study and why this study is important.

In this interview, more attention should be paid to how the designers select colors, not on their user experience of the tool. If the participants notice they are evaluating this software the interviewer designed, they might give favorable responses (Lazar et al., 2010) which commonly occurs. In this case, the responses need to be discounted and more focus placed on critical remarks.



a



b

Figure 6.1 a) Interface of the WCAG colour picker tool,

b) Interface of the non-WCAG colour picker tool

Each designer was given two wireframe designs and asked to select foreground/background colours for both heading and body text with the inspiration of a clothes store in summer (see Figure 6.2) and a games website with Japanese cartoon characters (see Figure 6.3), respectively. The whole session is conducted in person and design process of each participant was recorded with a screen recorder and audio files.

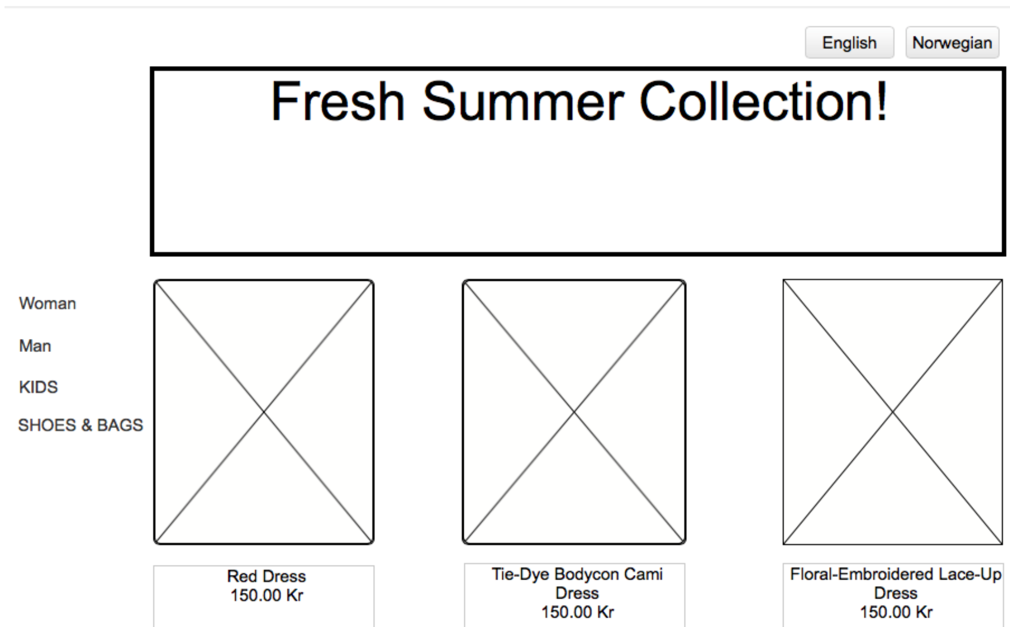


Figure 6.2 Prototype of the cloth website

Figure 6.3 Prototype of the game website[13]

The prototype for the cloth website only provided text content to the participants as their design

[13] Reproduced from http://mario.nintendo.com

inspiration. In the other case, the game website mainly present a colourful image and little text as a design source. This difference was designed deliberately to examine if it will cause changes in the designers' choices on colour selection or design thinking process.

Chapter 7

7 Testing results

This chapter presents correlation results for the compare colour picker testing. All the RGB values of the colours selected by each participant had been documented in appendix C.

This colour picker tool appeared to lack some colours in RGB in colour layout. For example, a participant complained the shades of colour yellow in the tool were all somehow greenish, without the yellow he needed. The colour he finally chose did not fully satisfy the design he envisioned.

When they choose colours for the game websites, they all prefer to pick a colour from the elements in the images given. However they had difficulty finding the exact colour using the colour picker.

An interesting observation was that the designs for the summer collection clothes website fell into two distinct categories. One group preferred warm colours such as yellow and pink, which they associated with sunshine and heat. The other group chose cool colour such as blue and green as these colours were associated with beaches and the ocean. This observation does not directly relate to the utility of the colour picker tool, but rather a unexpected consequence of the experimental design.

The participants provided positive feedback on the WCAG colour picker tool compared to the non-WCAG colour picker tool. Obviously, when the participants use the non-WCAG tool, they need more attempts to meet the standard than when using the WCAG tool.

The sessions revealed that when either the foreground colour or the background colour is black or white it is easier to select colours that adhere to the WCAG 2.0 guidelines. One interpretation of this is that web sites based around black and white may achieve sufficient contract by chance (Sandnes & Zhao, 2015b).

The colour contrast requirement for large-scale text is 3:1, which is less stringent than the requirement for normal text that is 4.5:1. However, four of six participants failed to fulfill the requirement for headings when they use the non-WCAG colour picker tool to choose colours for the cloth website at the first try. Meanwhile, two of six participants failed to pass the standard at the first attempt for normal text when using the same tool to select colours for the clothes website. Thus more participants found it harder to set the heading colours than body text colours, although the contrast limits for headings (3:1) is lower than that for body text (4.5:1).

Two participants asked if they could manually input the values cause it is easier for them to find the colour they need than moving mouse and searching on the colour cubes of the picker tool interface.

One participant failed to achieve a sufficiently high contrast for the body text on the game website using the WCAG tool.

No colours preferred according to gender appeared in the interview. The two male participants selected a pink/yellow colour combination and a green/green colour combination while four female participants chose white/pink, green/green, pink/yellow and yellow/green respectively (see Appendix C).

Chapter 8

8 Discussion

Since the interface of present the RGB colour is not user friendly enough to the designers, it is very possible that our implementation to display the RGB colours need adjust according to their feedback. Therefore the next step should focus more attention on how to present the colour layout to make the designer more quickly locate the colour they need. Another explanation for this situation could be that the presentation pattern of the colour space biases the perception of the colours in an unfavorable manner (Sandnes & Zhao, 2015b).

The designers want to keep consistence in the game website, they wanted to use these given colours as a basis for their design. However, they spent much time finding the exact colour. Previous interview results in Chapter I reveal an important document the clients often bring to the designers, a profile that contains the colours the brand agent company already have chosen for the clients. Often, the file has the company logo colours, product brand colours or colours that highlight the company's culture, etc. A feature such as the dropper tool in Photoshop built into the colour picker would be very helpfulfor this purpose. A future version of the colour picker tool should therefore also incorporate such functionality.

An interesting observation was that the designs for the summer collection clothes website fell into two distinct categories. One group preferred warm colours such as yellow and pink, which they associated with sunshine and heat. The other group chose cool colour such as blue and green as these colours were associated with beaches and the ocean.

All the participants give positive feedback on the WCAG colour picker tool and believe it can save effort and time. Even though the WCAG colour picker tool provides less choice, they found it useful in that it helped them adhere to the WCAG 2.0 colour guidelines and hence saved time and effort by not having to use colour contrast calculation tools after each selection.

However, one negligence during the user testing is that the participants were not told the sessions were being timed and during the design session they are free to share their ideas and explain opinions. Due to this reason, the timing observations had to be discarded. Future tests should also record the colour selection time in a more systematic manner.

The sessions revealed that when either the foreground colour or the background colour is black or white it is easier to select colours that adhere to the WCAG 2.0 guidelines. In the previously sections, the paper discussed whether WCAG 2.0 is too strict at requiring sufficient colour contrast. However, according to the testing results, four of six participants failed to fulfill the requirement for headings, at the same time two of six participants failed to pass the standard at the first attempt for normal text when using the same tool to select colours for the cloth website. Thus, more participants found it harder to set the heading colours than body text colours, although the contrast limits for headings (3:1) is lower than that for body text (4.5:1). This fails to support the hypothesis that a more strict level of the guidelines necessarily restrict the designers' creativity or performance of the design process.

Participants who are familiar with setting RGB values directly via insert to text fields are able to locate the desired colours more quickly than seeking the colour in the colour space. Therefore the colour picker tool should be redeveloped to provide both direct manipulation and text based modes of input.

The reason why one participant failed on pass the standard for body text on the game website using the WCAG tool was that this participant accidentally set the incorrect threshold to headings instead of body text by clicking on the wrong radio button. And during the testing, neither the participant nor researcher noticed this problem. Clearly, the design satisfied the contrast (3.28:1), constraints for heading (3:1), but not for body text (4.5:1). This result suggests that the user interface of the colour picker tool needs a redesign with the goal of preventing the setting of incorrect thresholds. Otherwise for people have fewer experience and knowledge on the Levels of the guidelines, they get higher opportunity to make mistake at choosing the right button and fail to pass the standard without noticing.

Several studies have investigated gender differences in colour preferences (Ellis & Ficek, 2001). A study conducted in United States college (Silver et al., 1988) found that greater proportions of males chose blue as their favorite colour than females. On the contrary, other studies (Mather, Stare, & Breinin, 1971; Tate & Allen, 1986) revealed that there were no significant differences between men and women in their preferences for various colours. For instance, in this research, the female and male participants showed the same probability to choose blue colours or pink colours for the headings of the cloth company. However, the participants were not asked to explicitly discuss their preferred colours and the scope of the sample is too small, thus this is a guessing and need future study to support. This study is not intending to find the connection regarding of gender difference, but we can assume that profession designers are less affected by gender.

This project proposed a colour picker tool to help website designers providing sufficient contrast in their designs. It offers features including display valid colours based on given colour contrast and different colour scheme filter. According to the comments from the participants, the tool is proved sound, helps save time and improves the chances of meeting the colour contrast standards. However, the sample in the study is relatively small to make general conclusions. Larger sample combined with statistic analysis is proposed for future work.

Chapter 9

9 A HSV-based Colour picker tool

At the final stage of this project, a prototype of colour picker tool using HSV colour representation was developed. Designers often prefer to use other models than RGB such as the HSV model, because it allows designers to reason about colours more closely to how they speak about colours. Often designers refer to the basic hue with adjectives defining the characteristics of that hue. For instance, people can easily comprehend descriptions such as dark red, a saturated green, etc (Sandnes & Zhao, 2015a).

The tool is depicted in Figures 9.2 and 9.3 The main features are reused from the RGB version, such as the inclusion of a preview with foreground text on a background and the inverse. First, the user manually inputs the Hue in degrees, then selects the desired colour harmony (Figure 9.2), sets the desired contrast level and the corresponding colour planes are displayed (Sandnes & Zhao, 2015a). Figure 9.1 shows the half section of the HSV model is a triangle, thus the colours in the tool are displayed in a triangle.

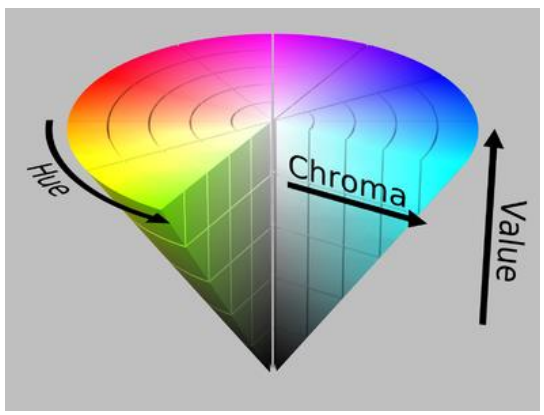


Figure 9.1 HSV colour model [14]

This HSV version of the colour picker tool requires the user have some basic knowledge about the HSV colour model, that is it needs the user to insert the Hue value. If the user is not familiar with the properties of a colour, he or she will face the challenge to find the desired colour. Unlike the RGB colour picker tool that presents all colours to the users, this HSV version only presents colours corresponding with the Hue value and the chosen colour scheme. This approach is thus challenging if the user wants to choose colours other than the ones related to the Hue and colour scheme. Thus, due to these practical reasons (limited time), this tool has not been user tested, but developed merely as a proof of concept.

Figure 9.2a displays the complementary colours of whose colours with Hue value 200°. That is, all

[14] http://en.wikipedia.org/wiki/HSL_and_HSV

the colour presented in the Figure 9.21 are with Hue value 20°. Figure 9.2b displays the analogous scheme of colours with Hue value 200°, the upper triangle (blue) and lower triangle (green) present colours locate 230° and 170° at the colour wheel respectively. Similarly, Figure 9.2c shows the triadic colur scheme. The upper triangle (pink) and lower triangle (yellow-green) present colours locate 320° and 80° at the colour wheel.

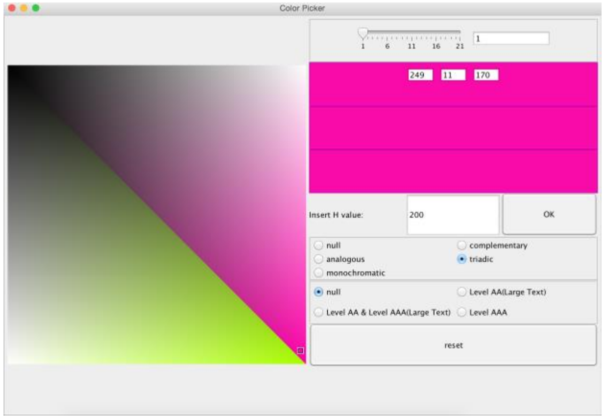
a

b

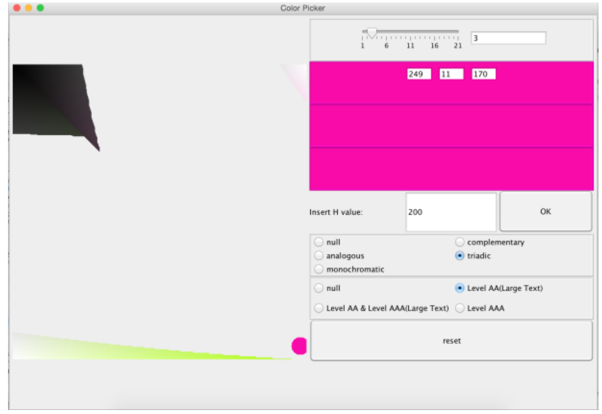
c

Figure 9.2 Colour harmonies. First select insert Hue values (200), a) colours with a complementary colour harmony, c) colours with a analogous colour harmony, d) colours with a triadic colour harmony

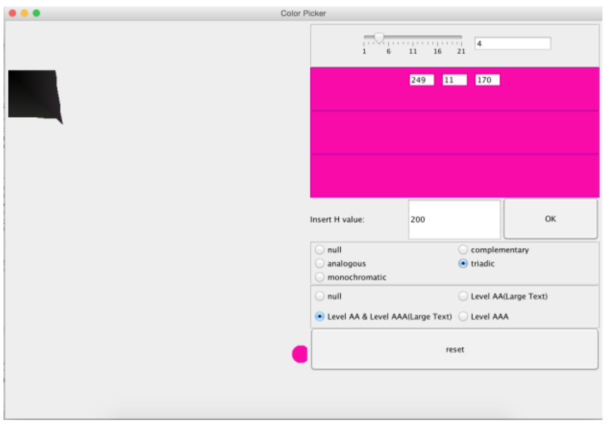
Figure 9.3 shows an example after choosing a pink colour with triadic scheme under different contrast levels of contrast levels. As the level of contrast gets higher, the valid colours meet the standard become fewer. There is no colour can be selected to meet level aaa for body text.



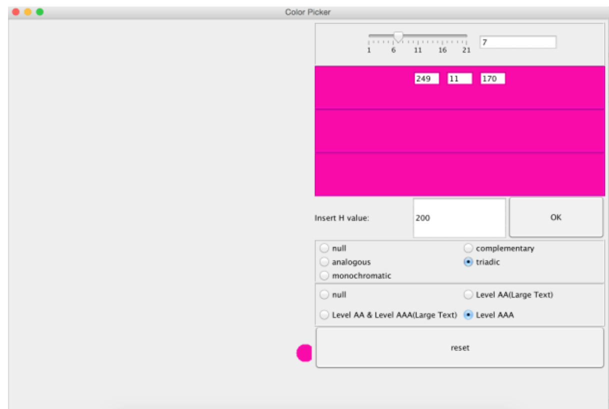
a



b



c



d

Figure 9.3 Varying contrast levels: Valid colours after selecting a light pink with triadic scheme, a) with contrast level 3 (aa headings), b) with contrast level 4.5 (aa body text), c) with contrast level 7 (aaa body text) and, d) with contrast level 10.

Chapter 10

10 Conclusion

This dissertation presented a qualitative two-stage study of what is graphic/website designers' practices on working with colour contrast and to what extent they understand the WCAG 2.0 success criteria. In addition, this work analyzed what the colour design process in website design is, how website designers make colour selections, proposed colour picker tool that display valid colours based on WCAG 2.0 colour contrast standard wand suggested that both educational organizations and businesses offer curriculums on web accessibility. Further, user testing was conducted to assess the usability of the tool and the user experience. It proves a tool that is efficient address the problem identified in the Introduction.

Colour contrast is an important aspect in website accessibility. WCAG 2.0 suggests the best colour ratio for the text and image content for designers to check. However, designers cannot often select colours and achieve the standard because the presentation of WCAG 2.0 appears incomprehensible, designers lack of relevant colour contrast knowledge and helpful tools.

Even though the colour contrast guidelines in WCAG 2.0 and evaluation tools exit, they are insufficient for the design process, since they encouraged to check after the design is made. Thus, in this dissertation, a contrast colour picker tool to assist designers chose colour schemes that meet WCAG 2.0 while they avoid limiting creativity. Another method to improve designers' colour selection performance is simplifying the passages in WCAG 2.0, and make it more clear and easy to read. For example, give a real example of how to calculate colour contrast ratio of two colour step by step.

Future work includes a redesign of the tool for improved usability. Thus, the following suggestions and recommendations for the colour picker tool feature for future version in this colour picker tool are proposed:

First, incorporate a colour dropper feature to the tool. This feature allows user to pick colours from every pixel in the screen and get the RGB value at the same time. It helps under the circumstance when the designers wanted to use given colours as a basis for their design. This meets the need to locate existing elements such as company logo colours, product brand colours, etc.

Second, the tool should allow the users manually input RGB values. The corresponding colour with input RGB values will be located and highlighted in the colour model presentation.

An extra colour schemes filter function should be added in addition to the colour harmonies, such as rectangle colour schemes, warm colour schemes, cool colour schemes or colours based on different meanings in multi cultures should be combined in the this tool.

A redesign with the goal of preventing the setting of incorrect thresholds. In the current colour picker tool, the contrast limits were displayed either by a slider with contrast ratio, or buttons with text. This tool should be also designed to people who are not familiar with the specific colour contrast ratio requirements in WCAG 2.0.

Major tasks have been accomplished during this project:

A cross-culture interview between Chinese and Norwegian designers was conducted to study the different understanding about colour contrast and WCAG 2.0. The results indicate Chinese designers interviewed lack of knowledge of WCAG treat colour contrast as a individual preference. Meanwhile, Norwegian designers interviewed were more behave professional on select colours in terms of colour contrast. Awareness among designers and Norway could be the result of the legal requirement to comply with WCAG, but that it is beyond the scope of this study. Future research examines how the WCAG 2.0 requirement in Norway has contributed to a higher level of awareness of WCAG among developers is recommended.

A colour picker tool was developed that provided valid colours according to a given colour contrast requirement. The interactive tool only allows the selection of colour combinations that adhere to given contrast thresholds, including the contrast levels defined by WCAG 2.0. By working with valid colours during the entire design process it is likely that a better result is achieved in shorter since unnecessary and time-consuming post-design adjustments are avoided. The interactivity of the tool allows it to be used as a pedagogical learning aid as the effects of various colour selections are visualized in an understandable manner.

The colour picker tool provides a colour scheme filter feature to ensure this colour picker tool can be used as a real design tool, not just for meet the guidelines.

A user testing was implemented and verified the usability on six product designers. The results of the testing has been fully analyzed and discussed. Recommendations and suggestions about the advanced feature of the colour picker tool in the future research have been propound.

The interview and the colour picker tool in this dissertation is only a beginning to investigate what is the designers' opinion towards one of the many success criteria in WCAG 2.0. Many web developers get no training in colour theory or understanding of how to create colour schemes with sufficient colour contrast on a website. Hence, more research to investigate designers' understanding about other criteria and tools aim to assist designers meet other WCAG 2.0 standards could be helpful for both standard makers and designers. For instance, in WCAG 2.0 1.1.1 Non-text Content it formulated as "All non-text content that is presented to the user has a text alternative that serves the equivalent purpose(W3C, 2008).", a tool that detect can non-text content and support automatically transfer charts or audio recordings to text content can save web developers time. The main spirit of the idea such as the one behind the colour picker tool in this dissertation is that it gives the websites designers or developers valid choices that meet the guidelines and try to avoid checking phase.

The findings and achievements of in this dissertation supply a deeper view into graphic and about what they know about colour contrast, how they select colours and what they actually need. This dissertation also explore solutions intend to help designers enhance their performance on colour selection based on colour contrast.

During the master study in Universal Design of ICT, the author realized the importance to make ICT solutions accessible to all, including people with disabilities, so that all citizens can take an active part in social activities and employment. Especially seeing the huge gap between China and Norway in terms of Universal Design. China has the biggest population of people need accessibility equipment or ICT solutions, however, neither the government nor citizens put enough attention nor effort on that. Through the two years of study, the author has gained advanced knowledge in universal design and specialized knowledge in ICT and can apply knowledge in new areas of universal design of ICT into the master thesis.

In addition, the author also learned to how to find a problem, and analyze and deal critically with various sources of information and formulate scholarly arguments. Particularly, the researcher learned how to contribute to new thinking and innovation processes in colours for website.

References

Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-centered design. Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications, 37(4), 445-456.

Agarwal, R., Veer Arya, K., & Shashi, S. (2010, July 29 2010-Aug. 1 2010). An architectural framework for web information retrieval based on user's navigational pattern. Paper presented at the Industrial and Information Systems (ICIIS), 2010 International Conference on.

Al-Khalifa, A. S., & Al-Khalifa, H. S. (2011). An educational tool for generating inaccessible page examples based on WCAG 2.0 failures. Paper presented at the Proceedings of the International Cross-Disciplinary Conference on Web Accessibility, Hyderabad, Andhra Pradesh, India.

Convention on the Rights of Persons with Disabilities (2006).

Bann, D. (2006). The all new print production handbook: RotoVision SA.

Brooks, F. P., & Bullet, N. S. (1987). Essence and accidents of software engineering. IEEE computer, 20(4), 10-19.

Caldwell, B., Chisholm, W., Slatin, J., & Vanderheiden, G. (2007). Understanding WCAG 2.0. World Wide Web Consortium, Working Draft WDUNDERSTANDING-WCAG20-20071211.

Chan, X., Goh, S., & Tan, N. (2014). Subjects with colour vision deficiency in the community: what do primary care physicians need to know? Asia Pacific Family Medicine, 13(1), 1-10.

Choudhury, A., & Medioni, G. (2009, Sept. 27 2009-Oct. 4 2009). Perceptually motivated automatic color contrast enhancement. Paper presented at the Computer Vision Workshops (ICCV Workshops), 2009 IEEE 12th International Conference on.

Choudhury, A., & Medioni, G. (2010, 13-18 June 2010). Color contrast enhancement for visually impaired people. Paper presented at the Computer Vision and Pattern Recognition Workshops (CVPRW), 2010 IEEE Computer Society Conference on.

Clark, J. (2006). To Hell with WCAG 2. Retrieved May 4, 2015 from http://alistapart.com/article/tohellwithwcag2

Cohen-Or, D., Sorkine, O., Gal, R., Leyvand, T., & Xu, Y.-Q. (2006). Color harmonization. ACM Trans. Graph., 25(3), 624-630.

Collazos, C. A., & Gil, R. (2011, 11-13 April 2011). Using Cross-cultural Features in Web Design Patterns. Paper presented at the Information Technology: New Generations (ITNG), 2011 Eighth International Conference on.

Cyr, D., Head, M., & Larios, H. (2010). Colour appeal in website design within and across cultures: A multi-method evaluation. International Journal of Human-Computer Studies, 68(1–2), 1-21.

Dagonneau, V., Martin, E., & Cosquer, M. (2014). Collaborating & being together: influence of screen size and viewing distance during video communication. Paper presented at the Proceedings of the 2014 Virtual Reality International Conference, Laval, France.

Dame, N. (2015). University Colors.

Disability Rights Commission. (2004). The web: Access and inclusion for disabled people. The Stationary Office.

Douglas, & Kirkpatrick. (1999). Model and representation: the effect of visual feedback on human performance in a color picker interface. ACM Trans. Graph., 18(2), 96-127.

Douglas, S., & Kirkpatrick, T. (1996). Do color models really make a difference? Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Vancouver, British Columbia, Canada.

Dow, S., Saponas, T. S., Li, Y., & Landay, J. A. (2006). External representations in ubiquitous computing design and the implications for design tools. Paper presented at the Proceedings of the 6th conference on Designing Interactive systems, University Park, PA, USA.

Ellis, L., & Ficek, C. (2001). Color preferences according to gender and sexual orientation. Personality and Individual Differences, 31(8), 1375-1379.

Flatla, D. R. (2011). Accessibility for individuals with color vision deficiency. Paper presented at the Proceedings of the 24th annual ACM symposium adjunct on User interface software and technology, Santa Barbara, California, USA.

Foley, J. D., Dam, A. v., Feiner, S. K., & Hughes, J. (1995). Computer Graphics: Principles and Practice (2nd edition ed.): Addison-Wesley.

Fridell Anter, K. (2008). Book review: Colouring the Past—On colour in archaeological research: Wiley Online Library.

Gambino, O., Pirrone, R., & Giorgio, F. (2014). Accessibility of the Italian institutional web pages: a survey on the compliance of the Italian public administration web pages to the Stanca Act and its 22 technical requirements for web accessibility. Universal Access in the Information Society, 1-8.

Geert Hofstede, G. J. H., Michael Minkov. (2010). Cultures and organizations (3rd ed.): London: McGraw-Hill.

Gittings, N. S., & Fozard, J. L. (1986). Age related changes in visual acuity. Experimental Gerontology, 21(4–5), 423-433.

Haddad, R. (2014). Research and Methodology for Interior Designers. Procedia - Social and Behavioral Sciences, 122(0), 283-291.

Hanson, V. L., & Richards, J. T. (2013). Progress on Website Accessibility? ACM Trans. Web, 7(1), 1-30.

Hearnshaw, A. (2011). Struggling with WCAG 2.0 Accessibility Guidelines for content authors.

Heechul, H., & Hyunsuk, H. (2012, 18-20 July 2012). Illumination Estimation Based Color Contrast Enhancement. Paper presented at the Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP), 2012 Eighth International Conference on.

Hofstede, G. (1991). Cultures and organizations: London: McGraw-Hill.

Hoftede, G., Hofstede, G. J., & Minkov, M. (2010). Cultures and organizations: software of the mind: intercultural cooperation and its importance for survival: McGraw-Hill.

Hunt, R. W. G., & Pointer, M. R. (2011). Measuring colour: John Wiley & Sons.

Itten, J., & Van Haagen, E. (1973). The art of color: the subjective experience and objective rationale of color: Van Nostrand Reinhold New York, NY, USA.

Jang, Y. G., Kim, H. Y., & Yi, K. M. (2007). A Color Contrast Algorithm for E-learning Standard. International Journal of Computer Science and Network Security, 7.

Jefferson, L., & Harvey, R. (2006). Accommodating color blind computer users. Paper presented at the Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility, Portland, Oregon, USA.

Knoblauch, K., Arditi, A., & Szlyk, J. (1991). Effects of chromatic and luminance contrast on reading. JOSA A, 8(2), 428-439.

Lau, S. T., & Manager, R. D. (1999). Contrast formulae for use with contrast measuring devices

: Spectrum Technologies PLC.

Law, C., Jaeger, P., & McKay, E. (2010). User-centered design in universal design resources? Universal Access in the Information Society, 9(4), 327-335.

Lazar, J., Feng, J. H., & Hochheiser, H. (2010). Research methods in human-computer interaction: John Wiley & Sons.

Leavitt, M. O., & Shneiderman, B. (2006). Research-based web design & usability guidelines. US Department of Health and Human Services.

Lin, C.-C. (2003). Effects of contrast ratio and text color on visual performance with TFT-LCD. International Journal of Industrial Ergonomics, 31(2), 65-72.

Lujan-Mora, S., Navarrete, R., & Penafiel, M. (2014, 24-25 April 2014). Egovernment and web accessibility in South America. Paper presented at the eDemocracy & eGovernment (ICEDEG), 2014 First International Conference on.

Ma, X.-j., Yao, K.-j., Wei, G.-j., & Zhang, W.-s. (2009, 26-29 Nov. 2009). The practical principles for website design. Paper presented at the Computer-Aided Industrial Design & Conceptual Design, 2009. CAID & CD 2009. IEEE 10th International Conference on.

Madi, A., & Ziou, D. (2014). Color constancy for visual compensation of projector displayed image. Displays, 35(1), 6-17.

Mather, J., Stare, C., & Breinin, S. (1971). Color preferences in a geriatric population. The Gerontologist, 11(4 Part 1), 311-313.

May, S., & Zhu, Q. (2010). A web accessibility assessment on the Texas public school system. Universal Access in the Information Society, 9(1), 87-96.

Mereuţă, A., Aupetit, S., & Slimane, M. (2012). Improving Web Accessibility for Dichromat Users through Contrast Preservation. In K. Miesenberger, A. Karshmer, P. Penaz, & W. Zagler (Eds.), Computers Helping People with Special Needs (Vol. 7382, pp. 363-370): Springer Berlin Heidelberg.

Michelson, A. A. (1995). Studies in optics: Courier Corporation.

Mullis, I. V., Martin, M. O., Foy, P., & Arora, A. (2012). TIMSS 2011 international results in mathematics: ERIC.

Naiman, A. (1985). Color spaces and color contrast. The Visual Computer, 1(3), 194-201. doi: 10.1007/BF01910022

Nathans, J., Thomas, D., & Hogness, D. S. (1986). Molecular genetics of human color vision: the genes encoding blue, green, and red pigments. Science, 232(4747), 193-202.

Nguyen-Tri, D., Overbury, O., & Faubert, J. (2003). The role of lenticular senescence in age-related color vision changes. Investigative ophthalmology & visual science, 44(8), 3698-3704.

Nietzio, A., Eibegger, M., Goodwin, M., & Snaprud, M. (2012). Following the WCAG 2.0 Techniques: Experiences from Designing a WCAG 2.0 Checking Tool. In K. Miesenberger, A. Karshmer, P. Penaz, & W. Zagler (Eds.), Computers Helping People with Special Needs (Vol. 7382, pp. 417-424): Springer Berlin Heidelberg.

Noiwan, J., & Norcio, A. F. (2006). Cultural differences on attention and perceived usability: Investigating color combinations of animated graphics. International Journal of Human-Computer Studies, 64(2), 103-122.

Ortner, D., & Miesenberger, K. (2005, 22-26 Aug. 2005). Improving Web accessibility by providing higher education facilities for Web designers and Web developers following the design for all approach. Paper presented at the Database and Expert Systems Applications, 2005. Proceedings. Sixteenth International Workshop on.

Peli, E. (1990). Contrast in complex images. JOSA A, 7(10), 2032-2040.

Pinckers, A. (1980). Color vision and age. Ophthalmologica, 181(1), 23-30.

Pölönen, M., Salmimaa, M., & Häkkinen, J. (2011). Effect of ambient illumination level on perceived autostereoscopic display quality and depth perception. Displays, 32(3), 135-141.

Reid, L. G., & Snow-Weaver, A. (2008). WCAG 2.0: a web accessibility standard for the evolving web. Paper presented at the Proceedings of the 2008 international cross-disciplinary conference on Web accessibility (W4A), Beijing, China.

Rello, L., Kanvinde, G., & Baeza-Yates, R. (2012). Layout guidelines for web text and a web service to improve accessibility for dyslexics. Paper presented at the Proceedings of the International Cross-Disciplinary Conference on Web Accessibility, Lyon, France.

RGB Color Codes Chart. (2014). Retrieved March, 27, 2015 from http://www.rapidtables.com/web/color/RGB_Color.htm

Rømen, D., & Svanæs, D. (2008a). Evaluating web site accessibility: validating the WAI guidelines through usability testing with disabled users. Paper presented at the Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges, Lund, Sweden.

Rømen, D., & Svanæs, D. (2008b). Evaluating web site accessibility: validating the WAI guidelines through usability testing with disabled users. Paper presented at the Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges, Lund, Sweden.

Rømen, D., & Svanæs, D. (2012). Validating WCAG versions 1.0 and 2.0 through usability testing with disabled users. Universal Access in the Information Society, 11(4), 375-385.

Sandnes, F. E. (2015a). Exploring WCAG2.0 web page colour contrast limits. Oslo and Akershus University College of Applied Sciences.

Sandnes, F. E. (2015b). Selecting suitable colors: Exploring the limits of WCAG2.0 web page color contrast constraints. Gower Handbook on Information Design. U.K.

Sandnes, F. E., & Zhao, A. (2015a). A Contrast Colour Selection Scheme for WCAG2.0-compliant Web Designs based on HSV-half-planes. Hong Kong.

Sandnes, F. E., & Zhao, A. (2015b). An interactive color picker that ensures WCAG2.0 compliant color contrast levels. Elsevier.

Schloss, K., & Palmer, S. (2011). Aesthetic response to color combinations: preference, harmony, and similarity. Attention, Perception, & Psychophysics, 73(2), 551-571.

Schmitt, S., Stein, S., Hampe, F., & Paulus, D. (2012, 24-26 May 2012). Mobile services supporting color vision deficiency. Paper presented at the Optimization of Electrical and Electronic Equipment (OPTIM), 2012 13th International Conference on.

Schwarz, M. W., Cowan, W. B., & Beatty, J. C. (1987). An experimental comparison of RGB, YIQ, LAB, HSV, and opponent color models. ACM Trans. Graph., 6(2), 123-158.

Silver, N. C., MC CULLEY, W. L., Chambliss, L. N., CHARLES, C. M., SMITH, A. A., WADDELL, W. M., & WINFIELD, E. B. (1988). Sex and racial differences in color and number preferences. Perceptual and Motor Skills, 66(1), 295-299.

Tate, F. B., & Allen, H. (1986). Color preferences and the aged individual: Implications for art therapy. The Arts in Psychotherapy, 12(3), 165-169.

Thorell, L. G., & Smith, W. J. (1990). Using Computer Color Effectively: An Illustrated Reference: Prentice Hall.

Tominaga, S. (2014). Color Model. In K. Ikeuchi (Ed.), Computer Vision (pp. 116-120): Springer US.

Tractinsky, N. (1997). Aesthetics and apparent usability: empirically assessing cultural and methodological issues. Paper presented at the Proceedings of the ACM SIGCHI Conference on Human factors in computing systems, Atlanta, Georgia, USA.

Van Buren, J. M. (1963). The retinal ganglion cell layer: a physiological-anatomical correlation in man and primates of the normal topographical anatomy of the retinal ganglion cell layer and its alterations with lesions of the visual pathways: Charles C. Thomas.

W3C. (1999). Web content accessibility guidelines 1.0. World Wide Web Consortium. Available online at: http://www. w3. org/TR/WCAG10/(accessed 28 September 2005).

W3C. (2008). Web Content Accessibility Guidelines (WCAG) 2.0.

Weinman, L. (2002). Color aesthetics for web graphics creation. Paper presented at the ACM SIGGRAPH 2002 conference abstracts and applications, San Antonio, Texas.

WHO. (2013). Visual impairment and blindness.

Widdel, H., & Post, D. L. (1992). Color in electronic displays (Vol. 3): Springer Science & Business Media.

Wieger, L., & Davrout, L. (1965). Chinese Characters: Their Origin, Etymology, History, Classification and Signification : a Thorough Study from Chinese Documents: Paragon Book Reprint Corporation.

Wikipedia. (2014). CMYK color model Wikipedia.

Wolfmaier, T. G. (1999). Designing for the color-challenged: A challenge. ITG Publication, 2.

Wong, B. (2011). Points of view: Color blindness. nature methods, 8(6), 441-441.

Yu, C., Xing, X., Wei-Ying, M., & Hong-Jiang, Z. (2005). Adapting Web pages for small-screen devices. Internet Computing, IEEE, 9(1), 50-56.

Appendix

A.Interview questions and research questions

This appendix includes the interview questions and corresponding research questions cross Chinese and Norwegian designers.

	Research questions	Interview questions
Intro information	Built trust relationship between the participation. Try to let them feel relaxed.	Give the interviewee brief intro about the topic of the interviewer checks through the ethical issues. . If you feel any uncomfortable question or do not want answer, please stop me. Do you have questions before we start? During the interview, keep eye contact. What is your name? What is your job? How long have you been a designer?
Main question	How designers understand colour and colour contrast? How designer choose colours? What is their thinking process?	At first, I will ask the participants to explain how to make their design noticeable and readable? Why? (observer if they mentioned colour contrast, or they do mean colour contrast but cannot use this specific term) Can you tell me what exactly do you design? Does it often involved with colour? (which stage of design do you start consider colour, at beginning or after the other design

		was done?) When two colours put together, it creates colour contrast, can you explain what is colour contrast? How to get it? For you, what is a good colour contrast? Bad contrast? Higher contrast means better visual performance? Have you heard of WCAG 2.0? Show them the formula $LCR = \frac{L_1 + 0.05}{L_2 + 0.05}$, tell them L_1 is the relative luminance of the lighter of the colours, and L_2 is the relative luminance of the darker of the colours. L = 0.2126 * R + 0.7152 * G + 0.0722 * B Ask them to explain formula What software do you use? You were asked to design a website/interface for a travel company and pet stuff website, you need to select colours for headings, foreground (text), background, what colour will you choose? During the design process, ask them what you are doing, why they choose the specific colour, do you have other possibilities? Do you think the colour contrast is enough? Check and write down the colour contrast after the design with colour analyser. Tell them the results and ask them what they think to improve it(change another colour).

Finish question		Do you have any question for me? Do you have anything else want to share? Thanks for your time.

B.Prototype user testing

This is the testing script for the prototype user testing. First, the researcher explain the testing to the participants:

The purpose of this test is to explore colour contrast on websites. Imagine you are invited to design the colour palette for two companies, the first a cloth company, the second a game company. Figure 1 shows a sketch of cloth company web-site. They want to promote their products and want the colours to feel like summer and very fresh. Figure 2 shows a sketch of a video game company website. They want release a new game and they want to make the web design very exciting. In addition, the colours also have to meet colour contrast guidelines from WCAG 2.0. That is, 3:1 for Large Text, 4.5:1 for body text.

Second is the training session:

Here are the two tools you use to chose the foreground and background colours. This tool will display the colours and you can choose from them, such as simple version of Photoshop; the other tool will provide you colours which already meet the contrast standards. You are free to explore them now and ask any questions.

Next is the formal testing:

Now, if you don't have any further questions and are ready to select the colours, please let me know and we can start. (note all the colours they choose and audio record the whole time).

C.Testing results from prototype user testing

Appendix C documented colours chosen by all six participants in order.

Participant 1	Colours	Colour contrast
1. PS Cloth Heading	(250,30, 80) (250,210,150)	Fail (AA) 2.74:1
Second try	(200,40,10) (250,230,210)	Pass (AA) 4.60:1
2. PS Cloth Body	(0,0,0) (250,210,0)	Pass (AA) 14.28:1
3.WCAG cloth Heading	(180,0,140) (250,220,190)	Pass (AA) 4.83:1
4. WCAG Cloth Body	(0,0,0) (250,200,130)	Pass (AA) 13.65:1
5.WCAG Game Heading	(210,0,10) (220,230,240)	Pass (AA) 4.44:1
6. WCAG Game Body	(10,0,210) (240,220,180)	Pass (AA) 8.03:1
7. PS Game Heading	(200,10,20) (220,230,60)	Pass (AA) 4.40:1
8.PS Game Body	(40,140,210) (230,240,0)	Fail (AA) 2.92:1
Second try	(60,30,200) (230,240,0)	Pass (AA) 7.61:1
Participant 3	**Colours**	**Colour contrast**
1. PS Cloth Heading	(255,255,255)(240,150,170)	Fail (AA) 2.09:1

Second try	(250,250,250) (220,80,90)	Pass (AA) 3.77:1
2. PS Cloth Body	(250,250,250)(80,50,100)	Pass (AA) 10.15:1
3.PS Game Heading	(240,30,40) (0,0,0)	Pass (AA) 4.92:1
4. PS Game Body	(250,250,250)(10,60,150)	Pass (AA) 9.58:1
5.WCAG Cloth Heading	(200,70,100) (200,230,130)	Pass (AA) 3.34:1
6. WCAG Cloth Body	(160,60,110) (210,230,190)	Pass (AA) 4.69:1
7. WCAG Game Heading	(130,100,40) (210,230,150)	Pass (AA) 4.08:1
8.WCAG Game Body	(200,30,20) (190,240,240)	Pass (AA) 4.63:1
Participant 3	Colours	Colour contrast
1. PS Cloth Heading	(255,255,255)(240,150,170)	Fail (AA) 2.09:1
Second try	(250,250,250) (220,80,90)	Pass (AA) 3.77:1
2. PS Cloth Body	(250,250,250)(80,50,100)	Pass (AA) 10.15:1
3.PS Game Heading	(240,30,40) (0,0,0)	Pass (AA) 4.92:1
4. PS Game Body	(250,250,250)(10,60,150)	Pass (AA) 9.58:1
5.WCAG Cloth Heading		Pass (AA)

	(200,70,100) (200,230,130)	3.34:1
6. WCAG Cloth Body	(160,60,110) (210,230,190)	Pass (AA) 4.69:1
7. WCAG Game Heading	(130,100,40) (210,230,150)	Pass (AA) 4.08:1
8.WCAG Game Body	(200,30,20) (190,240,240)	Pass (AA) 4.63:1
Participant 4	Colours	Colour contrast
1. WCAG Cloth Heading	(160,210,80)(40,110100)	Pass (AA) 3.38:1
2.WCAG Cloth Body	(70,0,0) (255,255,255)	Pass (AA) 16.66:1
3. WCAG Game Heading	(60,50,200) (250,150,200)	Pass (AA) 4.13:1
4. WCAG Game Body	(50,40,120) (255,255,255)	Pass (AA) 12.28:1
5. PS Cloth Heading	(10,90,130) (160,230,220)	Pass (AA) 5.31:1
6.PS Game Heading	(30,60,130) (230,140,200)	Pass (AA) 4.42:1
Participant 5, 6 (Marte /Karina)	Colours	Colour contrast
1. PS Game Heading	(0,0,0) (240,160,30)	Pass (AA) 9.75:1
2. PS Game Body	(0,0,0) (140,200,230)	Pass (AA) 11.52:1
3. WCAG Cloth Heading	(160,60,90) (120,200,150)	Pass (AA) 3.19:1

4. WCAG Cloth Body	(0,0,0) (255,255,255)	Pass (AA) 21:1
5. PS Cloth Heading (Marte)	(240,130,160)(250,200,120)	Fail (AA) 1.62:1
Second try	(160,60,150) (250,200,120)	Pass (AA) 3.80:1
5. PS Cloth Heading (Kriana)	(250,200,120)(150,210,170)	Fail (AA) 1.12:1
Second try	(90,130,160) (250,200,120)	Fail (AA) 2.65:1
Third try	(180,230,220)(240,130,190)	Fail (AA) 1.77:1
Fourth try	(130,60,140) (200,220,160)	Pass (AA) 4.77:1
6.PS Cloth Body	(0,0,0) (255,255,255)	Pass (AA) 21:1
7. WCAG Game Heading	(0,0,0) (230,40,40)	Pass (AA) 4.70:1
8. WCAG Game Body	(0,0,0) (80,180,220)	Pass (AA) 8.90:1

D.Main coding of the prototype

Appendix D contains the main coding for the RGB colour picker tool in the dissertation.

```
H = 0;
var_Min = Math.min(r, Math.min(b, g));
var_Max = Math.max(r, Math.max(b, g));
del_Max = var_Max - var_Min;
L = (var_Max + var_Min) / 2;
if (del_Max == 0) {
    H = 0;
    S = 0;
} else {
    if (L < 128) {
        S = 256 * del_Max / (var_Max + var_Min);
    } else {
        S = 256 * del_Max / (512 - var_Max - var_Min);
    }
    del_R = ((360 * (var_Max - r) / 6) + (360 * del_Max / 2))
            / del_Max;
    del_G = ((360 * (var_Max - g) / 6) + (360 * del_Max / 2))
            / del_Max;
    del_B = ((360 * (var_Max - b) / 6) + (360 * del_Max / 2))
            / del_Max;
    if (r == var_Max) {
        H = del_B - del_G;
    } else if (g == var_Max) {
        H = 120 + del_R - del_B;
    } else if (b == var_Max) {
```

```
                H = 240 + del_G - del_R;
            }
            if (H < 0) {
                H += 360;
            }
            if (H >= 360) {
                H -= 360;
            }
            if (L >= 256) {
                L = 255;
            }
            if (S >= 256) {
                S = 255;
            }
        }
        float[] hsl = new float[3];
        hsl[0] = H;
        hsl[1] = S;
        hsl[2] = L;
        return hsl;
    }



    protected void resetlabelcolour(int whatnumber) {
        if (img == null)
            img = new BufferedImage(640, 640,
BufferedImage.TYPE_4BYTE_ABGR);            for (int i = 0; i < img.getWidth(); i++) {
            for (int j = 0; j < img.getHeight(); j++) {
                int n1, n2, n3;
                if (whatnumber == 1) {
```

```
                n1 = (int) ((i / 5) % 26) * 10;
                n2 = (int) ((i / (5 * 26f)) > (j / (5 * 26f)) ? (i / (5 * 26f))
                        * (i / (5 * 26f))
                        : (j / (5 * 26f)) * (j / (5 * 26f))) * 10;
                n3 = (int) ((j / 5) % 26) * 10;
            } else if (whatnumber == 2) {
                n1 = (int) ((i / 10) % 16) * 16;
                n2 = (int) ((i / (10 * 16f)) > (j / (10 * 16f)) ? (i / (10 * 16f))
                        * (i / (10 * 16f))
                        : (j / (10 * 16f)) * (j / (10 * 16f))) * 16;
                n3 = (int) ((j / 10) % 16) * 16;
            } else {
                n1 = (int) ((i / 2) % 47) * 5;
                n2 = (int) ((i / (2 * 47f)) > (j / (2 * 47f)) ? (i / (2 * 47f))
                        * (i / (2 * 47f))
                        : (j / (2 * 47f)) * (j / (2 * 47f))) * 5;
                n3 = (int) ((j / 2) % 47) * 5;
            }
            Colour colour = new Colour(n1, n2, n3);
            img.setRGB(i, j, colour.getRGB());
        }
    }
}
protected void setLRGB(float low, float high) {
    int c = img.getRGB(3, 0);
    for (int i = 0; i < img.getWidth(); i++) {
        for (int j = 0; j < img.getHeight(); j++) {
            Colour colour = new Colour(img.getRGB(i, j), true);
            Double l = getL(colour);
            Float temp = (float) ((l + 0.05) / (postionL + 0.05));
```

```
                if (temp <= 1) {
                    temp = (float) ((postionL + 0.05) / (l + 0.05));
                }
                if (low <= temp && temp <= high) {
                    img.setRGB(i, j, img.getRGB(i, j));
                } else {

                    img.setRGB(i, j, c & 0x00ffffff);                }
            }
        }

}
protected Double getL(Colour colour) {
    Double tempr, tempg, tempb;
    Float colourred = colour.getRed() / 255f;
    Float colourgreen = colour.getGreen() / 255f;
    Float colourblue = colour.getBlue() / 255f;
     if (colourred < 0.03928) {
        tempr = (double) (colourred / 12.92f);
    } else {
        tempr = Math.pow(((colourred + 0.055f) / 1.055f), 2.4);
    }
    if (colourgreen < 0.03928) {
        tempg = (double) (colourgreen / 12.92f);
    } else {
        tempg = Math.pow(((colourgreen + 0.055f) / 1.055f), 2.4);
    }
    if (colourblue < 0.03928) {
        tempb = (double) (colourblue / 12.92f);
    } else {
```

```
        tempb = Math.pow(((colourblue + 0.055f) / 1.055f), 2.4);
    }
    return 0.2126 * tempr + 0.7152 * tempg + 0.0722 * tempb;
}
```

E. Published paper I

6th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Infoexclusion (DSAI 2015)

An interactive colour picker that ensures WCAG 2.0 compliant colour contrast levels

Frode Eika Sandnes[1,2*] and Anqi Zhao[1]

[1]*Faculty of Technology, Art and Design, Oslo and Akershus University College of Applied Sciences, 0130 Oslo, Norway*
[2]*Faculty of Technology, Westerdals School of Art, Communication and Technology*

Abstract

Insufficient contrast between text and the background is a common problem on the web. WCAG 2.0 addresses this problem, but the definition is hard to understand for most designers. Therefore, some web designers check their designs with contrast checking tools after the design is finished. If the design does not meet the WCAG 2.0 guidelines the designer will have to go back and make adjustments. To overcome this problem a colour picker tool is proposed that allows designers to select WCAG 2.0 compliant colours during the design process thus eliminating the need for post-design colour adjustments. First, the designer selects the first colour freely from all available colours. Subsequently, only colours are presented that meets the chosen contrast level. In addition to being a design tool, it also serves as a pedagogical visualization aid that can help students and designers better understand the complex relationships between colours palettes and their contrasts.

Peer-review under responsibility of organizing committee of the 6th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-exclusion (DSAI 2015).

Keywords: colour contrast; universal design, WCAG 2.0; web design

1. Introduction

Web is probably one of the most important sources of textual information. For text to be visually readable when rendered on computer displays the text has to be sufficiently large and the text has to have a sufficient contrast in relation with the background [1]. If the text colour is too similar to the background colour, it is not possible to read the text even if the text is rendered in large letters. The contrast is too small.

Current web browsers, especially those shipped with touch based devices, makes it easy for users to adjust the text size at any time using the shrink and expand gestures to fit the reading comfort of the user. Unfortunately, the user has not got the same level of control over colours and contrast. Although, colour settings can be overridden in many web browsers, it is not easy not easy to do in practice.

Web designers are responsible for providing sufficient contrast on the web. Still, many web pages do not adhere to standards such as WCAG 2.0. This suggests that many designers are unaware of the problems associated with contrast and reduced vision.

Web developers commonly work with hardware oriented RGB (red, green, blue) representations as used in HTML, while some web designers rely on the HSB (hue, saturation, brightness) representation. In the HSB model contrast can be achieved with different hues, different levels of saturation, and different levels of brightness or a combination of these.

It is recommended to rely on brightness contrast as hue and saturation contrasts are harder to perceive for users with colour deficiencies [1]. A visual design based on brightness contrast is therefore also robust in terms of colour blindness.

1.1. WCAG 2.0 contrast

The World Wide Web Consortium (W3C) Web Contents Accessibility Guidelines (WCAG 2.0) [2] refers to luminance contrast. The WCAG 2.0 guidelines for level a criterion (criterion 1.4.3) recommends that body text should not rely on hue contrast at all. The level aa criterion states that the contrast should have a luminance contrast ratio of at least 4.5:1 for body text and 3:1 for headings. The level aaa criterion defines a contrast ratio between body text and its background of 7:1 and a contrast ratio for headings of 5:1.

WCAG 2.0 defines luminance contrast according to the standards ISO-9241-3 [3] and ANSI-HFES-100-1988 as

$$contrast = \frac{L1 + 0.05}{L2 + 0.05} \quad (1)$$

where *L1* is the luminance of the brightest colour and *L2* is the luminance of the darkest colour. Luminance is defined as

$$L = 0.2126r + 0.7152g + 0.0722b \quad (2)$$

The factors r, g and b represent linear red, green and blue colour components. The conversion between linear c and non-linear components k is based on IEC/4WD 61966-2-1 [4] and [5] as

$$c = \frac{k}{12.95} \quad (3)$$

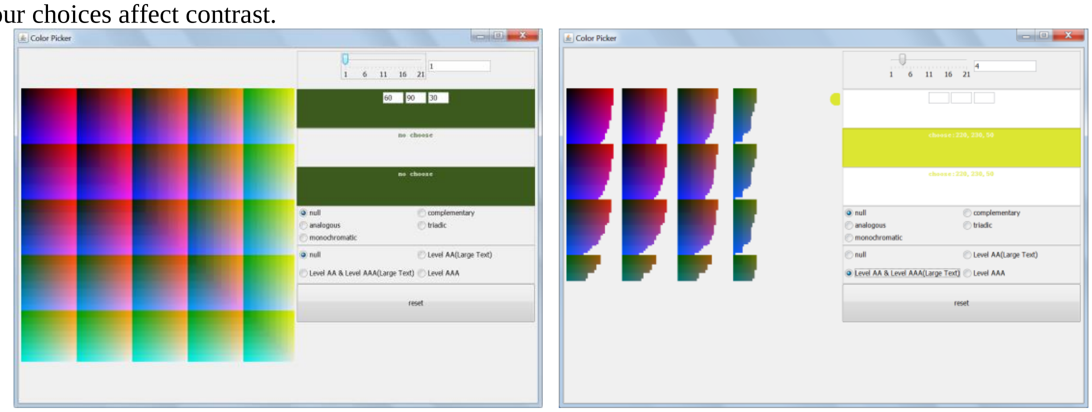
If $k \leq 0.03928$, or

$$c = \left(\frac{k + 0.055}{1.055}\right)^{2.4} \quad (4)$$

If $k > 0.03928$. The value k is given by

$$k = \frac{C}{255} \quad (5)$$

Here C represents one of the three RGB-vector values defined by an 8-bit value in the interval 0 til 255. This mathematical contrast definition is non-trivial and it is understandably not easy for designers to build a mental model of how colour choices affect contrast.



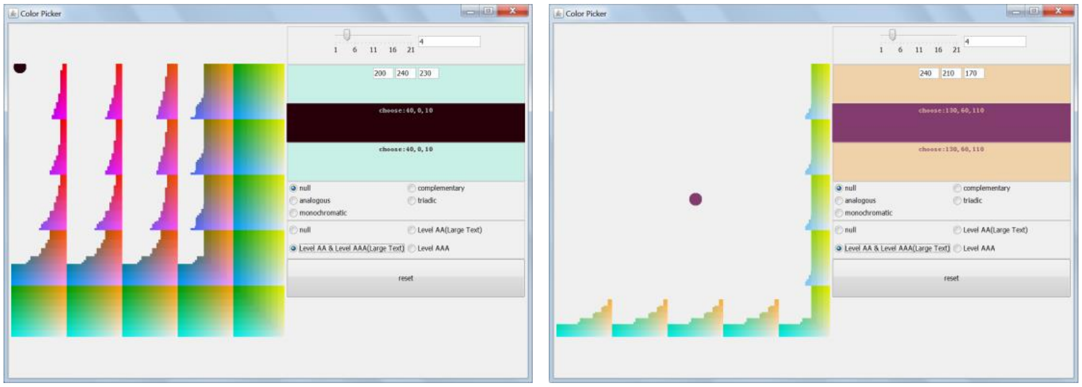


Fig. 1. Effect of colour selections using the tool. a) The entire colour space represented using red-green plane slices for different levels of blue, b) Valid colours after selecting a yellow colour, c). Valid colours after selecting a dark grey colour and d) Valid colours after selecting a purple colour in the middle of the colour space.

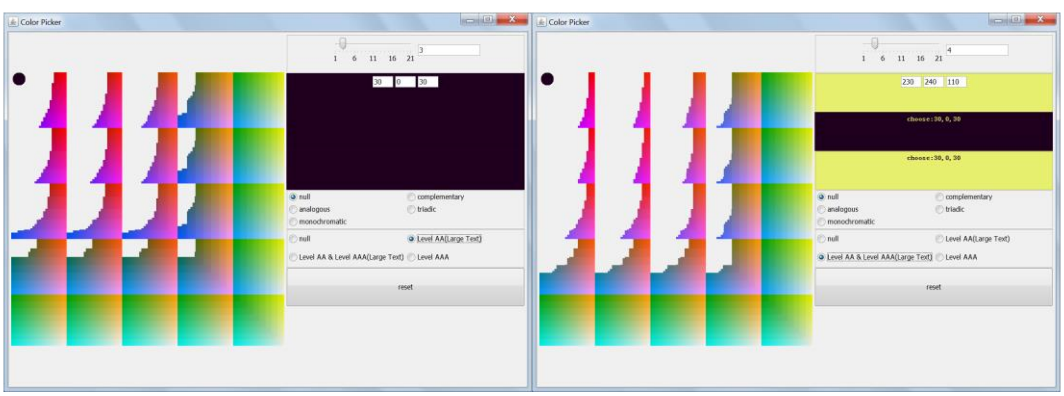
Web designers that are aware of the problems associated with low contrast levels may use tools to check whether their design provides sufficient contrast. One of many such online colour contrast checker tools is Snook (http://snook.ca/technical/colour_contrast/colour.html). With such tools the contrast checks are performed after a design is finished. If a design fails to meet contrast checks the designer will have to go back and adjust the design. Moreover, such approaches are also vulnerable to the diligence of the designers, and it is easy to forget to check for sufficient contrast.

2. Background

The legibility of text has long been an active area of research from the pioneering studies of printed text by Tinker [6, 7] up until the present day with research into readability of displays. These include studies of visual performance with cathode ray tubes [8], effects of prior experiences with printed text on reading computer displays [9], effects of display quality on visual search [10], effects of polarity [11], effects of text-background colour combinations [12, 13] and effects of chromatics and luminance contrast on reading [14, 15, 16]. None of these studies have addressed visual impairments. More recently electronic paper has received attention [17, 18, 19].

Not only size and colour combinations affect readability. Also, stroke width can make low contrast text easier to read. Ricco's law predicts this [20], namely that the product of the threshold intensity and the area is constant. The detection of luminance intensity differences is predicted by Weber's law in that larger differences are needed to detect higher luminance. This relationship exploited in several image-contrast enhancement algorithms [21].

Check for accessibility of web sites, such as sufficient contrast levels, are frequently performed after the main design phase [22] or real-time proxy-based contrast corrections during browsing [23]. Some research also has addressed making general images robust to colour blindness via various colour palette transforms [24, 25].



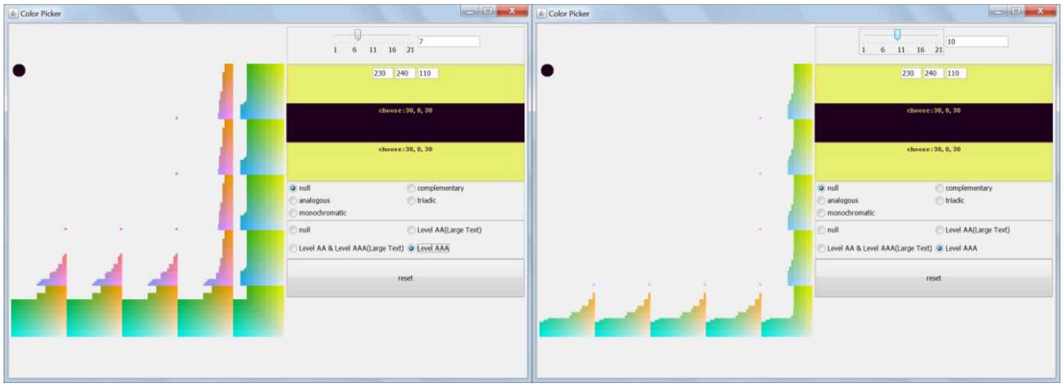


Fig. 2. Varying contrast level: a) Valid colours after selecting a dark gray with contrast level 3 (aa headings), b) Valid colours after selecting a dark gray with contrast level 4.5 (aa body text), c) Valid colours after selecting a dark gray with contrast level 7 (aaa body text) and d) Valid colours after selecting a dark gray with contrast level 10.

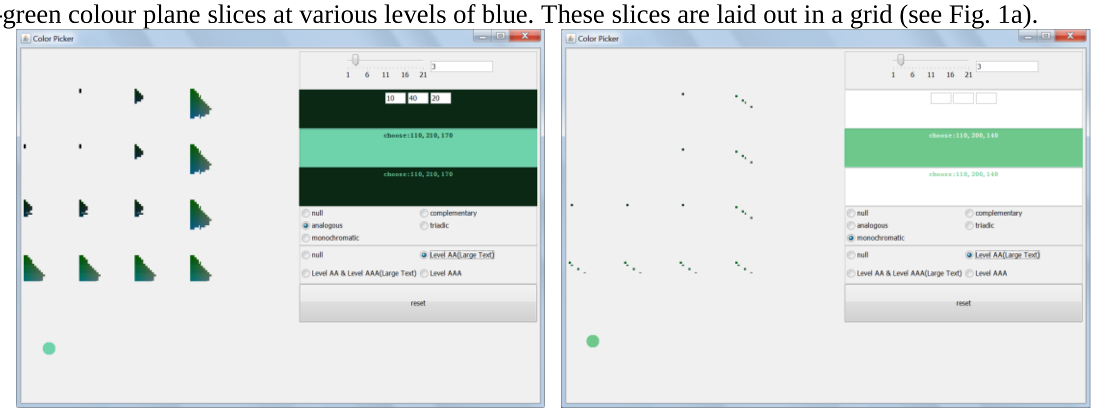
Little research has been conducted into the general computer colour selection process. Van den Broek el al. [26] found that several common colour picking interfaces are complex to use. Various textbooks and internet discussions reveal that there are different opinions about which colour model a colour picking tool should have. However, Douglas and Kirkpatrick found that that visual feedback is more important than the actual colour model used [28]. Other colour selection studies include that of Gonzales [27].

In terms of contrast, attempts have been made at generating palettes that help designers cater for colour blindness [29]. Light emitting displays also pose different problems to printed text. In particular, it may be difficult to read text suffering from colour bleeding which may occur with self-luminous white text on black backgrounds [30].

It has been argued that the WCAG 2.0 contrast requirements should be incorporated into the design tools such that low contrast colour combinations are avoided [31]. This study attempts to realize this principle by exploring a concrete colour picking prototype that only allow WCAG 2.0 compliant colour combinations to be selected.

3. Colour Picker Tool

An interactive prototype colour picker tool was developed. First, the tool displays a representation of the entire colour space. The prototype employs the hardware oriented RGB colour space for simplicity. The colour cube is displayed as red-green colour plane slices at various levels of blue. These slices are laid out in a grid (see Fig. 1a).



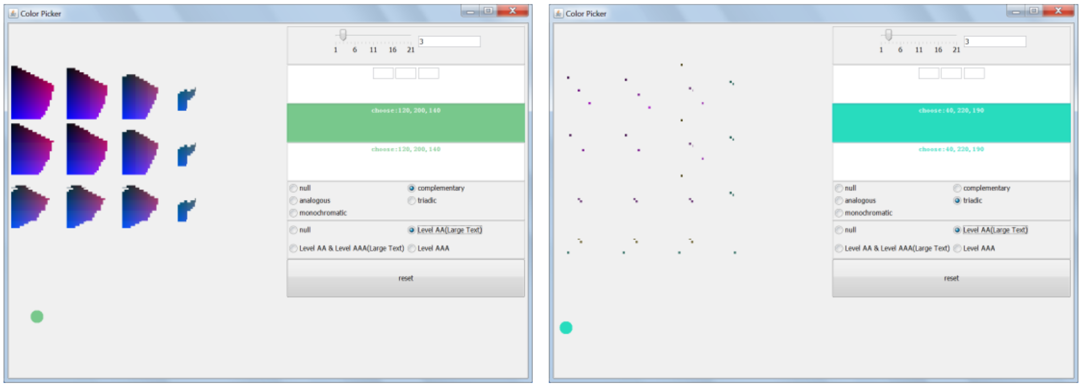


Fig. 3. Colour harmonies: a) Valid colours with a analogue colour harmony after selecting a cyan with contrast level 3, b) Valid colours with a monochrome colour harmony after selecting a cyan with contrast level 3, c) Valid colours with a complimentary colour harmony after selecting cyan with contrast level 3 and d) Valid colours with a triadic colour harmony after selecting a cyan with contrast level 3.

The user first choose a colour and the chosen colour is highlighted. All the colours that do not adhere to the set contrast level are disabled leaving only valid colours. Figs.1b, 1c and 1d show the result after selecting different colours in the colour space.

The contrast level can be set in two ways. Either by using the contrast slider or choosing the specific WCAG 2.0 levels, that is level aa for body text, level aa for heading, level aaa for body text or level aaa for headings. The effect of selecting different contrast levels are illustrated in Figs. 2a, 2b, 2c and 2d.

The contrast level is related to the visual acuity of the user. Colours with low contrast levels are perceivable by users with high visual acuity, while the required contrast level increases as a function of reduced visual acuity. For WCAG 2.0 the level aa criteria (4.5:1 for body text and 3:1 for headings) are based on empirical findings for users with a visual acuity of 20/40 and the level aaa criteria (7:1 for body text and 5:1 for headings) are based on empirical findings for users with a visual acuity of 20/80 (W3C, 2008).

The higher the contrast level is the larger portion of the population is included. According to Laitinen [32] approximately 95.9% of the Finish population have a visual acuity of 20/40, 1.6% of the population has a visual acuity of 20/80, and 0.5% are technically blind. Visual acuity is also connected to age as vision is often reduced with aging [33]. At the same time, high contrast levels reduce the design space. It may be tempting for designers to sacrifice the last 5% or even the last 10% of the population by relying on low contrast levels. However, the WCAG 2.0 level aaa criterion covers most of the population.

Most designers employ colour harmonies in their designs such as monochromatic colours, neighboring colours, contrast colours, triads, split complementary, etc. We therefore also provided a colour harmony filter that allows designers to immediately see all the contrast compliant colours for a given colour contrast. This further limited the colour space and gives the designer a smaller colour palette to choose from and hopefully leads to more rapid design decisions. The colour harmony filters are demonstrated in Figs. 3a, 3b, 3c and 3d.

4. Experimental results

4.1. Experimental setup

The prototype WCAG colour picker tool was evaluated by six designers in individual talk aloud design sessions and compared to an ordinary non-WCAG colour picker tool with the same colour layout. The participants were asked to adhere to the WCAG 2.0 guidelines in their designs. The ordinary colour picker tool did not constrain the choice of colours and the participants were therefore asked to use a contrast calculator together with the non-WCAG tool. In this way we attempted to simulate the current practice in a controlled environment.

The six designers varied in experience and background. Each designer was given two wireframe designs and asked to select colours for the text with the inspiration of a clothes store in summer and a games website with Japanese cartoon characters, respectively.

4.2. WCAG 2.0 contrast

The main feedback from the design sessions were as follows: The colour picker tool appeared to lack some colours in colour layout. In particular, this designer claimed that the shades of yellow were too greenish. Consequently, this designer did not find the desired colours. It is likely that there could be a problem with our implementation in that it does not display the colours correctly. Another explanation could be that the presentation biases the perception of the colours in an unfavorable manner.

The game design comprised a partial design with some colours given. Most of the designers wanted to use these given colours as a basis for their design. However, they found it difficult to locate the exact colour on the colour picker. This illustrates the need for a colour analyzer as new designs often are based on existing elements. This could for instance be company logo colours, product brand colours, etc. Commonly used tools such as Photoshop have such colour analysis functionality built in. A future version of our colour picker tool should also incorporate such functionality.

An interesting observation was that the designs for the clothes company fell into two distinct categories. One group preferred warm colours such as yellow and pink, which they associated with sunshine and heat. The other group chose cool colour such as blue and green as these colours were associated with beaches and the ocean. This observation does not directly relate to the colour picker tool, but rather a consequence of the experimental design..

The participants provided positive feedback on the WCAG colour picker tool compared to the non-WCAG colour picker tool. Even though the WCAG tool provided less choice they found it useful that it helped them adhere to the WCAG 2.0 colour guidelines and hence saved time and effort by not having to use the contrast calculator.

The sessions revealed that when either the foreground colour or the background colour is black or white it is easier to select colours that adhere to the WCAG 2.0 guidelines. One interpretation of this is that web sites based around black and white may achieve sufficient contract by chance.

Four of the six participants failed to satisfy the contrast constraints for clothes website headings at the first attempt using the non-WCAG tool, while only two of the participants failed at the first attempt at selecting body text colours. Thus more participants found it harder to set the heading colours than body text colours, although the contrast limits for headings (3:1) is lower than that for body text (4.5:1).

Participants who are familiar with setting RGB values directly via text fields are able to locate the desired colours more quickly. A tool such therefore provide both direct manipulation and text based modes of input in parallel.

One participant failed to achieve a sufficiently high contrast for the body text on the game website using the WCAG tool. The reason was that this participant accidentally set the incorrect threshold to headings instead of body text by clicking on the wrong radio button. Clearly, the design satisfied the contrast constraints for heading, but not for body text. This result suggests that the user interface of the colour picker tool needs a redesign with the goal of preventing the setting of incorrect thresholds.

Finally, the sessions did not reveal any signs that that gender influenced the designers' colour choices, despite the fact that gender related colour preferences are claimed by some researchers [34]. One explanation for their absence in our study could be that the designers we included have a more professional approach to colours than non-designers.

5. Conclusions

A colour picking tool for assisting designers selecting colour combinations that exhibit sufficient contrasts has been presented. The interactive tool only allows the selection of colour combinations that adhere to given contrast thresholds, including the contrast levels defined by WCAG 2.0. By working with valid colours during the entire design process it is likely that a better result is achieved in shorter since unnecessary and time-consuming post-design adjustments are avoided. The interactivity of the tool allows it to be used as a pedagogical learning aid as the effects of various colour selections are visualized in an understandable manner.

Future work includes a redesign of the tool for improved usability. A more intuitive representation of contrast limits needs to be devised. Improved usability could perhaps also be achieved if the hardware-centric RGB presentation is replaced with an HSB presentation where colours are represented in terms of hue, saturation and brightness. The HSB-model is closer to how designers work with colours.

References

1. Knoblauch K, et al. Effects on chromatic and luminance contrasts on reading. J Opt Soc Am A 1991; 8: 428-439.

2. World Wide Web Consortium (W3C). Web Content Accessibility Guidelines (WCAG) 2.0, W3C Recommendation 11 December 2008, http://www.w3.org/TR/WCAG20/

3. ISO-9241-3. Ergonomic requirements for office work with visual display terminals (VDTs) --

Part 3: Visual display requirements, International Organization for Standardization 1992.

4. IEC/4WD 61966-2-1. Colour Measurement and Management in Multimedia Systems and Equipment - Part 2-1: Default RGB Colour Space – sRGB, International Electrotechnical Commission 1998.

5. Stokes M, Anderson M, Chandrasekar S, Motta R (1996) A standard default colour space for the internet—sRGB, http://www.w3.org/Graphics/Colour/sRGB

6. Tinker MA. Legibility of print. Iowa: Iowa State University Press; 1963.

7. Tinker MA, Paterson DG. Studies of typographical factors influencing speed of reading. J Appl Psychol 1931; 15(3): 241.

8. Mathews ML. Visual performance with coloured CRT displays: research update. Appl Ergon 1989; 20(1): 58.

9. Stone DS, Fisher K, et al. Adults' prior exposure to print as a predictor of the legibility of text on paper and laptop computer. J Reading Writing 1999; 11(1): 1-28.

10. Nasanen R, Karlsson J, et al. Display quality and the speed of visual letter search. Displays 2001; 22:107-113).

11. Buchner A, Baumgartner N. Text – background polarity affects performance irrespective of ambient illumination and colour contrast. Ergon 2007; 50(7): 1036-1063.

12. Greco M, Stucchi N, et al. On the Portability of Computer-Generated Presentations: The Effect of Text-Background Colour Combinations on Text Legibility. Hum Factors 2008; 50(5): 821-833.

13. Hall RH, Hanna P. The Impact of Web Page Text-Background Colour Combinations on Readability, Retention, Aesthetics and Behavioural Intention. Behav Inform Technol 2004; 23(3): 183-195.

14. Knoblauch KA, Arditi, et al. Effects of chromatics and luminance contrast on reading. J Optical Soc Am A 1991; 8: 428-439.

15. Lin CC. Effects of contrast ratio and text colour on visual performance with TFT-LCD. International J Ind Ergon 2003; 31(2): 65-72.

16. Ling J, van Schaik P. The effect of text and background colour on visual search of Web pages. Displays 2002; 23(5): 223-230.

17. Lin PH, Lin YT, et al. Effects of anti-glare surface treatment, ambient illumination and bending curvature on legibility and visual fatigue of electronic papers. Displays 2008; 29: 25-32.

18. Lee DS, Shieh KK, et al. Effect of character size and lighting on legibility of electronic papers. Displays 2008; 29: 10-17.

19. Shen IH, Shieh KK, et al. Lighting, font style, and polarity on visual performance and visual fatigue with electronic paper displays. Displays 2009; 30: 53-58.

20. Hood DC, Finkelstein MA. Sensitivity to light. In Boff KR, Kaufman L, Thomas JP, editors. Handbook of perception and human performance Vol. I, New York: John Wiley; 1986, p. 5-66.

21. Majumder A, Irani S. Perception-based contrast enhancement of images. ACM T Appl Percept 2007; 4(3)

22. Alonso F, Fuertes JL, Gonzalez AL, Martinez L. On the testability of WCAG 2.0 for beginners. In Proceedings of the 2010 International Cross Disciplinary Conference on Web Accessibility (W4A) (W4A '10). New York, NY, USA: ACM; 2010.

23. Aupetit S, Mereuţă A, Slimane M. Automatic colour improvement of web pages with time limited operators. In: Computers Helping People with Special Needs, LNCS 2012; 7382: 355-362.

24. Ruminski J, Wtorek J, Ruminska J, Kaczmarek M, Bujnowski A, Kocejko T, Polinski A. Colour transformation methods for dichromats. In: The 3rd Conference on Human System Interactions (HSI), IEEE; 2010, p. 634-641.

25. Poret S, Dony RD, Gregori S. Image processing for colour blindness correction. In IEEE Toronto International Conference on Science and Technology for Humanity (TIC-STH), IEEE; 2009, p. 539-544.

26. van den Broek EL, Kisters PMF, Vuurpijl LG. Design guidelines for a Content-Based Image Retrieval colour-selection interface. In: Proceedings of the conference on Dutch directions in HCI (Dutch HCI '04). New York, NY, USA: ACM; 2004, p. 14-18.

27. Douglas SA, Kirkpatrick AE. Model and representation: the effect of visual feedback on human performance in a colour picker interface. ACM T Graph 1999; 18(2): 96-127.

28. Gonzalez B, Latulipe C. BiCEP: bimanual colour exploration plugin. In: CHI '11 Extended Abstracts on Human Factors in Computing Systems, New York, NY, USA: ACM; 2001, p. 1483-1488.

29. Troiano L, Birtolo C, Miranda M. Adapting palettes to colour vision deficiencies by genetic algorithm. In: Keijzer M, editor. Proceedings of the 10th annual conference on Genetic and evolutionary computation (GECCO '08), New York, NY, USA: ACM; 2008, p. 1065-1072.

30. Bressan P, Mingolla E, Spillmann L, Watanabe T. Neon colour spreading: a review. Perception 1997; 26(11), 1353-1366.

31. Sandnes FE. Selecting suitable colours: Exploring the limits of WCAG 2.0 web page colour contrast constraints. In: Lund O, editors. Gower Handbook on Information Design, Surrey, U.K: Gower, 2015; (in press).

32. Laitinen A, Koskinen S, Härkänen T, Reunanen A, Laatikainen L, Aromaa A. A nationwide population-based survey on visual acuity, near vision, and self-reported visual function in the adult population in Finland. Ophthalmology 2005; 112(12): 2227-2237.

33. Wood JM. Aging, driving and vision. Clin Exp Optom 2002; 85 (4): 214–220.

34. Silver NC, Culley MC, Chambliss WL, Chambliss LN, Charles CM, Smith AA, Waddell WW,

Winfield EB. Sex and racial differences in colour and number preferences. Percept Motor Skill 1988; 66(1): 295-299.

F.Unpublished paper II

A Contrast Colour Selection Scheme for WCAG 2.0-compliant Web Designs based on HSV-half-planes

Frode Eika Sandnes[1,2] and Anqi Zhao[1]

[1]Faculty of Technology Art and Design, Oslo and Akershus University College of Applied Sciences, Oslo, Norway
[2]Faculty of Technology, Westerdals school of Art, Communication and Technology, Oslo, Norway
Frode-Eika.Sandnes@hioa.no

***Abstract*—Sufficient colour contrast between text and background is necessary in order for the text to be readable. WCAG 2.0 defines contrast guidelines that ensure that web pages can be read by people with a visual acuity of as low as 20/80. However, the WCAG 2.0 specification is hard to understand for web-designers and they often perform colour checks after the design is finished using colour contrast calculators. It is then often too late to make significant changes to the design. This paper proposes a new colour selection scheme that integrates contrast constraints into the main design phase by only allowing designers to select colour pairs that contains sufficient contrast. The mechanism is compatible with the colour harmony systems commonly used by designer giving. The designers then get an easily perceivable overview of the design space of available colours. The paper briefly describes a prototype of a colour picker tool that implements the proposed scheme.**

Keywords- colour, HSV, RGB, contrast, WCAG 2.0

Introduction

The perception of visual stimuli is requires difference. For text to be readable by observers it needs to be sufficiently different from the background. This is often referred to as contrast. There is a vast body of research into contrast and its effect on reading. The pioneering studies investigated printed text [1, 2], later studies addressed text on various forms of displays [3-9], the web [10, 11] and more recently the legibility of text on electronic paper [12].

Recommendations for what constitute sufficient contrast on the web are specified in the W3C Web Accessibility Guidelines WCAG 2.0 [13]. WCAG 2.0 divides contrast into three levels according criterion a, aa and aaa. The basic a-level criterion ensures that web pages are readable by individuals with colour blindness; the stricter level aa-criterion ensures that there is sufficient contrast to accommodate individuals with 20/40 vision and the most strict aaa-level criterion caters for individual with 20/80 vision. Clearly, there is a relationship between humans' visual acuity, the text sizes and the levels of contrast. By supporting contrast levels for 20/80 visual acuity levels the majority of the population is included [14]. Attention to contrast level and readability is extremely important as our visual acuity deteriorate with age [15].

Although WCAG 2.0 provides precise advice, its mathematical form makes the advice hard to understand and use in practice for most designers. Instead, designers often use ordinary colour picker such as the ones shown in Figs. 1 and 2 and rely on contrast calculators to determine the contrast level between two colours. Such contrast calculators are widely available on the web. However, a problem with this approach is that designers tend to check their design after the designs are finished. Often this is too late.

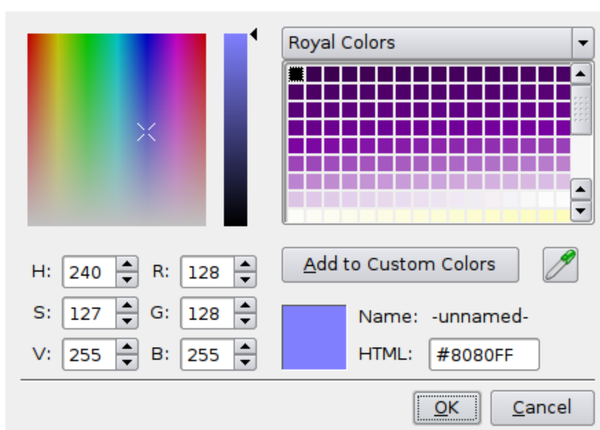


Figure 1. "Qt colour chooser" by Trolltech - Qt. Licensed under GPL via Wikimedia Commons

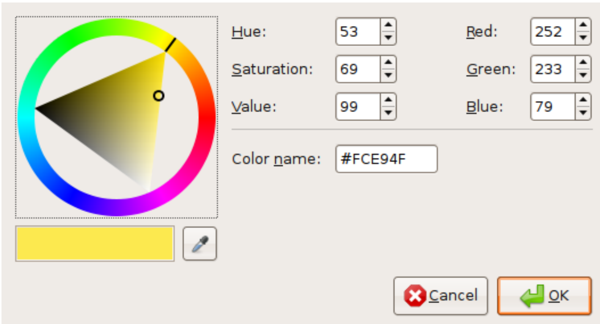


Figure 2. "GTK colour chooser" by GNOME Foundation - GTK+. Licensed under LGPL via Wikimedia Commons

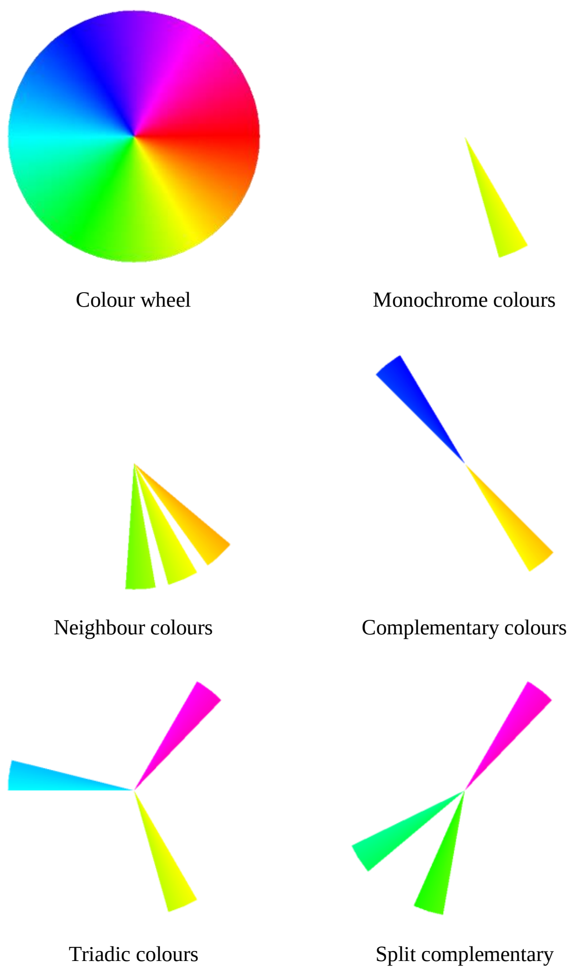


Figure 3. Common colour harmonies

There is surprisingly little research into how designers select colours and how colour picking interfaces should be designed. Of the few studies available van den Broek et al. [16] explored a colour picking interface for information retrieval applications. Douglas and Kirkpatrick [17] addressed the visual presentation of colour picker interfaces.

Gonzales and Latulipe [18] studies two hand interactions to explore colours and Troiano et al [19] optimized palettes to account for colour blindness.

Sandnes [20] explored the colour space in light of the WCAG 2.0 contrast constraints and proposed the idea of limiting the available colours in the colour picking interface. In a later study Sandnes and Zhao demonstrated such a tool [21]. However, their tool operated in the RGB colour space by laying out incremental slices of the colour cube. This layout scheme made colour selection difficult, because the valid colours were dispersed throughout the colour selection area. This study thus builds on Sandnes and Zhao’s work where the objective is to allow knowledge about contrast levels to be integrated into the design process. The novel contribution herein is to limiting the displayed colours to HSV half-planes defined by hues of a chosen colour scheme. This allows the colour selection area to be used more effectively.

Colour Harmonies

The colours space is huge as web pages often can be coded with as much as 256 x 256 x 256 = 16 777 216 different colours. For the novice this abundance of colours is overwhelming. Web designers however, often constrain themselves to smaller sets of colours known as colour harmonies. These colour harmonies are known to work well together. The colour wheel is commonly used as a tool to define colour harmonies. The colour wheel contains all the available hues organized in a circle from red (0°), yellow (60°), green (120°), cyan (180°), blue (240°), magenta (300°), and the colours in between.

The colour circle can be viewed as a projection of the RGB colour cube on to a plane defined by the normal line going from black (0,0,0) to white (255, 255, 255) as shown in Figure 3. The most common colour harmonies include

Monochromatic colours: Monochromatic colours all have the same hue, but vary in brightness and saturation. Monochromatic colours give the impression of order.

Neighbour colours: Neighbour colours are characterised by lying next to each other on the colour wheel, for instance yellow, green-yellow and green. Neighbour colours are often found in nature.

Complimentary colours: Complimentary colours are located 180° in relation to each other on the colour wheel, for instance red (0°)and cyan (180°) or yellow (60°) and blue (240°). Complimentary colours are vibrant.

Triadic colours: Triadic colours are separated by 120° on the colour wheel dividing the wheel into three parts, for example red (0°), green (120°) and blue (240°), or yellow (60°), cyan (180°) and magenta (300°). Triadic colours are also vibrant and express excitement.

Split Complimentary colours: Split Complimentary colours comprise a basic hue and the two neighbours of the complimentary colour on the colour wheel.

The colour harmonies greatly limit the available set of colours while ensuring that the design achieves the effect associated with the respective colour harmony.

Colour Models – RGB and HSV Transformation

Designers often prefers to use other models than RGB such as the HSV model, because it allows designers to reason about colours more closely to which they speak about colours. Often we refer to the basic hue with adjectives defining the characteristics of that hue. For instance, we can easily comprehend descriptions such as dark red, a saturated green, etc. Contrastively, it is hard for humans to reason around and describe colours using the machine centric RGB-model.

This study uses the HSV-model based on hue, saturation and value. The hue is the colour on the colour wheel described previously. Saturation is the pureness of a colour, while an unsaturated colour contains white. Value represents the strength of the colour. A low value is close to black while a high value is bright.

We therefore need to be able to transform HSV values to RGB. One commonly cited formulations where a colour is specified using hue H in [0..360], saturation S in [0, 1] and value V in [0,1] and the corresponding RGB values are computed using

Error! Objects cannot be created from editing field codes. (1)

where the chroma C is defined as

$$C = SV \tag{2}$$

and

$$H' = \frac{H}{60} \tag{3}$$

and

$$X = C(1 - |H' \bmod 2 - 1|) \tag{4}$$

The values are then scaled using

$$(R, G, B) = (R' + m, G' + m, B' + m) \tag{5}$$

Where m is given by

$$m = V - C \tag{6}$$

In our implementation the HSBtoRGB function provided by the java graphics framework was used (Colour-class).

Colour Contrast Distance Function

The colour presentation approach presented herein is based on only displaying valid colours given a certain colour choice defined by C_1. In order to determine if a colour C_2 is valid it needs to be sufficiently different from the chosen colour. We therefore need a colour distance function $d(C_1,C_2)$ defined in terms of contrast.

$$d(C_1, C_2) = contrast(C_1, C_2) \tag{7}$$

The World Wide Web Consortium (W3C) Web Contents Accessibility Guidelines (WCAG 2.0) [2] refers to luminance contrast which combines of hue, value and saturation. The WCAG 2.0 guidelines for level a-criterion (criterion 1.4.3) recommends that text should not rely on hue contrast. The level aa criterion recommend a luminance contrast ratio of at least 4.5:1 for text and 3:1 for headings. The level aaa criterion specifies a contrast ratio between text and its background of 7:1 and similarly 5:1 for headings. WCAG 2.0 defines luminance contrast as

$$contrast = \frac{L1 + 0.05}{L2 + 0.05} \tag{8}$$

where $L1$ is the luminance of the brightest colour and $L2$ is the luminance of the darkest colour. Luminance is defined as

$$L = 0.2126r + 0.7152g + 0.0722b \tag{9}$$

The factors r, g and b represent linear red, green and blue colour components. The conversion between linear c and non-linear components k is

$$c = \frac{k}{12.95} \tag{10}$$

If $k \leqslant 0.03928$, or

$$c = \left(\frac{k + 0.055}{1.055}\right)^{2.4} \tag{11}$$

If $k > 0.03928$. The value k is given by

$$k = \frac{C}{255} \tag{12}$$

where C represents one of the three RGB-vector values defined by an 8-bit value in the interval 0 to 255. This mathematical contrast definition is non-trivial and it is understandably not easy for designers to build a mental model of how colour choices affect contrast.

Colour Presentation Model

The colour presentation model is based on the designer first choosing a given colour scheme. Having selected a colour scheme the tool displays the colour half-planes of the HSV cylinders for each of the hues selected for the colour scheme. Each such half-plane lists all the combinations of saturation and values for the respective hue. This process is illustrated in Figure 3.

Once the user selects the first colour the contrast distance function is applied and only the colours with sufficient contrast distance from the selected colour are displayed. This process is illustrated in Figures 4, 5 and 6.

An RBG Formulation

The proposed scheme can also be expressed completely in the RGB colour space. The respective colour space is then represented by the polygon defined by the two end points black (0, 0, 0) and white (255, 255, 255) and a point on the edge of the colour cube according to the desired hue (see Figure 9). The colour wheel is thus represented by traversing the outer edges as follows.

1. Red (255, 0, 0) -> yellow (255, 255, 0)
2. Yellow (255, 255, 0) -> green (0 , 255, 0)
3. Green (0, 255, 0) -> cyan (0 , 255, 255)
4. Cyan (0, 255, 255) -> blue (0 , 0, 255)
5. Blue (0, 0, 255) -> magenta (255 , 0, 255)
6. Magenta (255, 0, 255) -> red (255 , 0, 0)

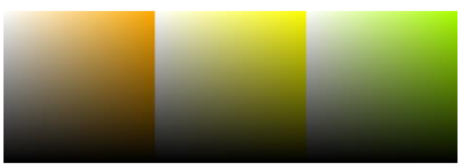
Colour planes for a triadic colour scheme (yellow, cyan, magenta)

Valid colours after selecting a dark(0) half saturated (0.5) cyan.

Valid colours after selecting a medium dark (0.5) half saturated (0.5) cyan.

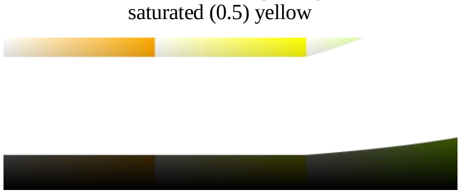
Valid colours after selecting a bright (1) half saturated (0.5) cyan

Figure 4. HSV half-planes for a triadig colour harmony



Neighouring colour sheme with orange, yellow and green.

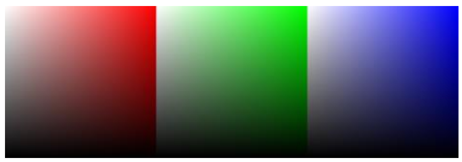
Valid colours after selecting a bright (1) half saturated (0.5) yellow



Valid colours after selecting a medium dark (0.5) half saturated (0.5) yellow

Valid colours after selecting a dark (0) half saturated (0.5) yellow

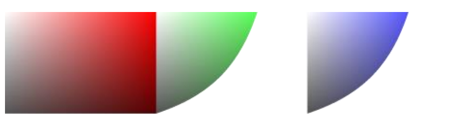
Figure 5. HSV half-planes for a neighour colour harmony



Colour planes for a triadic colour scheme (red, green and blue)

Valid colours after selecting a medium dark (0.5) half saturated (0.5) green

Valid colours after selecting a medium bright (1) half saturated (0.5) green



Valid colours after selecting a medium dark (0) half saturated (0.5) green

Figure 6. HSV half-planes for a triadic colour harmony

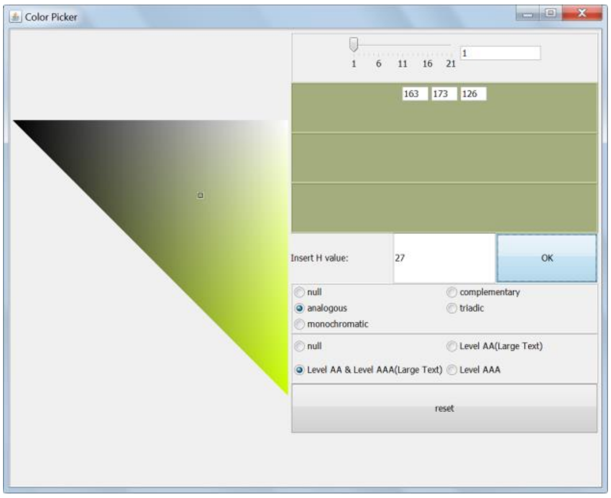


Figure 7. The colour picker tool

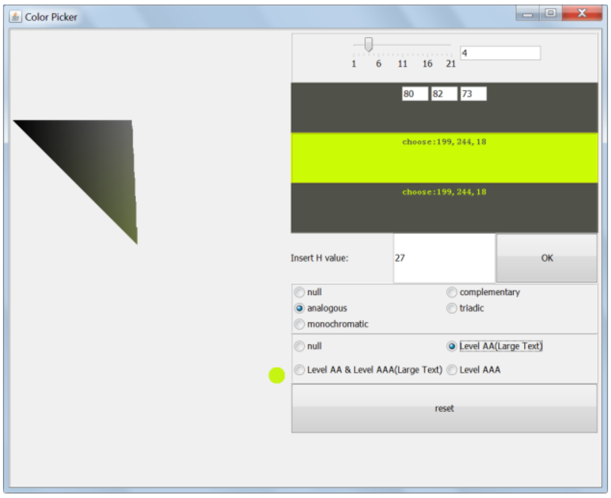


Figure 8. The colour picker tool with one chosen colour and colour space constraints.

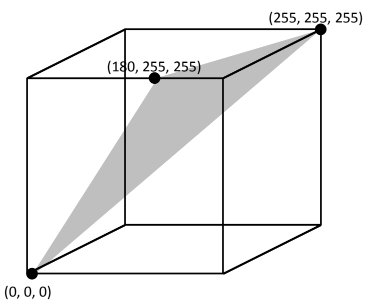


Figure 9. Colour plane for a given hue in the RGB colour space.

The respective polygon can then be directly mapped into a colour picking tool.

The Colour Picker Tool

We developed a prototype of a colour picker tool in Java. The tool is depicted in Figures 7 and 8. The user selects the desired colour harmony scheme, the basic hue in degrees, sets the desired contrast level and the corresponding colour planes are displayed. By altering any of the parameters the colours are adjusted allowing the designer to experiment with the various settings. The tool also includes a preview with foreground text on a background and the inverse.

Conclusions

A novel colour picking scheme is proposed. Colours are represented according to a given colour scheme and the colour planes for saturation and value for each respective hue is displayed. A contrast distance function based on the WCAG 2.0 guidelines are used to only display colours on each respective colour plane that has sufficient contrast compared to a selected selected first colour. The proposed scheme allows knowledge about constrast to be seamlessly integrated into the design process relieving the designers from the mathematical details of contrast computations. Moreover, the set of available colours as intuitively laid out hiding all irrelevant colour combinations for a given design. The approach is simple and relatively easy to implement and it should be possible to easily retrofit existing design tools with the improved colour picker model. first colour. The proposed scheme allows knowledge about constrast to be seamlessly integrated into the design process relieving the designers from the mathematical details of contrast computations. Moreover, the set of available colours as intuitively laid out hiding all irrelevant colour combinations for a given design. The approach is simple and relatively easy to implement and it should be possible to easily retrofit existing design tools with the improved colour picker model.

References

[1] M. A. Tinker, (1963). Legibility of print. Arnes, Iowa, Iowa State University Press.

[2] M. A. Tinker, and D. G. Paterson (1931). "Studies of typographical factors influencing speed of reading." Gen. PsychoL.

[3] M. L. Mathews, (1989). "Visual performance with coloured CRT displays: research update." Applied Ergonomics 20(1): 58.

[4] D. Stone, S. K. Fisher, et al. (1999). "Adults' prior exposure to print as a predictor of the legibility of text on paper and laptop computer." Journal Reading and Writing 11(1): 1-28.

[5] R. Nasanen, J. Karlsson, et al. (2001). "Display quality and the speed of visual letter search." Displays 22(107-113).

[6] A. Buchner and N. Baumgartner (2007). "Text – background polarity affects performance irrespective of ambient illumination and colour contrast." Ergonomics 50(7): 1036-1063.

[7] M. Greco, N. Stucchi, et al. (2008). "On the Portability of Computer-Generated Presentations: The Effect of Text-Background Colour Combinations on Text Legibility." Human Factors 50(5): 821-833.

[8] K. Knoblauch, A. Arditi, et al. (1991). "Effects of chromatics and luminance contrast on reading." Journal of the Optical Society of America A 8: 428-439.

[9] C.-C. Lin, (2003). "Effects of contrast ratio and text colour on visual performance with TFT-LCD." International Journal of Industrial Ergonomics 31(2): 65-72.

[10] R. H. Hall, and P. Hanna (2004). "The Impact of Web Page Text-Background Colour Combinations on Readability, Retention, Aesthetics and Behavioural Intention." Behaviour & Information Technology 23(3): 183-195.

[11] J. Ling and P. van Schaik (2002). "The effect of text and background colour on visual search of Web pages." Displays 23(5): 223-230.

[12] I.-H. Shen, K.-K. Shieh, et al. (2009). "Lighting, font style, and polarity on visual performance and visual fatigue with electronic paper displays." Displays 30: 53-58.

[13] World Wide Web Consortium (W3C), Web Content Accessibility Guidelines (WCAG) 2.0, W3C Recommendation 11 December 2008, http://www.w3.org/TR/WCAG20/

[14] A. Laitinen, Koskinen, S., Härkänen, T., Reunanen, A., Laatikainen, L., & Aromaa, A. (2005). A nationwide population-based survey on visual acuity, near vision, and self-reported visual function in the adult population in Finland. Ophthalmology, 112(12), 2227-2237.

[15] J. M.Wood, (2002) Aging, driving and vision, Clinical and Experimental Optometry 85 (4): 214–220.

[16] E. L. van den Broek, Kisters, P. M. F. and Vuurpijl, L. G. (2004) Design guidelines for a Content-Based Image Retrieval colour-selection interface. In Proceedings of the conference on Dutch directions in HCI (Dutch HCI '04). ACM, New York, NY, USA, 14-18.

[17] S. A. Douglas, and Kirkpatrick. A. E. (1999) Model and representation: the effect of visual feedback on human performance in a colour picker interface. ACM Trans. Graph. 18(2): 96-127.

[18] B. Gonzalez and Latulipe, C. (2011) BiCEP: bimanual colour exploration plugin. In CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11). ACM, New York, NY, USA, 1483-1488.

[19] L. Troiano, Birtolo, C. and Miranda. M. (2008) Adapting palettes to colour vision deficiencies by genetic algorithm. In Proceedings of the 10th annual conference on Genetic and evolutionary computation (GECCO '08), Maarten Keijzer (Ed.). ACM, New York, NY, USA, 1065-1072.

[20] F. E. Sandnes, Selecting suitable colours: Exploring the limits of WCAG 2.0 web page colour contrast constraints, In Gower Handbook of Information Design, edited by O. Lund B. Sheperd, Gower, 2015 (in press).

[21] F. E. Sandnes and A.-Q. Zhao, An interactive colour picker tool that support Web designs with WCAG 2.0 compliant colour contrast levels, in Proceedings of DSAI2015, Proceedia, 2015 (in press).