AN IMPROVED LEGIBILITY GUIDELINE FOR TEXT IN WEB PAGES

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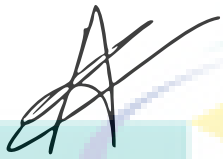
Signature : 
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DEDICATION

To Him who continuously gives me good health,
peace of mind, and eases path to my success

My beloved mom
Jamaliah Nuruddin
for her endless prayers

&

My dear wife
Faezah Mohd Sa'oad
for her boundless patience, care, and support

&

My lovely daughter
Nur Amani Ahmad Affendi
and
My adorable son
Ahmad Zaim Hakim Ahmad Affendi
for giving me strength to achieve my success

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ABSTRACT

Delivering information through the Internet is universal, offering significant advantages in terms of accessibility and flexibility in designing the appearance of text on the World Wide Web. Video Display Terminal (VDT) technology has recently been equipped with higher and higher pixel densities, and it is important to ensure that the text display as legible and as comfortable as low resolution VDTs. The purpose of this research is to investigate the VDT resolutions that affect reading performance in terms of legibility and comfortability. A reading task based experiment was conducted to measure the level of legibility and comfortability focusing on four texts in the web pages design parameters: the type of fonts, font sizes, colour combinations, and colour contrast ratio between text and background colour. Two sets of experiments were carried out using the selected VDT resolutions for low and high resolutions. The experiments were intended to investigate the relationship between legibility performance and VDT resolutions using reading and word counting tasks. Assessing the comfortable level, subjects then rated their comfort level based on experience doing the reading and word counting task. Improvement was observed almost on all text in the web design parameters when high resolution is used. Legibility levels between the two resolutions tested on type of fonts, font sizes, and colour combinations were not significant. However, in terms of colour contrast ratio, significant improvement was noted. The recommended colour contrast ratio is decreasing (2.35:1) compared to selected low resolution and recommendation from existing guideline (3.32:1). The decrease on colour contrast ratio value will lead to more flexibility in choosing the colour combination of text and background. Prototype Legibility Assessment Tool (LAT) was developed using the improved Legibility Guideline (LG) based on the results of this research. The purpose of this tool is to assess the existing web page legibility level and as a contribution from this research. A black box testing was done to the LAT by comparing the output from the LAT and the output from two web browser selected, Firefox and Internet Explorer. The result is 100% accuracy. Based on the result of the testing also indicate 100% accurate when assessing the text on the web font properties against the newly improved LG.

ABSTRAK

Menyampaikan maklumat melalui Internet adalah universal, yang menawarkan kelebihan yang ketara dari segi akses dan fleksibiliti dalam mereka bentuk rupa teks di World Wide Web. Teknologi terminal paparan video (VDT) baru-baru ini telah dilengkapi dengan kepadatan piksel yang semakin lebih tinggi, dan ia adalah penting untuk memastikan bahawa paparan teks yang mudah dibaca dan sama seperti tahap keselesaan VDTs resolusi rendah. Tujuan kajian ini adalah untuk menyiasat resolusi VDT yang menjejaskan prestasi pembacaan dari segi kejelasan dan keselesaan. Eksperimen berasaskan tugas membaca telah dijalankan untuk mengukur tahap kebolehbacaan dan keselesaan dengan memberi tumpuan kepada empat parameter reka bentuk teks dihalaman web: jenis fon, saiz fon, kombinasi warna, dan nisbah kontras warna antara teks dan warna latar belakang. Dua set ujikaji telah dijalankan dengan menggunakan resolusi VDT terpilih untuk resolusi rendah dan tinggi. Eksperimen ini bertujuan untuk mengkaji hubungan antara prestasi kebolehbacaan dan resolusi VDT menggunakan bacaan dan tugas pengiraan perkataan. Penilaian terhadap keselesaan subjek, kemudian memberikan penilaian terhadap tahap keselesaan mereka semasa menjalankan tugas pembacaan dan tugas pengiraan perkataan. Hasilnya, penambahbaikan diperhatikan hampir pada semua parameter rekabentuk teks dalam web apabila resolusi tinggi digunakan. Walau bagaimanapun tahap kebolehbacaan di antara kedua-dua resolusi yang diuji ke atas jenis fon, saiz fon, dan kombinasi warna adalah tidak ketara. Dari segi nisbah kontras warna, peningkatan yang ketara telah dicatatkan. Nisbah kontras warna yang disyorkan semakin berkurangan (2.35:1) berbanding dengan resolusi dipilih rendah dan cadangan daripada garis panduan yang sedia ada (3.32:1). Penurunan nilai nisbah kontras warna akan membawa kepada lebih banyak fleksibiliti dalam memilih kombinasi warna teks dan latar belakang. Prototaip alat penilaian kebolehbacaan (LAT) telah dibangunkan menggunakan garis panduan kebolehbacaan (LG) yang lebih baik yang berdasarkan keputusan kajian ini. Tujuan alat ini dibangunkan adalah untuk menilai tahap kebolehbacaan laman web yang sedia ada dan sebagai sumbangan daripada kajian ini. Pengujian kotak hitam telah dilakukan terhadap LAT dengan membandingkan output dari LAT dan output dari dua pelayar web terpilih, Firefox dan Internet Explorer. Hasilnya ialah ketepatan 100%. Berdasarkan hasil ujian, juga menunjukkan 100% tepat apabila menilai sifat font teks pada halaman web terhadap LG baru yang ditambah baik.

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LIST OF ABBREVIATIONS

XML	Extensible Markup Language
HTML	Hypertext Markup Language
VDT	Video Display Terminal
PT	Point
PPI	Pixel-per-inch
CRT	Cathode Ray Tube
LCD	Liquid Crystal Display
ANOVA	Analysis Of Variance
W3C	World Wide Web Consortium
ANSI	American National Standard Institute
WCAG	Web Content Accessibility Guideline
LAT	Legibility Assessment Tool
SD	Standard Deviation
HSV	Hue, Colour Saturation, and Value
RGB	Red, Green, and Blue
CSS	Cascading Style Sheet
FWI	Firefox Web Inspector
IEDT	Internet Explorer Developer Tool
MOA	Minute of arc

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In this chapter, the background and motivation of this study will be presented. This chapter will then presenting the research questions, objectives, and research scope. Organisation of the thesis will conclude this chapter.

1.2 RESEARCH BACKGROUND AND MOTIVATION

Web pages are made from a collection of Extensible Markup Language (XML) like tags, which are then used or interpreted by a web browser to control how the contents should be displayed on screen.

One of the segments or parts of a webpage is the content. Webpage contents are the part used to determine how useful or beneficial the webpage to the user. The quality of web contents is not just depending on the presented information but also the way it is designing. Based on eye-tracking studies done by J. Duckett, (2011) and Nielsen, (2000), users actually read just a few parts of a webpage and then decide the webpage is useful or not. In a separate analysis done by Nielsen, (2008), users were actually likely read only 20% of the text. The results from eye-tracking study and a study on how little the users actually read on a webpage prove that the qualities of the web contents have to be taken care seriously.

Since a webpage is made from XML-like tags called Hypertext Markup Language (HTML), it is intended to be very flexible. Web designers or web developers are free to choose among thousands of colours for text in web pages and backgrounds, and thousands of typefaces or fonts, to be mixed and match to design an attractive and informative web page. This flexibility, however, has introduced a dilemma that can reduce quality of web content. The wrong combination of colour for text and background or the wrong typefaces used may lead to problematic legibility.

Much research has been conducted recently on the legibility and suggestion to improve legibility has been made. On colour combinations, most of the researchers have suggested that the best colour combinations for text in web pages are the colour combinations that are very high contrast, which recommends black and white colour combinations. This recommendation, however, limits the creativity thus might lead to unattractive and less appealing web page. Some web designers or developers maybe experience difficulties if forced to use other than black and white due to following user requirements or corporate web page colour schemes.

On typography, most of the researchers recommend a text that is designed for on-screen viewing which is obviously optimised to be displayed on screen. On serif versus sans serif fonts, earlier research done by Tinker, (1932), Zachrisson, (1965), Poulton, (1965), and Moriarty and Scheiner, (1984) has proven that there is no difference between legibility of serif and sans serif fonts. These findings are also supported by research done by De Lange et al., (1993), and Bernard et al., (2001). However, some researchers claim the superiority of serif typefaces, as proven by research done by Schultz, (1997) and Wheildon, (1996).

A legible text in web pages does not just make the web page easily readable, but also increases usability. A less legible webpage can lead to fatigue and tires the eyes quickly, decreasing user focus on reading the text resulting from extra challenges to recognising the text.

More recent Video Display Terminals (VDTs) implement up to date technologies that are able to produce sharper images, resulting from high amount pixels available per square inch. This could provide additional flexibility about choosing the fonts and colour combinations for texts and backgrounds. More recent research done by Adipat et al., (2011), Buchner et al., (2009), Chang et al., (2012), Hasan et al., (2011) and a few more researchers on legibility, has been found to be less focused on VDT resolution. This factor combines with earlier research results, used as a basis for constructing a well establish guideline has made it significant to investigate VDT resolution that has been proven to improve the quality of image displayed but yet to be prove able to increase the legibility of text in web pages.

Choosing the right colour combinations for text and the background is very important. It can influence users to stay or stick to the web page. Proven by research done by Kulkarni et al., (2011), her research reveals that, web colour application, influence website trust, and satisfaction. Chang et al., (2012) later demonstrated that chromaticity had a little effect on legibility speed, but that the subjective preference for chromaticity is more important than luminance. However, Hasan et al., (2011) proved that colour combinations for text and background do significantly affect the eye blink rate. This shows that an incorrect colour combination can affect legibility level and also expose the users to various eye problems.

Colour contrast, or the difference between the two colours used for text and background, may also affect the legibility level. A study done by Lee and SUK, (2011) showed that users are a lot more comfortable reading text with 60% grey as the text colour averse to a white background. Wang and Chen, (2003) also demonstrated that the difference between the two colours does considerably influence legibility.

Humar et al., (2008), and Buchner et al., (2009) in their research concluded that polarity of a text and the background colour also influence legibility. Polarity here refers to whether text or background has the higher luminance (which colour is brighter). Buchner et al., (2009) found out that only on a display that is capable of displaying a high luminance level does positive colour polarity have an advantage.

The size of font has a great influence on legibility. Not much research has focused on this area since the conclusion is very clear and simple. The larger the text more legible text is. A study by Bernard et al., (2001) proved that the size of the font used is influence legibility greatly. Bernard found out that the larger the font size will promote faster reading. Wu, (2011) based on his research result also suggested that font size must be considered when designing text on e-paper and minimum recommended font size is 42.0 minutes of arcs[1].

Li and Suen, (2010) in their study on a different type of font or typeface proved that typeface used also greatly influences legibility. Their research result suggests the use of font Garamond, Centaur, Times New Roman, Arial, Helvetica, Rockwell, and Footlight MT Light is the best font to ensure an optimum legibility level.

There are a few more variables that are affecting legibility of a text. However, on the web design aspects on the characteristics of the text in web pages, the factor influence legibility is summarized in Table 1.1. Other aspects that have been studied and proven to have affected legibility include the size of the VDT, the viewing distance, ambience lighting and angle of the display. They are also several researchers who have studied human factors, such as visually impaired users and dyslexics, who require different conditions compared to normal or corrected to normal visioned users.

Table 1.1: Factors influencing the legibility of a text in web pages

Factors influencing legibility of a text in web pages	**Descriptions**
Colour Combinations	Certain colour combinations for text and the background proved to provide difficulties in reading the text.
Colour Contrast	The closer the colour difference, the more difficult to read the text.

[1] A minute of arc (MOA), arc minute, or minute arc, is a unit of angular measurement equal to 1/60 of one degree. - Wikipedia contributors, (2014)

Table 1.1: Continued

Factors influencing legibility of a text in web pages	Descriptions
Type of fonts/Typefaces	Certain typefaces are proven to have more legible compared to others.
Font size	The larger the font size, the more legible text is.

Presentation of an image on a VDT is influenced greatly by the VDT resolution used. Modern VDTs are capable of displaying a very high resolution, thus having smaller pixels that are packed densely together. This high density of pixels per square inch on the VDT leads to sharper image but also makes the image displayed looks smaller. This might affect the legibility of a text in web pages, and therefore require further study on it. In this study, the advantage, or disadvantage of high and low VDT resolution on text in web pages legibility will be explored. Any advantage will be investigated and may be suggested as new recommended guidelines on ensuring text in web pages legibility.

1.3 RESEARCH APPROACH

This research concentrates on the legibility of a text in web pages on a different resolution. This research aim is proposing a new legibility guidelines that will enhance the legibility of a text in web pages thus increase the usability of a web page for high and low resolution. This research is also proposing a new legibility tool based on the proposed legibility guideline for high VDT resolution that will assist a web designer or web developer to investigate the elements on their web page to quickly improve the legibility when displayed on high resolution.

The objectives of this research are as follows:

i. To develop an improve Legibility Guideline (LG) by investigating the influence of colour combinations, colour contrast, type of fonts, and font sizes, in terms of legibility performance and subjective preference on comfortable level on a five-point Likert scale – Very uncomfortable, uncomfortable, normal, comfortable, and very comfortable.

ii. To develop a Legibility Assessment Tool (LAT) based on the proposed legibility guidelines on high resolution.

1.4 SCOPES OF RESEARCH

The scopes of this research is as follows:

i. Focusing on colour combinations for text and background, colour contrast, type of fonts and font sizes.

ii. Focusing on Latin characters. Other types of characters, such as Arabic or chinese characters are not in the scope of this study.

iii. To compare the results, legibility performance between the two resolutions has been selected for this research for low and high resolution and recommended guidelines.

iv. Focusing on proposed high-resolution guidelines when developing the LAT.

1.5 ORGANISATION OF THESIS

This thesis consists of six chapters. Chapter one will provide a brief background of the research by defining the research problem statements, objectives, and the scope of the research.

Chapter two will present the literature review of earlier studies on colour combinations, type of fonts, colour contrast, and font sizes on legibility. A review of the currently available guidelines on optimizing the legibility is also presented. Lastly, a review on experiments with designs on previously studied will also be presented and a suitable legibility measurement method proposed.

In chapter three, the methodologies use in this research will be presented. In this chapter, a detail process of each phase of research will be discussing and describe. This chapter will start by describing the data collection process, the analysis use to derive the result from the data collected, and the validation process involved. The result comparison will be come next, followed by prototype development process through prototype testing and reporting.

In chapter four, detailed results for each dependant variable studied will be presented for each low and high resolution. Then, the results will be then compared for low and high resolutions to determine the improvement of legibility on high resolution. Lastly, the new proposed legibility guidelines will be presented, and any findings will be shared.

Chapter five will focus on the implementation of the new proposed legibility guideline. A detailed architecture and algorithm use case will be presented.

Lastly, in chapter six, suggestions and any recommendations to provide extensions or future work for this research will be presented.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews some recent studies on legibility factors and their influence on on-screen readings. This chapter will start by exploring what legibility is all about and its relationship with readability. This chapter will then explore the typographical factors affecting the legibility, and the effects of colour combinations used on legibility. Later, the possible effects of resolutions on legibility will be discussed. Lastly, the methods used to quantify the legibility will be explored. Finally, conclusions from this chapter are presented.

2.2 DEFINING LEGIBILITY

Legibility, "the quality of being clear enough to be read" according to the Oxford Dictionary of English (oxforddictionaries.com), basically determines the readability level of a text. The more legible the text is, the more readable and understandable it is.

Based on previous research, Mohammad Ali et al., (2013), Moret-Tatay and Perea, (2011), Li and Suen, (2010), Mackiewicz, (2006), and Arditi and Cho, (2005) have demonstrated that font type does affect legibility. For colour combinations Humar et al., (2008), Greco et al., (2008), Hall and Hanna, (2003) and Ling and van Schaik, (2002) also proved that they also effect legibility. Based on research findings of Sanchez and Jaeger, (2015), Beymer et al., (2008), and Hall and Hanna, (2004) when letters in text are difficult to read, this can make the text more difficult to encode and

slows down the reading process because of the longer eye fixations required to recognise the characters displayed.

Resulting from these slow reading results, the webpage may be considered low in quality, thus reducing the usability level. As proven by eye tracking studies done by Nielsen, (1999) and P. Duckett, (2003), users actually read a certain part of a webpage while trying to find the certain keyword related to the information they are looking for. On separate analysis did by Nielsen, (2008) also supporting this claim. Based on his research results, users actually only read about 20% of the text.

As a conclusion, legibility is significantly important, and directly affects the usability level of a webpage.

2.3 TYPOGRAPHY FACTORS AFFECTING LEGIBILITY

Recent research suggests that choosing the right font size and type of fonts can affect the legibility of a webpage. For font size, the larger the font the better the legibility performance. In terms of type of fonts, however, legibility is influenced by the characteristics or shape of the fonts. The characteristics of the fonts include serif and sans serif properties, and the categories of fonts, which include fonts designed for printed materials and fonts design for on-screen viewing. In this section, the characteristics of fonts and recommendations from the results of previous research will be discussed.

2.3.1 Serif And Sans Serif Fonts

Serif and sans serif are the two main categories of fonts design. Serif fonts have curls or an extra stroke at the end of each letter. Typefaces or fonts that do not have serifs are called sans serif. Figure 2.1 illustrates the difference between serif and sans serif fonts.

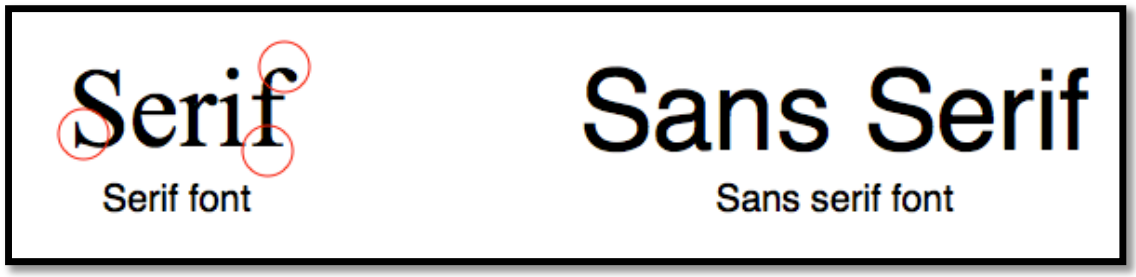


Figure 2.1: Serif and sans serif fonts

Zhang, (2006) found out that, based on typographic literature, sans serif fonts are generally believed to have an advantage in terms of legibility. However, the debate on whether serif versus sans serif fonts are more legible is on going.

Several researches were made in this area. Most researchers have suggested that serif fonts are more legible because serif fonts, which provide more information to the eyes (Geske), and increase the legibility of a text by assisting the readers to distinguish the letters more easily resulting from more visibility of end stroke (McCarthy and Mothersbaugh, 2002).

However, Moret-Tatay and Perea, (2011) stated that sans serif fonts are better than serif fonts. They have presented two reasons sans serif is better than serif fonts: First, serifs are extra parts of letters added to the letters. This acts as visual noise when eyes try to detect the characters. Secondly, the spacing between the letters is reduced because of their ornamentation.

Several recent researches also agree with Moret-Tatay and Perea. Banerjee et al., (2011) on their study on readability also reveals that sans serif is better than serif fonts. Morris et al., (2002) also suggested the use of sans serif fonts. Based on their research, readers can actually read 20% faster on sans serif fonts at a very small size font. Several other researchers also suggest the use of sans serif fonts. Based on research by Mackiewicz, (2006), Bernard et al., (2001), and Bernard and Mills, (2000), the results cannot prove any significant difference between serif and sans serif fonts. Their research results do indicate that sans serif fonts do have a small advantage in terms of legibility.

However, some of the researches found in the literature conclude that there is no significant difference between the serif and sans serif fonts. Table 2.1 summarizes recommendations from previous researchers. Based on Table 2.1, it is observed that none of the previous researches focus on VDT resolution in their experiments.

Table 2.1: Result and recommendation on serif versus sans serif fonts

Research	Serif	Sans Serif	Comparison of resolution
Paterson and Tinker, (1931)	No Significance		✖
Lenze, (1990)		✔	✖
Schultz, (1997)	✔		✖
Boyarski et al., (1998)	✔		✖
Yager et al., (1998)		✔	✖
Geske	✔		✖
Bernard et al., (2002)		✔	✖
McCarthy and Mothersbaugh, (2002)	✔		✖
Arditi and Cho, (2005)	✔		✖
Erdogan, (2008)		✔	✖
Moret-Tatay and Perea, (2011)		✔	✖
Banerjee et al., (2011)	✔		✖
Soleimani and Mohammadi, (2012)	No Significance		✖

2.3.2 Fonts Designed For Printed and On-Screen

Most of the fonts are actually designed and optimised to be viewing either on-screen or in printed materials. Fonts designed for on-screen are enhanced to increase the readability level when viewing on screen. The clear enhancement made to the fonts designs for on-screen is the x-height. X-height is basically a height of character “x” that determines the height or how tall the font. According to Boyarski et al., (1998), and

Poulton, (1965) the x-height has been proven to influence legibility. The larger the x-height, the taller the font. Figure 2.2 shows the difference between Verdana (Font designed for on-screen viewing) and Times New Roman (font designed for printed materials) with both on 10 pt. (point) size.

come see the play look up is cat not my and dog f0r you to the play look up is cat not my and dog for you to come see look up come you the pl@y is cat not my see dog for to and is cat not co~e see the play look up my and dog for you to dog for come see the play look up is to cat not my and you	come see the play look up is cat not my and dog f0r you to the play look up is cat not my and dog for you to come see look up come you the pl@y is cat not my see dog for to and is cat not co~e see the play look up my and dog for you to dog for come see the play look up is to cat not my and you

Figure 2.2: Verdana (Left), and Times New Roman (Right) on 10 pt size

Based on Figure 2.2, the Verdana font does not just have relatively higher x-height compared to Times New Roman but also more spacing between the characters.

Based on the results from previous studies done by Camnalbur and Mutlu, (2011), Sheedy et al., (2005), Chaparro et al., (2006), Beymer et al., (2008), and Weisenmiller, (1999) page 81, it is clearly indicated that font design for on-screen viewing is the best and recommended type of fonts to be use on text in web pages. However, based on Table 2.2, it is oddly finding to find out that, enhancement to the font legibility due to higher VDT resolution used is not explored. Table 2.2 provides an overview on the research done previously on text legibility.

Table 2.2: Existing research on fonts legibility

Research	Fonts Tested	Most Recommended Fonts	Comparison of resolution
Hill and Scharff, (1997)	Arial, Courier New, and Times New Roman.	Times New Roman.	✖
Yager et al., (1998)	Swiss, and Dutch.	Swiss.	✖
Boyarski et al., (1998)	Georgia, Times Roman, and Verdana.	Georgia, and Verdana.	✖
Bernard and Mills, (2000)	Arial, and Times New Roman.	Arial.	✖
Subbaram, (2004)	Verdana, Arial, Georgia, and Times New Roman.	Verdana.	✖
Sheedy et al., (2005)	Arial, Georgia, Times New Roman, and Verdana.	Verdana.	✖
Mackiewicz, (2006)	10 fonts including Verdana, Times New Roman, and Arial.	Gil Sans.	✖
Chaparro et al., (2006)	8 fonts including Times New Roman, and Verdana.	Consolas, and Cambria.	✖
Li and Suen, (2010)	15 fonts including Times New Roman, and Arial.	Times New Roman	✖

Table 2.2: Continued

Research	Fonts Tested	Most Recommended Fonts	Comparison of resolution
Mohammad Ali et al., (2013)	Georgia, Verdana, Times New Roman, and Arial.	Georgia, and Verdana.	✖
Hojjati and Muniandy, (2014)	Times New Roman, and Verdana.	Verdana.	✖

2.3.3 Design of the Fonts

Besides, the aesthetic design or shape of characters that influence the legibility of the fonts, x-height, ascender, descender, and character spacing also influences the legibility of a font. Subbaram, (2004) on page 198 has proved that ascenders and descenders do improve legibility. Of characters spacing, the larger the space the more distinctive the characters are. Recent studies by Ou et al., (2015), and Hojjati and Muniandy, (2014) do agree with characters spacing does influence legibility. Figure 2.3 illustrates the x-height, ascenders, and descenders found in fonts.

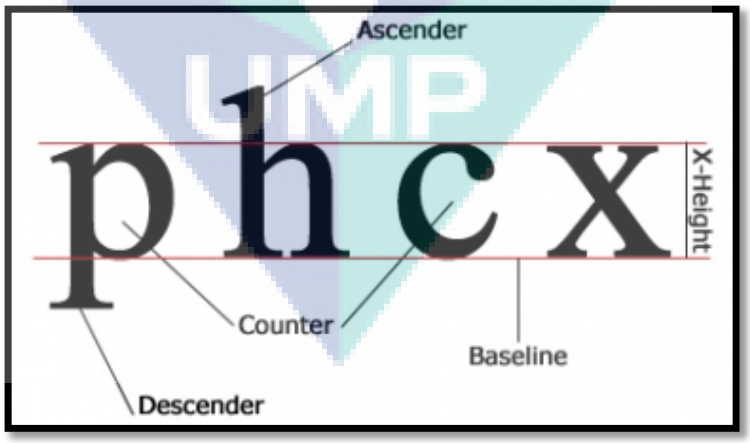


Figure 2.3: Illustrations on x-height, descenders and ascenders

As a conclusion, the x-height, descenders, ascenders, and characters spacing do determine the legibility of a font. Table 2.2 shows the fonts recommended for optimum legibility.

2.3.4 Font Sizes

Font sizes have a great influence on legibility. As proven by previous results, the larger the size of a font, the more legible it is. Subbaram, (2004) on page 200 found that larger fonts were generally more legible than a smaller font. However, Bergfeld and Weldon, (1987) indicated that too large a font might slow reading speed, since the user has to scan a larger area to acquire the same amount of information. Eye tracking studies by Beymer et al., (2008) have proven that sweeping time does increase for larger font types, thereby slowing the reading speed. This effect is also found in Beymer et al., (2005) research on the effect of line length on reading. Beymer et al. also indicated that although the small font reduces the sweeping time, it does however increase fixation time compared to a larger font size. Based on Bernard et al., (2002), Bhatia et al., (2011), and Ivory and Hearst, (2002), a font size of at least 12 pt. is the best suited to a web page. Table 2.3 below summarizes the recent research done in font size. Referring to Table 2.3 does reveal that none of the researches focus on the effect of VDT resolution on their research, which is the main focus of this research.

Table 2.3: Existing research on font sizes

Researches	Font sizes tested	Recommended font size	Comparison of resolution
Bernard and Mills, (2000)	10 pt, and 12 pt.	12 pt.	✖
Bernard et al., (2002)	10 pt, 12 pt, and 14 pt.	12 pt.	✖
McCarthy and Mothersbaugh, (2002)	8 pt, and 10 pt.	No significant difference.	✖
Bernard, (2003)	10 pt, 12 pt, and 14 pt.	No significant difference.	✖

Table 2.3: Continued

Researches	Font sizes tested	Recommended font size	Comparison of resolution
Subbaram, (2004)	8 pt, 10 pt, 12 pt, and 14 pt.	At least 10 pt, 14pt is the most legible.	✖
Beymer et al., (2008)	10 pt, 12 pt, and 14 pt.	14 pt.	✖
Kim et al., (2014)	8pt, 10 pt, and 12 pt.	No significant difference 10 pt, and 12 pt.	✖

2.4 COLOUR FACTOR AFFECTING LEGIBILITY

Text on screen is based on light waves. White is generated by a combination of equal intensities of red, green, and blue light waves, while black is the absence of these light waves (Timpany, 2009). The measurement of the light wave is in terms of wavelength. The Figure below shows the relationship among eye sensitivity, colour wavelength, and colour luminosity.

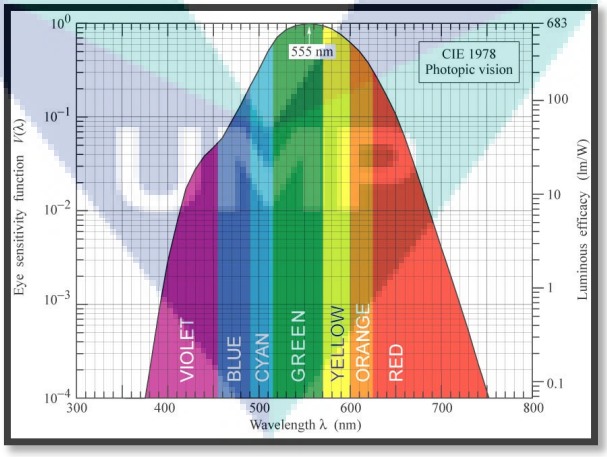


Figure 2.4: Relationship between eye sensitivity and colour wavelength and luminosity

Source: Department of Electrical, Computer and Systems Engineering, Rensselaer Polytechnic Institute

Based on Figure 2.4, green has proven to be the most sensitive to our eyes, while red and violet shows the least sensitivity. A different wavelength means that the curvature of the lens in the human eye has to change accordingly. Blue and red colour combinations might necessitate the eyes to make constant changes in the lens curvature, causing the eyes to tire quickly. According to the literature exploration (Buchner et al., 2009, Humar et al., 2008, Erdogan, 2008, Hall and Hanna, 2004, and Shieh and Lin, 2000), there are two main factors in colour combinations that influencing legibility, colour contrast and colour polarity. Colour contrast is more focused on the contrast ratio of the relative luminance of the colours. On the other hand, colour polarities are divided into two types - negative polarity and positive polarity. Negative polarity is where the text colour contrast is lighter than the background colour. For example, white text on black background while positive polarity is vice-versa. Colour combination exploration has shown that choosing the right colour combination is very important, not just for legibility but also for long reading durations.

Previous research results have proven that users usually prefer colours that have strong contrast, and, mostly, they prefer pure black and pure white. Ferrari and Short, (2002) in their experiment, on evaluating colour combinations on web pages, have proven that the black and white colour combination was the best in all measurements in their studies. Erdogan, (2008) research on legibility of websites designed for instructional purposes also agreed with Ferrari and Short. Erdogan compared 15 colour combinations in his experiment and found significant differences between each colour combination in terms of legibility. Humar et al., (2008) also researched colour combinations affecting legibility on CRT displays. They also agree with Erdogan research that, colour combination does affect legibility. Humar et al., however, have found that yellow text with a black background is the most legible colour combination. More recent studies using eye-tracking method also proved that black and white is the best colour combination. Rello and Marcos, (2012) research has found that participants prefer a white background with black text and black text with a white background more compared to other colour combinations. There is several more researchers study colour combinations effect on legibility. Table 2.4 provides an overview of recent research done on the effect of colour combination on text in web pages legibility.

Table 2.4: Existing research on colour combinations. Effects on legibility

Researcher(s)	Summary of method studies	Results		Comparison of resolution
		Most preferred colour	Least preferred colour	
Shieh and Lin, (2000)	To rate text-background colour on a ten-point scale with the aesthetic appearance.	Blue on yellow.	Purple on red.	✖
Ferrari and Short, (2002)	Participants answered a set of questionnaire and are given 3-point scale.	Black on white.	Red on green.	✖
Camgöz et al., (2002)	To ask subjects to select the colour square they preferred from the 8 most saturated background colours presented.	Blue was the most preferred hue regardless of background shown. Foreground colour with maximum brightness and saturation levels were more preferred than any other colours.		✖
Shieh and Ko, (2005)	To rate icon-background colour combination on a five point scale with subject preference.	Red on black.	Cyan on green.	✖

Table 2.4: Continued

Researcher(s)	Summary of method studies	Results		Comparison of resolution
		Most preferred colour	Least preferred colour	
Erdogan, (2008)	124 students to rate 45 web pages designed with different combinations of fonts, font sizes and different combinations of background/foreground colours on five-point scale.	Dark text on light background or black foreground with white background is the most preferred.	Dark text on dark background and red on blue.	✖
Humar et al., (2008)	Participants were asked to identify the characters displayed in the centre of the screen generated by multiple combinations of background and foreground colour combinations.	White on black.	Yellow on white.	✖
Greco et al., (2008)	Participants with normal colour vision to rate combinations of 702 foreground/back- ground colours presented on PowerPoint slide on 3-point scale.	Dark text on light background or black foreground with white background is the most preferred.	Cyan on magenta; and green on red.	✖
Buchner et al., (2009)	Participants were asked to read a series of short stories and mark the error by clicking the word that had an error.	Positive polarity. Dark text with light background.	Negative polarity.	✖
Timpany, (2009)	Participants were presented with text with the same font and colour combination and were asked to make a comparison.	Black on white; and blue on white.	Red on green; and fuchsia on blue.	✖

Table 2.4: Continued

Researcher(s)	Summary of method studies	Results		Comparison of resolution
		Most preferred colour	Least preferred colour	
Vanderschantz et al., (2010)	Rate-of-error test conducted followed by four questions survey.	Black on white.	Yellow on black.	✖
Rello and Marcos, (2012)	By recording eye movements and questionnaire. Participants were asked to choose which colour combination they preferred.	Prefer strong contrast. Pure black font with pure white background.		✖
S.-M. Huang, (2012)	To rate icon-background colour combinations on a seven-point scale with subjective aesthetic preferences. The recommended colour combinations were those with high rating consistencies and high rating score.	Light cyan on dark green; yellow on dull blue; and dull green on pale green.	Dark green on greyish red; deep-greenish yellow on purple; greyish purple on dark purple; dark greyish yellow on dark green; light-greyish blue on strong purple; dark green on greyish-red; and greyish blue on dark green.	✖

There are a few established guidelines on colour combinations. UsabilityNet, (2006) is a project funded by the European Union (EU) to provide resources and networking for usability practitioners, managers, and EU projects. Referring to their guidelines, patterned backgrounds are the most not recommended choice since they make text difficult to read. U.S. Dept. of Health and Services, (2006) (HSS) is another organisation that strongly supports this recommendation. Usability.gov is a website containing primary government sources for information concerning usability and user-centred design, and is managed by the HHS. According to their findings, reading black text on a plain white background is up to 32% faster compared to other colour combinations, and HHS has recommended using black text on a plain high contrast background. Generally, high contrast between the text and background colour makes the reading task easier (HHS, UsabilityNet, Erdogan, 2008, and Nielsen and Loranger, 2006).

The World Wide Web Consortium (W3C) is an international community in which the member organisations and a full-time staff, along with the public, work together to develop a web standard. They developed the Web Content Accessibility (WCAG) guideline that covers a wide range of recommendations for making web content more accessible (Caldwell et al., 2008). Referring to the guidelines, WCAG suggests that the contrast ratio of the text and the background should be at least 4.5:1. The equation below shows the formula for calculating the contrast ratio.

$$Colour\ Contrast\ Ratio = \frac{(L1 + 0.05)}{(L2 + 0.05)}, Where \tag{2.1}$$

i. L1 is the relative luminance of the lighter of the foreground or background colours; and

ii. L2 is the relative luminance of the darker of the foreground or background colours.

2.5 VDT RESOLUTION ON LEGIBILITY

One of the challenging aspects of designing web pages is VDT resolution. According to Nielsen, (2012), VDT gets larger with resolution. However, referring to the previous sub sections in this chapter none of the researches actually do the VDT resolution comparison. The higher the resolution means the smaller the size of a pixel so the more pixels per-inch-square (PPI^2). As an effect of this increase in PPI^2, the images displayed will look sharper but all the web page components will look smaller than lower resolution VDTs.

There are a few researches done on quality of text on the effects of VDT resolution. Ziefle, (1998) performed research on the effects of display resolution on visual performance and demonstrated that higher resolutions are better than a lower resolution. In his research, he recommended the use of higher resolution to make prolonged on-screen reading more comfortable, and to avoid visual fatigue. Bridgeman et al., (2003) conducted research on the effects of screen size, screen resolution, and display rate on computer base test performances and indicated that, based on the results, screen size and resolutions do make a difference in reading comprehension. However, they then explicitly mentioned that the screen resolution might be more important that screen size. One of the advantages of having a high-resolution display is, more viewable area, which led to more data, can be viewed simultaneously. Based on Ball and North, (2005) research, the advantages of high resolution VDT in displaying finely detailed data have supported these claims. D.-L. Huang et al., (2009) studied the effects of VDT resolutions on readability. They also demonstrated that higher resolution could make the reading task better. However, their research has also found the effects of higher resolution on the character size. Based on their findings, characters sized 1mm have been shown to be significantly slower to read for higher resolution compared to a lower resolution.

Although fewer researchers have focused on VDT resolution as one of their variables in their experiment. It is however clearly indicated that there is proven improvement on text in web pages legibility on high VDT resolutions compared with low VDT resolutions.

2.6 METHODS IN QUANTIFYING LEGIBILITY

There are several types of measurement use to measure legibility. However, in this subsection, we will only discuss the measurement method used by previous researchers to measure legibility effect on dependant variables defined within the scope of this research.

2.6.1 Speed of Reading

In this method, it has been assumed that the more legible the text is, the faster the reading speed. The users or subjects were asked to read the text, and errors in reading the text and the speed of reading process was recorded.

Several researchers have used this method. Mohammad Ali et al., (2013) used this method to evaluate sans serif and serif fonts. In their research, they used text using different type of fonts. Timpany, (2009) also using text in her research on evaluating different colour combinations used for text and background. In her research, text was designed using several colour combinations. The reading speed was recorded and used to determine the legibility level for each colour combination. Several more researchers used this method in evaluating legibility, such as Soleimani and Mohammadi, (2012), Buchner et al., (2009), and Hall and Hanna, (2004). Many other previous researchers have attempted to evaluate legibility using this method. However, this method may not be perfect, resulting from the influence of cognitive factors.

Several variations of this method were identified used by the previous researchers. Gradisar et al., (2007) and Chang et al., (2012) designed an experiment that required subject to read aloud a series of characters presented on screen as fast as possible. Any errors made during the reading and the speed of reading were recorded. This method, however, had a serious disadvantage, because it is not the natural way we read a text.

Another variation of reading method is proofreading. This method requires the subjects to proofread and report any typographical error in the text presented. Piepenbrock et al., (2013) used this method to investigate the positive display polarity advantage on small character. This method has also been used by Ziefle, (1998) in investigating the effect of display resolution on visual performance and Gould et al., (1987) when investigating performances in reading between the Cathode Ray Tube (CRT) displays and paper. This method seems fits very well with the objective to quantify the legibility level in text in web pages due to its provide natural way of reading texts.

2.6.2 Eye Movement

Recently, many research have implemented eye movement techniques to evaluate legibility. This technique is claimed to be the best tools to understand the silent reading. This technique relies on the assumption that, analysing eye movements during a reading task can assess legibility. The longer fixation time on a certain area of text can lead to visual difficulties in reading the text. However this technique have some serious drawbacks, which should not be neglected. The eye tracking system can be mounted remotely (on top of computer monitor for example) or mounted to the participant's head. Mounting on participant's head will restrict the range and speed of head motion and can also cause discomfort. However, if mounted remotely, the experimenter may have to deal with frequent track loses and manual reacquiring of the eye track. This method was used by Rello and Marcos, (2012), Slattery and Rayner, (2010), and Beymer et al., (2008) in their experimental setup.

2.6.3 Blink Rate

This technique is based on the assumption that the decreases of blink rates leads to reducing the legibility level. A study conducted by Emina, (2003) has shown that there is a significant drop of blink rate during visual task. This result also confirmed the result from previous studies done by Acosta et al., (1999), which revealed that blink rate reduced by about half on young subjects (19-26 years old). Tanaka and Yamaoka, (1993) also revealed that various mental activities, including reading, could modify the

blink rate. However, Subbaram, (2004) found that the validity of this method is questionable since blink rate is affected by ambience luminance, glare, humidity, and so on.

On this section and previous subsections have discussed the method used in quantifying the legibility. The method chose by this study is proof reading. Even the method chosen have some disadvantages. The actual implementation in this study (refer subsection 3.3 on experiment method) should minimized if not eliminate the disadvantages. Table 2.5 will summarized the advantage and disadvantage of each method.

Table 2.5: Comparison between quantifying methods in legibility research

Methods	**Advantage**	**Disadvantage**
Speed of reading	Natural way of reading text.	Some participants are a slow reader and some is a fast reader. It is also influence greatly by cognitive factor.
Read aloud	Easy to participant as it only require to read a single character leads to less stressful experience.	Not the natural or normal way we read text.
Eye movement	The best technique to evaluate legibility. Used by many researchers recently.	Require a device to be attached to participant's head or faces frequently loses track that require manual reacquire tracking process.
Blink rate	Natural way of reading text.	Require manual blink rate counting. Influence greatly by glare, humidity, ambience luminance and so on.
Proof reading	Natural way of reading text.	Can provide linguistics challenges.

2.7 CONCLUSION

In this chapter, the factors influencing the legibility based on previous research are presented. Also in this chapter, the method used to measure legibility based on previous research has been covered. As a conclusion, colour combinations are proven influencing the legibility. Wrongly choose colour combinations can lead to visual fatigue. Typography has also been found to influence legibility. Some fonts are designed to be aesthetically appealing but are not necessary legible. While colour combinations influence the legibility greatly based on how human eye sensors react to the wavelength of the colour, fonts are more about the shape and sizes. Less researches, done previously, focusing VDT resolution as a dependant variable in their research. This has encouraged this research to investigate more on VDT resolution as it might influence legibility of typography and colour combinations used. Based on Morkes and Nielsen, (1997) a webpage scored higher on usability when text on the web page was easily scan-able (42%). Based on these two reasons, this research is significant and could improve the currently available guidelines. Lastly, in this chapter, methods of quantifying legibility have been reviewed. Each method of legibility measurement has its own method of study and leads to a different result recommendation. However, considering the basic concept of overall legibility (the ability to recognise the letter based on its shape), and considering the results of previous studies that prove that users actually read less and are simply trying to scan relevant keywords. This research has chosen proof reading as the method of quantifying legibility due to its advantage that provides natural way of reading text.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In the previous chapter, most of the research previously done on legibility has been explored. Most of the experimental methods applied to legibility research were presented and the results from the experiment also recommendation from existing guidelines are collected and tabulated. Based on the previous chapter, it has been shown that a gap still exists on developing legibility guideline since VDT resolution is yet to be fully explored on its influence in affecting legibility of text on web pages. Is this chapter, the methodology used in achieving the first and main objective layout in this research will be presented. Achieving the first objective, this chapter will start by introducing the design of the experiment that will explain the detail about subjects selection, experimental apparatus and the setup, and all the dependant variables. Following this, the experimental method, including the test method and how the legibility is measured will be explained. The method for validating the experiment will be present next, followed by detail presentation on the criteria that had been considered in creating the proposed LG. Lastly, the second objective of a general architecture and LAT creation will be presented.

3.2 EXPERIMENT DESIGN

To achieve the first objective, this section and all subsequent sections and sub-sections will present all aspects of experimental design. This chapter will start by explaining the subjects or the participant criteria that involved in this research experiment. Presenting the apparatus used in the experiments will then follow. Based on

the scope of this research, typeface, font size, the colour combination and the colour contrast ratio selected will be presented. Following this, the experimental method that will explain in detail on how the legibility will actually be evaluated and measured will be presented. Next, the technique used in validating the results will be also presented. Lastly, for reporting purposes, the analysis method used and the structure of the newly constructed guideline will be also presented.

3.2.1 Subjects

All subjects were recruited randomly from the student population at Politeknik Sultan Haji Ahmad Shah (POLISAS). Below are the criteria of the subjects used in this research experiment:

i. Age group: 18-32 years
ii. Normal vision or corrected to normal vision.
iii. Know how to and are used to browsing the Internet.

All subjects were sure to have no class or activity for the next two hours, to ensure they were not rushing or pressure to complete the experiments due to a tight timeline.

3.2.2 Display Instruments and Resolution Used

To ensure the accuracy of the experiments, a set of single model displays or VDT were used. Below are the specifications of the VDT:

i. VDT type: Liquid Crystal Display (LCD)
ii. VDT model: ThinkVision L2440p
iii. VDT viewable image size: 24-inch

To see the effects of resolution, two resolutions sizes were chosen in this experiment. Table 3.1 shows the two resolutions used and their pixels per inch (PPI). The PPI calculation is based on Equations 3.1 and 3.2 below:

To calculate the PPI takes two steps:

i. Calculate diagonal resolution in pixels using Pythagorean theorem:

$$d_p = \sqrt{w_p^2 + h_p^2} \tag{3.1}$$

ii. Calculate the PPI:

$$PPI = \frac{d_p}{d_i} \tag{3.2}$$

Where:

i. d_p is diagonal resolution in pixels
ii. w_p is width resolution in pixels
iii. h_p is height resolution in pixels
iv. d_i is diagonal size in inches

Table 3.1: Resolutions used in the experiments

	Resolution		**Monitor Size (d_i)**	**Pixel per inch (PPI)**	**Pixel per square inch (PPI^2)**
	Width (w_p)	**Height (h_p)**			
High	1920	1080	24-inch	91.79	8425
Low	1280	1024	24-inch	68.30	4664.89

Based in Table 3.1, two resolutions chose is 1920x1080, and 1280x1024. Both will be used on the same sets of VDT with 24-inch in size. To see the effects of any legibility improvement, the PPI^2 value for high resolution has almost double compared to low resolution.

3.2.3 Typeface and Font Sizes

Based on previous research, many researchers have not just compared legibility performance between each font, but also the category or type of fonts, such as serif versus sans serif, and fonts designed for printed materials versus fonts design for on-screen viewing. In this research, 6 fonts have been chosen. Table 3.2 shows the chosen fonts.

Table 3.2: List of fonts used in this experiments

Serif	**Sans serif**
[+]Courier	[+]Arial
[*]Georgia	[*]Calibri
[+]Times New Roman	[*]Verdana
[+]Fonts design for printed materials	[*]Fonts design for on-screen viewing

Based in Table 3.2, each category or type of fonts has 3 types of fonts. The Serif group has Courier, Georgia and Times New Roman while the sans serif group has Arial, Calibri and Verdana. To investigate the effects of fonts designed for on-screen viewing versus fonts designed for printed materials, the fonts designed for onscreen viewing include Calibri, Verdana and Georgia, while fonts designed for printed materials include Courier, Arial and Times New Roman.

Based on previous chapters, most of the researchers suggest the use of fonts sizes at least 10 pt. Since a high resolution was used, the higher resolution could be displayed more sharply on much smaller fonts. Due to this assumption, in this research, will be using a font size of 3 pt to 14 pt.

3.2.4 Colour Combination

13 colour combinations were selected in this research. The colour combinations selected are from Le Couriers table of legibility. Table 3.3 below shows the colour combinations on the Le Couriers table of legibility together with the colour code, contrast ratio, and colour polarity used in this research.

Table 3.3: Colour combinations in Le Courier table of legibility, colour code, contrast ratio, and the polarity of the colour combination

Colour Combinations	Colour Code (HEX)		Colour Contrast Ratio	Colour Polarity
	Text	Background		
Black on Yellow	#000000	#FFFF00	19.56:1	Positive
Green on White	#008000	#FFFFFF	5.14:1	Positive
Red on White	#FF0000	#FFFFFF	4.00:1	Positive
Blue on White	#0000FF	#FFFFFF	8.59:1	Positive
White on Blue	#FFFFFF	#0000FF	8.59:1	Negative
Black on White	#000000	#FFFFFF	21.00:1	Positive
Yellow on Black	#FAED09	#000000	19.56:1	Negative
White on Red	#FFFFFF	# FF0000	4.00:1	Negative
White on Green	#FFFFFF	#008000	5.14:1	Negative
White on Black	#FFFFFF	#000000	21.00:1	Negative
Red on Yellow	#FF0000	#FFFF00	3.72:1	Positive
Green on Red	#008000	#FF0000	1.28:1	Positive
Red on Green	#FF0000	#008000	1.28:1	Negative

3.2.5 Colour Contrast Ratio

On colour contrast ratio, 5 level of colour contrast ratio tested. Table 3.4 below shows the colour contrast ratio selected for this research.

Table 3.4: Selected colour contrast ratio

Colour Contrast Ratio	
1.37:1	
2.35:1	
3.32:1	Recommended by ANSI (3:1)
4.54:1	Recommended by W3C (4.5:1)
6.90:1	

3.3 EXPERIMENT METHOD

The objective of the experiment is to study the legibility level of text in web pages using all the dependent variables defined in the scope of this research and its effect when viewing on high and low resolutions. To achieve the objectives, all the dependant variables will be used for displaying text on the VDT. The text used in this experiment has been designed using Wilkins Rate of Reading Test text, seeded with a random number of words containing an error. The Wilkins Rate of Reading Test text was chosen because, the text is designed to be visually stress but at the same time minimizing the linguistic challenges (Wilkins et al., 1996). Based on previous research, the quality of web page is highly depending on the level of easily scan-able text in web pages (Morkes and Nielsen, 1997) and based on the definition of legibility presented on previous chapter, the text used was then modified with a random seeded number of words containing a spelling error. Figure 3.1 illustrates the example of text used in this research.

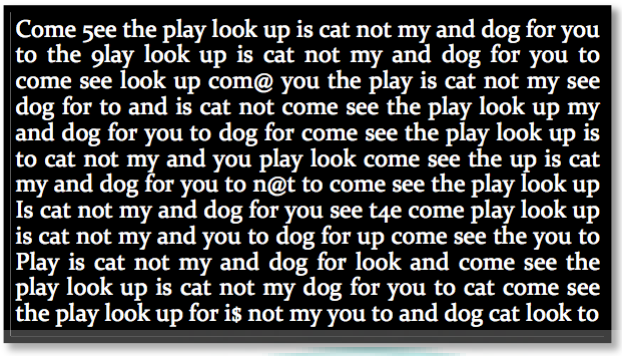


Figure 3.1: Wilkins Rate of Reading Test text seeded with random words that has spelling error

In Figure 3.2, the Wilkins Rate of Reading Test text has been seeded with a random number of words with spelling errors. The subjects will then be required to read the whole text and try to find and count how many words have a spelling error. The number of errors found by the subjects will be compared with the actual value and the percentage is calculated. The nearer this value to the actual value, the more legible the text is.

3.4 EXPERIMENT VALIDATION

The validation for this experiment uses results from the subjective preference test. As recommended by Malaysian Standards, (2009), International Organization for Standardization, (1998) (ISO), and Hart and Staveland, (1988) NASA-TLX (Task Load Index), it is recommended to measure the effects that might cause during the experiments. In this validation, the comfort level will be assessed and the results will be compared with the legibility test result. Figure 3.5 illustrates the scale used in subjective preference test.

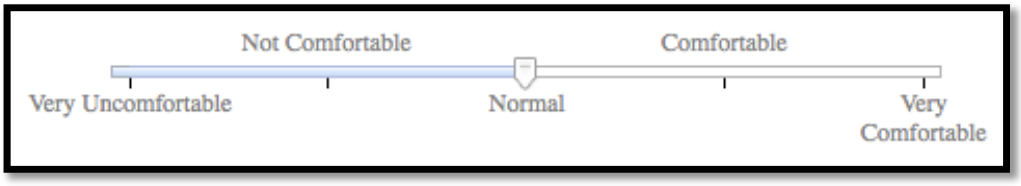


Figure 3.2: Comfort level scale use in subjective preference test

3.5 EXPERIMENT PROCEDURE

Two sets of experiments use high and low resolution as the experiment setups. Each experiment consists of about 100 randomly selected subjects. Before each experiment, subjects are given a brief introduction about the experiments. The subjects will be then told to sit comfortably while reading the experiments instructions. They were also asked to try not to change their sitting position when starting the experiment.

Each dependant variable is tested using test text designed for this research. The subjects then evaluate legibility for each dependent variable by answering two questions. The first one collects the number of words with spelling error that they found - legibility test. The second question is about how comfortable they are when they perform the legibility test - subjective preference test. On legibility test, there are 5 sets of text randomly used for the whole experiment.

This experiment is divided into 3 sub experiments: 1) Typeface; 2) Colour combinations; and 3) Colour contrast ratio. Figure 3.3 illustrates the entire structure of the experiments.

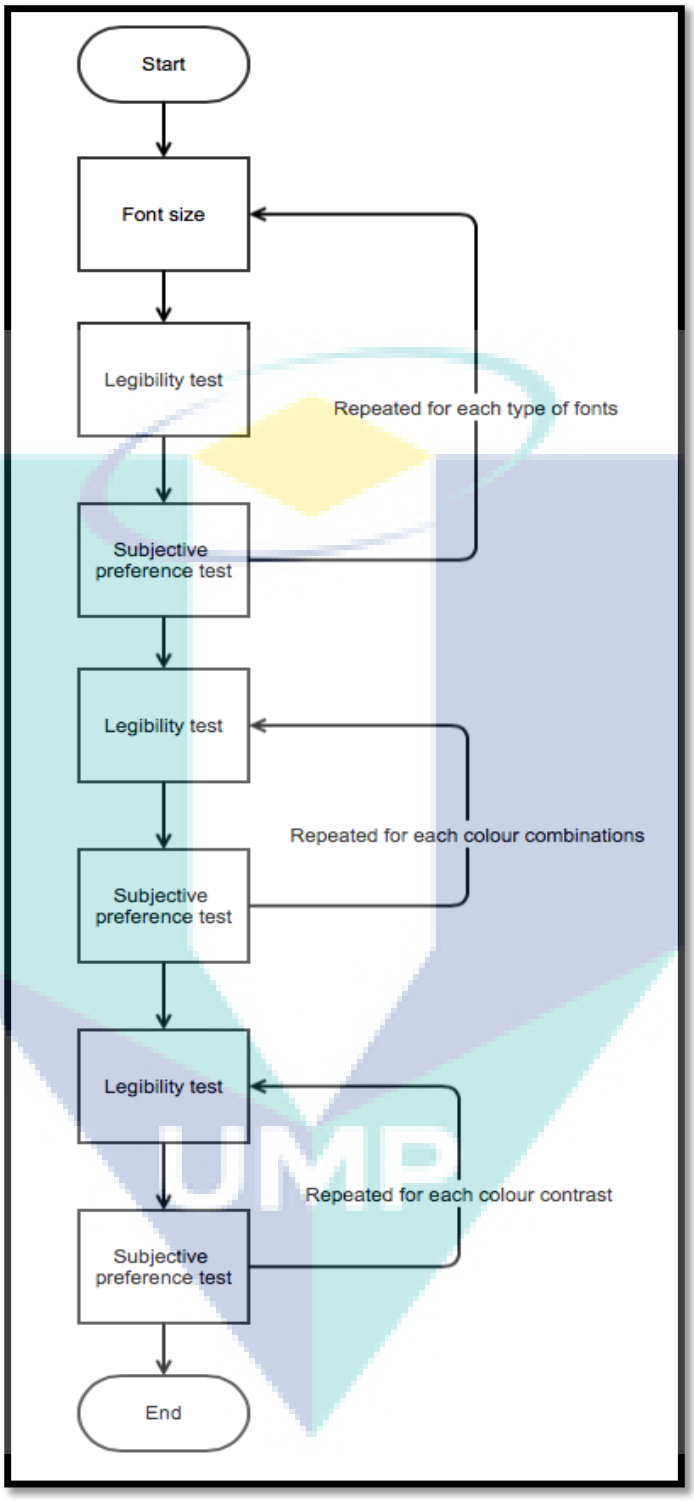


Figure 3.3: Structure of the experiments

3.5.1 Experiment Procedure – Typeface

For this sub-experiment, 6 typefaces are tested (refer Table 3.2). Each subject is first presented with a list of characters string design by using the font that is going to be tested with different font sizes (Figure 3.4). The subjects are then asked to read the whole string and chose the smallest font size that they think legible enough to read.

Based on the selected font size, the legibility test and subjective preference test begins and the text is presented using the selected font size and the fonts that going to be tested. On this experiment the independent variable, colour combination, is set to white colour background with black colour text.

Figure 3.4: Series of text presented with different font sizes

These sub experiments are repeated using high and low resolution. On this sub experiment, three hypotheses have been defined as follows:

$H_0$1: All types of fonts have equal legibility performance.

$H_0$2: Sans serif and serif fonts have equal legibility performance.

$H_0$3: Fonts designed for printed materials and fonts design for on-screen viewing have equal legibility performance.

3.5.2 Experiment Procedure – Colour Combination

On this sub experiment, subjects are tested on the legibility of 13 colour combinations selected. The subjects are then presented a text displayed using the colour combination to be tested. On this sub experiment, the independent variable, font, is set to Verdana and the font size is set to 14 pt. This sub experiment will also be repeated for low and high resolution. The hypothesis for this experiment will be as follows:

$H_0$1: All colour combinations have same or equal legibility performance.

$H_0$2: Positive and Negative colour combinations polarity have same or equal legibility performance.

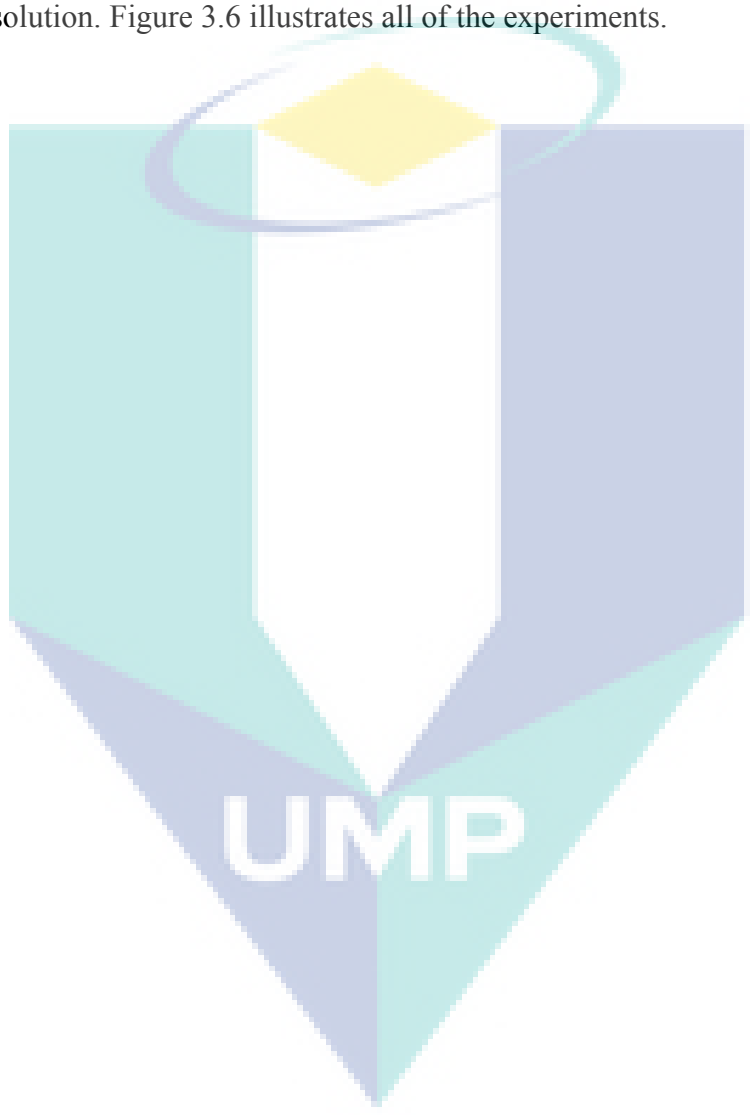
3.5.3 Experiment Procedure – Colour Contrast Ratio

On this sub experiment, there are five colour contrast ratios selected to be tested. Subjects will be presented with a text set using the colour contrast ratio tested. On this sub experiment the independent variables, font will be set to Verdana, font size is set to 14 pt. using white background colour with black text. The hypothesis for this sub experiment is as follows:

$H_0$1: All colour contrasts have the same or equal legibility performance.

3.6 EXPERIMENT ANALYSIS

The data collected in this experiment will be analysed using a statistical method. Analysis of Variance (ANOVA) and t-test will be used when possible. The data collected from Low and High resolutions experiments will be analysed separately and the result will be compared to determine the improvement in legibility (if any) caused by VDT resolution. Figure 3.6 illustrates all of the experiments.



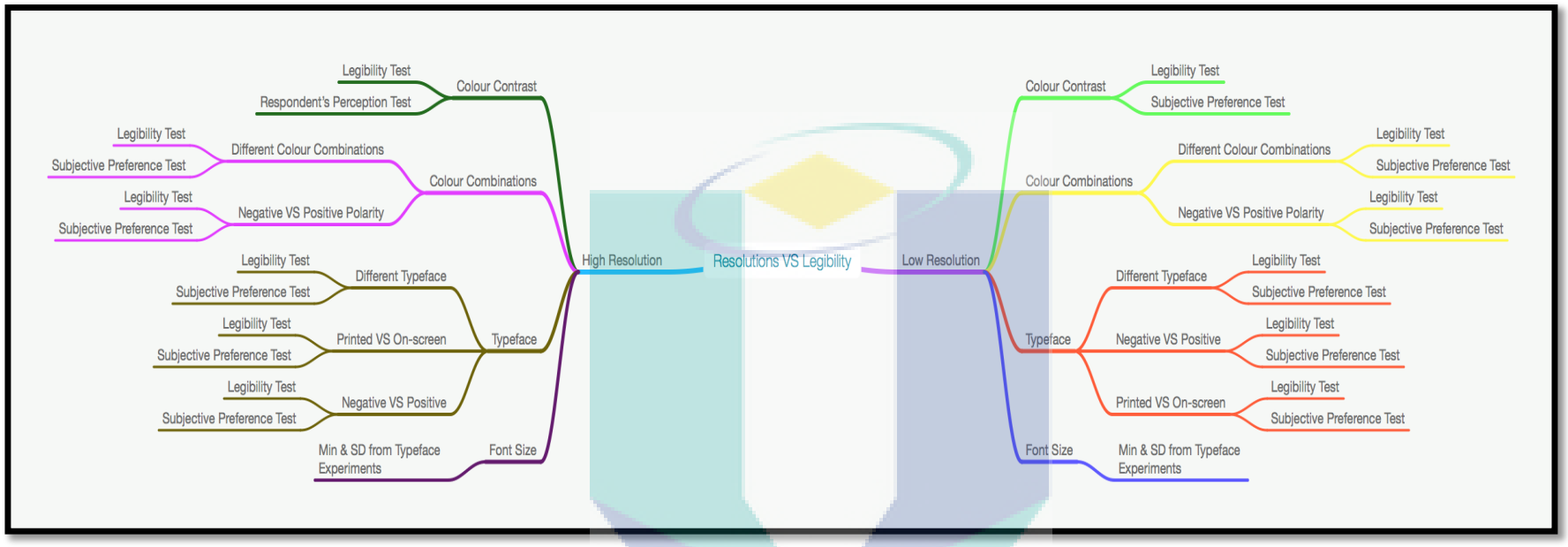


Figure 3.5: Overall view of all experiments

3.7 CONSTRUCTING NEW LEGIBILITY GUIDELINE

After the results have been obtained, an improved guideline will be constructed. The improved guideline should be able to provide recommendations to suggest or choose the best fonts and colour combinations to be viewed on high and low resolution by providing the recommended criteria as follows:

i. The best fonts/typeface – e.g. Verdana, Times New Roman or another.
ii. The best font category – e.g. Serif or Sans serif.
iii. The best font group by intended design – e.g. font design for printed materials or on screen viewing.
iv. The minimum recommended font size – at least 10 pt.
v. The best colour combination – e.g. Green text with White background or another.
vi. The best colour combination polarity – e.g. negative or positive polarity.
vii. The minimum recommended colour contrast ratio – e.g. 3:1.

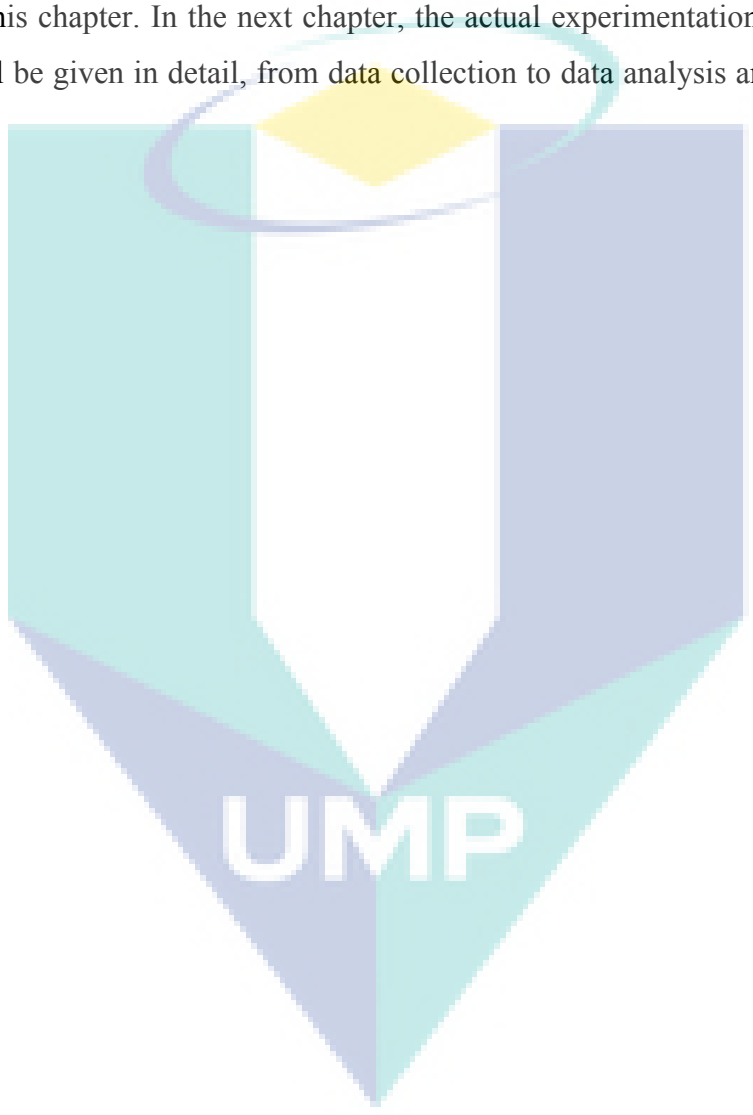
The new and recommended guidelines will be then compared to the existing guidelines to determine any improvement. Comparison analysis is also being carried out between both low and high-resolution experiment result to investigate the legibility improvement achieved by a high resolution.

3.8 LEGIBILITY ASSESSMENT TOOLS (LAT)

The proposed LAT will be developed by applying the proposed LG from this research. As a contribution from this research, the LAT should be able to detect the applied themes or font properties configuration and validate it against the proposed LG.

3.9 CONCLUSION

The methodology in investigating the effects of resolution and the process of constructing the proposed guideline has been presented. The method, dependant and independent variables, experiment design, as well as experimental procedure, validation and analysis are presented in detail in this chapter. The proposed LAT also explained briefly in this chapter. In the next chapter, the actual experimentation presented in this chapter will be given in detail, from data collection to data analysis and presentation of results.



CHAPTER 4

EXPERIMENTATION ON LEGIBILITY

4.1 INTRODUCTION

This chapter describes the implementation of the legibility experiments. This chapter will start by presenting the general and specific implementations for each dependant variable experiments and continues to the details analysis for each dependant variable define in the scope of this research. As defined in Chapter 1, this chapter will try to achieve the first objective by analysing the result from legibility experiments. Then, the second objective will be achieved by comparing the result for low and high VDT resolution. Finally, guidelines and conclusions from the results will be presented and discussed.

4.2 LEGIBILITY ANALYSIS

The legibility of each dependent variable will be analysed using two experiments, namely a legibility test experimental and subjective preference test experiment.

In the legibility test experiment, subjects are presented with text designed by using methods from Wilkins Rate of Reading Test and seeded with random words that contain a spelling error. Subjects will then count words that have the spelling error and will be recorded. The legibility performance for each dependant variable will be determined by calculating the percentage of the value recorded against the actual value, per equation (4.1).

$$\%\ Correctly\ Identified\ Character = \frac{Recorded\ Value}{Actual\ Value}\ x\ 100 \qquad (4.1)$$

The more the percentage nearly 100% meaning each dependents variable is more or has better legibility performance. The calculated percentage values will then be used in ANOVA to determine and compares the legibility performance for each typeface. Figure 3.1 illustrates an example of text used for legibility test experiments.

On subjective preference test experiment, the subject will be presented with a Likert scale as describe in chapter three. The subjects will then rate how comfortable they feel when performing legibility test experiment. The value recorded from this experiment will be then used to validate and determine the comfort level for each dependant variable. Figure 3.5 illustrates the Likert scale used on subjective preference test experiments.

The result from the legibility test experiments, and the result of the subjective preference test experiments will be then compared to determine the final ratings on the legibility level for each dependent variable.

4.3 FONTS LEGIBILITY EXPERIMENT

Legibility performance of the different fonts designs, and fonts categories describe in chapter three will be compared. Legibility performance will be evaluated based on the results derived from the legibility test experiment. The results will be then validated against the results from the subjective preference test experiment.

Before the actual experiment for each font begins, subjects will be presented with a series of texts that has different fonts sizes designed by using the fonts that will be used in the experiments, as depicted in Figure 3.4.

The subject will click on the smallest font size they see which is legible enough to be read. It will then use on the legibility test experiment. The independent variables for the fonts legibility analysis are the colour combinations and screen resolutions. The colour combinations will be set to white background with black text, as this is recommended by the existing guidelines and results from previous studies. The resolution for high and low describes in Chapter 3, will be used.

4.3.1 Legibility Analysis of Different Typefaces

The legibility of typeface will be assessed using the result from legibility test experimental and subjective preference test experiment. An analysis of variance (ANOVA) will be used to analyse data from both experiments. This sub-section will focus on analysis of the different type of fonts and classifications of fonts: a) Sans serif versus Serif fonts; and b) fonts design for printed materials versus fonts design for on-screen viewing. Three hypotheses have been defined for typefaces analysis as follows:

$H_0$1: All types of fonts have equal legibility performance.

$H_0$2: Sans serif and serif fonts have equal legibility performance.

$H_0$3: Fonts designed for printed materials and fonts design for on-screen viewing have equal legibility performance.

4.3.1.1 Legibility Analysis of Different Typefaces on Low Resolutions

The resolution used in this experiment is 1280x1024 and using 24" VDT. As describe in chapter three, the density of PPI^2 is 4665. Based on $H_0$1, all fonts should show equal legibility performance.

Table 4.1 shows the mean and standard deviation from legibility test experiment. Based on the ANOVA results, Calibri (M=85.12% ± 17.476) is the best font followed by Arial, Verdana, Times New Roman, Georgia and Courier (M=66.67% ± 15.681).

Table 4.1: Mean and SD from legibility test experiment on low resolution

Fonts	Mean (%)	Std. Deviation
Times New Roman	73.84	15.602
Courier	66.67	15.681
Georgia	70.77	21.640
Arial	83.27	14.574
Verdana	79.29	16.682
Calibri	85.12	17.476

Further ANOVA analysis reveals a significance level of 0.05. A test result (p-value) higher than 0.05 will allow the null hypothesis fails to be rejected; otherwise it has to be rejected. Comparison for each font type has revealed that p-value (smaller than 0.001) therefore, $H_0 1$ is rejected.

Table 4.2: Homogeneity test for each type of fonts in legibility test experiment on low resolution

Fonts	Subset for alpha = 0.05		
	1	2	3
Courier	66.67		
Georgia	70.77		
Times New Roman	73.84	73.84	
Verdana		79.29	79.29
Arial			83.27
Calibri			85.12

Homogeneity[2] test reveals that all the fonts used in this experiment divided into three subsets groups. Based on the results, the best legibility performance included Calibri (M=85.12%), Arial (M=83.27%) and Verdana (M=79.29%) while Times New Roman (M=73.84%) and Georgia (M=70.60%) and Courier (M=66.67%) proven to be a not-recommended font type. However, Times New Roman showed no significant difference with Verdana.

[2] The quality or state of being all the same or all of the same kind – oxforddictionaries.com

To validate the results further, subjects were asked about how they feel when reading the text using each font (subjective preference test experiment). By using the Likert-scale 1 (Very uncomfortable) to 5 (Very comfortable), the results reveal a p-value (0.028) that is again rejected the $H_0$1 hypothesis.

Table 4.3: Mean and SD from subjective preference test experiment on low resolution

Fonts	Mean	Std. Deviation
Times New Roman	2.66	0.853
Courier	2.82	0.769
Georgia	2.85	0.681
Arial	2.85	0.800
Verdana	3.05	0.654
Calibri	2.70	0.789

In the subjective preference test experiment, Verdana (M=3.05 ± 0.654) font proven to be the best fonts followed by Arial, Georgia, Courier, and Calibri, while the lowest subjective preference test score is Times New Roman (M=2.66 ± 0.853).

Table 4.4: Homogeneity test for subjective preference test experiment for each type of font

Fonts	Subset for alpha = 0.05	
	1	2
Times New Roman	2.66	
Calibri	2.70	2.70
Courier	2.82	2.82
Georgia	2.85	2.85
Arial	2.85	2.85
Verdana		3.05

On the homogeneity test (Table 4.4), the result reveals that all fonts have no significant difference except for Times New Roman (M=2.66), which is the lowest while Verdana (M=3.05) is the highest. However, all mean values, if rounded to nearest integer, are 3 (Normal) on the Likert scale.

By taking into consideration results from both experiments it is concluded that the best and recommended fonts are Calibri, Arial, and Verdana, while Courier, Georgia, and Times New Roman are the less recommended font types. Table 4.5 ranges from the less legible fonts to the most legible fonts and recommended fonts.

Table 4.5: Less legible fonts to the most legible fonts on low resolution

Fonts		
Courier	Not recommended fonts	Less legible fonts
Georgia		
Times New Roman		
Verdana	Recommended fonts	
Arial		
Calibri		Most legible fonts

A comparison on a group of fonts, grouped by serif and sans serif fonts was done to investigate more on the characteristics of the fonts. A t-test analysis was performed on both legibility and subjective preference test experiments.

Table 4.6: Comparison between serif and sans serif fonts on low resolution

Performance Measured		**Serif Fonts**	**Sans serif Fonts**
Legibility test experiment (%)	Means	70.35	82.48
	SD	18.091	16.407
Subjective preference test experiment (Likert scale)	Means	2.78	2.87
	SD	0.770	0.759

Table 4.6 shows the result of combining both legibility test experimental and subjective preference test experiment. A t-test analysis on legibility test experiment reveals a p-value (smaller than 0.001) smaller than 0.05; thus, $H_0 2$ is rejected. Therefore for the result of legibility test experiment, it is recommended to use sans serif fonts (M=82.48% ± 16.407) rather than serif fonts (M=70.35% ± 18.091).

However, on subjective preference test experiment reveals a p-value (0.183) that is higher than 0.05, makes it $H_0 2$ fails to be rejected. This therefore failed to see any significant difference between the serif (M=2.78 ± 0.770) and sans serif (M=2.87 ±

0.759) fonts. By considering both results, it is recommended to use sans serif fonts for optimal legibility.

Besides serif and sans serif fonts classification, fonts are classified based on its usage. There are two mainly types of font usages, for printed materials and for on-screen viewing.

Table 4.7: Comparison between fonts designed for printed materials and fonts designed for on-screen viewing on low resolution

Performance Measured		**Fonts Designed for Printed Materials**	**Fonts Designed for On-Screen Viewing**
Legibility test experiment (%)	Means	74.44	78.11
	SD	16.697	19.558
Subjective preference test experiment (Likert-scale)	Means	2.78	2.87
	SD	0.808	0.720

Table 4.7 shows the results of combining both legibility test experimental and subjective preference test experiments for both types of font. On legibility test experiment, the result reveals a p-values (0.031) less than 0.05 therefore H03 is rejected. On subjective preference test experiment, the p-value (0.197) is higher than 0.05 and therefore H03 fails to be rejected. Statistically, fonts designed for on-screen (M=78.11 ± 19.588) have a slight advantage over fonts designed for printed materials (M=74.44 ± 16.697).

Subjects were presented with a list of fonts with different sizes for each type of fonts tested. The subjects will then choose which font size is the smallest and legible enough to proceed with legibility test experiment of different typefaces.

Table 4.8: Mean and SD for font size on low resolution

Performance Measured	**Means**	**SD**
Fonts Sizes (pt)	9.54	2.370

Table 4.8 reveals the result for font size analysis. Based on the results, it is revealed that the recommended font size (M=9.54pt ± 2.370) is minimum 10 pt.

4.3.1.2 Legibility Analysis of Different Typefaces on High Resolutions

The resolution used in this experiments is 1920x1080 using a 24" VDT. As described in chapter three, the density of pixel per square inch is 8425, which is almost double the amount of pixel per square inch used for low resolutions. Based on $H_0$1 all fonts should have equal legibility performance. However, ANOVA results revealed that p-value (less than 0.001), thus rejecting $H_0$1.

Table 4.9: Means and standard deviation from legibility test experiment on high resolution

Fonts	Mean (%)	Std. Deviation
Times New Roman	72.41	13.305
Courier	70.95	15.603
Georgia	80.05	13.706
Arial	85.81	13.979
Verdana	87.72	13.644
Calibri	93.86	12.119

Based in Table 4.9, on legibility test experiment Calibri (M=93.82 ± 12.119) font is the best while Courier (M=70.95% ± 15.603) font is the lowest legibility score. To determine the significant difference for each type of fonts, Table 4.10 reveals the results from homogeneity test.

Table 4.10: Homogeneity test for each type of fonts on legibility test on high resolution

Fonts	Subset for alpha = 0.05			
	1	2	3	4
Courier	70.95			
Times New Roman	72.41			
Georgia		80.05		
Arial			85.81	
Verdana			87.72	
Calibri				93.86

A further homogeneity test revealed that the fonts are divided into 4 subsets. The results also clearly reveal that Calibri is the best font while Courier and Times New Roman are the less recommended fonts.

For subjective preference test experiments, the results reveal a p-value (0.001) thus again rejecting $H_0$1.

Table 4.11: Mean and SD values from subjective preference test experiment for each type of fonts on high resolution

Fonts	Mean (%)	Std. Deviation
Times New Roman	2.76	0.633
Courier	2.84	0.632
Georgia	3.03	0.535
Arial	2.97	0.602
Verdana	3.01	0.617
Calibri	3.03	0.476

On subjective preference test experiment (Table 4.11), the results reveal, Calibri (M=3.03 ± 0.476) is the best, followed by Georgia, Verdana, Arial, and Courier while Times New Roman (M=2.76 ± 0.663) is the lowest.

Table 4.12: Homogeneity test for subjective preference test experiment for each type of fonts on high resolution

Fonts	Subset for alpha = 0.05	
	1	2
Times New Roman	2.76	
Courier	2.84	2.84
Arial	2.97	2.97
Verdana		3.01
Georgia		3.03
Calibri		3.03

Based in Table 4.12 it is revealed that Calibri, Georgia, and Verdana are the best and recommended fonts while Times New Roman is clearly the most not recommended font. The results also reveal that all mean values when rounded to the nearest integer are 3 (Normal) on the Likert scale.

By combining both results, it is concluded that Times New Roman and Courier is the less recommended fonts while Arial, Verdana, Georgia and Calibri is the most recommended fonts. Table 4.13 shows the less legible fonts to the most legible fonts and recommended fonts.

Table 4.13: Least legible fonts to the most legible fonts on high resolution

Fonts		
Courier	Not recommended fonts	Less legible fonts
Times New Roman		
Georgia	Recommended fonts	
Arial		
Verdana		
Calibri		Most legible fonts

A comparison on a group of fonts, grouped by serif and sans serif fonts was done to investigate more on the characteristics of the fonts. *t*-test analysis were done on both legibility test and subjective preference test experiments.

Table 4.14: Comparison between serif and sans serif fonts on high resolution

Performance Measured		**Serif Fonts**	**Sans Serif Fonts**
Legibility test experiment (%)	Means	74.49	89.14
	SD	14.765	13.671
Subjective preference test experiment	Means	2.88	3.01
(Likert-scale)	SD	0.610	0.567

In analysis on both type of experiments, reveal p-value (less than 0.001) for legibility test experiment and p-value (0.004) for subjective preference test experiment, less than 0.05 therefore rejecting $H_0 2$. Based on the results (Table 4.14), sans serif (M=89.14% ± 13.671) fonts do have statistically significant advantage over serif (M=74.49% ± 14.765) fonts on legibility test experiment. Subjective preference test experiments also reveal that sans serif (M=3.01 ± 0.567) has statistically significant advantage over serif (M=2.88 ± 0.610).

Analysis on fonts designed for printed materials and fonts designed for on-screen viewing reveals a p-value of less than 0.001 for both experiments. These indicate that there is statistically significant advantage between both types of fonts therefore rejecting $H_0$3. This concludes that, it is recommended to use fonts designed for on-screen (M=87.19% ± 14.310) viewing for optimal legibility compared to font designed for printed (M=76.38% ± 15.792) materials. Table 4.15 shows the comparison between both types of fonts.

Table 4.15: Comparison between fonts designed for printed materials and fonts designed for on-screen viewing on high resolution

Performance Measured		**Fonts Designed for Printed Materials**	**Fonts Designed for On-Screen Viewing**
Legibility test experiment (%)	Means	76.38	87.19
	SD	15.792	14.310
Subjective preference test experiment (Likert-scale)	Means	2.86	3.02
	SD	0.627	0.544

Subjects were presented with list of fonts with different sizes for each type of font before the legibility test experiments begin. The subjects then choose which font size is the smallest and legible enough to proceed with legibility analysis of different typefaces. The results are presented in Table 4.16.

Table 4.16: Mean and SD value for font size on high resolution

Performance Measured	**Mean**	**SD**
Fonts Sizes (pt)	10.10	2.689

Table 4.16 reveals the result for font size analysis. Based on the results it has been revealed that, the recommended font size (M=10.10 pt ± 2.689) is a minimum of 10 pt.

4.4 COLOUR COMBINATION LEGIBILITY EXPERIMENT

The legibility of each colour combinations will be analysed and compared. The procedure for this experiment is identical to the fonts experiments as define in the previous subsections, with exception the font size will be fixed to the 14pt and the font type is fixed to Verdana.

The dependant variables for this analysis will be the 13-colour combinations recommended Courier table of legibility. Identical to the font analysis, the resolution use is the same VDT resolution for low and high resolution. This experiment has also used the same 24" VDT.

4.4.1 Legibility Analysis of Different Colour Combinations

The legibility performance for each colour combination will be assessed using the result from task-based experiments and subjective preference test experiments. ANOVA will be used to analyse data from both experiments. This sub-section will be focused on analysis of different type of colour combinations and group of colour combinations, positive and negative colour polarity as defined in chapter three. Two hypotheses has been defined for colour combinations analysis as follows:

$H_0$1: All colour combinations have same or equal legibility performance

$H_0$2: Positive and Negative colour combinations polarity have same or equal legibility performance

4.4.1.1 Legibility Analysis of Different Colour Combinations on Low Resolutions

For low resolutions on the legibility test experiment, the result reveals that, the p-value (smaller than 0.001) is smaller than 0.05, therefore rejecting the $H_0$1. Based on these results, it may be concluded that White background and Green text (M=88.25% ± 14.225) colour combination is the best while Red background with Green text

(M=76.33% ± 17.987) is the most not recommended colour combination. Table 4.17 reveals the mean and SD for all colour combinations.

Table 4.17: Mean and SD for all colour combinations on legibility test experiment on low resolution

Colour Combinations	Mean (%)	Std. Deviation
Yellow on Black	81.92	16.597
White on Green	88.25	14.225
White on Red	80.91	13.416
White on Blue	84.05	12.661
Blue on White	85.52	11.912
White on Black	85.23	12.729
Black on Yellow	81.38	13.664
Red on White	77.75	20.683
Green on White	80.25	22.950
Black on White	77.74	19.566
Yellow on Red	82.95	15.963
Red on Green	76.33	17.987
Green on Red	80.79	18.324

Further analysis on the homogeneity of the mean values have subbed grouped the colour combinations into three groups. The results, however, show that the colour combinations are quite closely together or have no statistically significant. Table 4.18 shows the result of the homogeneity test for the mean values of all colour combinations used in the experiments.

Table 4.18: Homogeneity test for mean values of all colour combinations on low resolution

Colour Combinations	Subset for alpha = 0.05		
	1	2	3
Red on Green	76.33		
Red on White	77.75	77.75	
Black on White	79.84	79.84	79.84
Green on White	80.25	80.25	80.25
Green on Red	80.79	80.79	80.79
White on Red	80.91	80.91	80.91
Black on Yellow	81.38	81.38	81.38
Yellow on Black	81.92	81.92	81.92

Table 4.18: Continued

Colour Combinations	Subset for alpha = 0.05		
	1	2	3
Yellow on Red	82.95	82.95	82.95
White on Blue	84.05	84.05	84.05
White on Black		85.23	85.23
Blue on White		85.52	85.52
White on Green			88.25

A further analysis is done on the subjective preference test experiment to assess the mental stress when they do the legibility test experiments. The results again reveal the p-value (smaller than 0.001), thus rejecting the $H_0$1.

Table 4.19: Mean and SD values of all colour combinations on subjective preference test experiment on low resolution

Colour Combinations	Mean	Std. Deviation
Yellow on Black	2.80	0.944
White on Green	2.75	0.856
White on Red	2.59	0.825
White on Blue	2.80	0.758
Blue on White	2.78	0.989
White on Black	2.89	0.751
Black on Yellow	2.83	1.016
Red on White	2.26	0.978
Green on White	1.65	0.748
Black on White	3.31	0.821
Yellow on Red	2.63	0.723
Red on Green	1.92	0.781
Green on Red	2.17	0.865

Referring to the Table 4.19, Black background and White text (M=3.31 ± 0.821) is the best colour combinations while Green background and White text (M=1.65 ± 0.748) is the most not recommended colour combination. To further see the significance difference of the mean values for each colour combinations, a homogeneity test was performed.

Table 4.20: Homogeneity test for all colour combinations on subjective preference test experiment on low resolution

Colour Combination	Subset for alpha = 0.05					
	1	**2**	**3**	**4**	**5**	**6**
Green on White	1.65					
Red on Green	1.92	1.92				
Green on Red		2.17	2.17			
Red on White		2.26	2.26	2.26		
White on Red			2.59	2.59	2.59	
Yellow on Red				2.63	2.63	
White on Green					2.75	
Blue on White					2.78	
White on Blue					2.80	
Yellow on Black					2.80	
Black on Yellow					2.83	
White on Black					2.89	2.89
Black on White						3.31

On homogeneity test (Table 4.20), the result reveals Green background and White text (M=1.65) is the lowest together with Red background with Green text (M=1.92). However, the analysis reveals that Green background and Red text (M=2.17) and Red background and White text (M=2.26) are also not recommended. These colour combination rated uncomfortable (2 on the Likert scale) while other colour combinations are rated normal (3 on the Likert scale).

Analysis on both experiments on colour combinations reveals the p-value is less than 0.05 therefore rejecting the $H_0$1 set earlier. As a conclusion, Red background with Green text (M=76.33%), Green background with White text (M=80.14%), Red background and White text (M=77.75%), and Green background with Red Text (M=80.79%) is the most not recommended colour combination. White background and Green Text (M=88.15%) scored the highest on legibility test experiment while Black background and White (M=77.64%) text is the most preferred colour combination on subjective preference test experiment. Table 4.21 illustrates the conclusive results on legibility performance for each colour combination after analysis of the results from both experiments.

Table 4.21: Legibility performance of each colour combinations on low resolution

Colour Combinations		
Red on Green Green on White Red on White Green on Red	Not recommended colour combinations	Less legible colour combinations
Black on White White on Red Black on Yellow Yellow on Black Yellow on Red White on Blue White on Black	Recommended colour combination	
Blue on White White on Green		Most legible colour combinations

Further analysis on the group of colour combinations grouped by colour polarity reveals the p-value (0.02) smaller than 0.05 on legibility test experiment thus rejecting the $H_0 2$. Based in Table 4.23 Positive Polarity (M=83.42 ± 15.084) has a statistically significant advantage over negative polarity (M=80.11 ± 18.066)

Table 4.22: Results for positive and negative colour combinations polarity on low resolution

Performance Measured		**Positive Polarity**	**Negative Polarity**
Legibility test experiments (%)	Means	83.42	80.11
	SD	15.084	18.066
Subjective preference test experiment (Likert scale)	Means	2.66	2.46
	SD	0.844	1.058

On subjective preference test experiment the p-value (0.01) is lower than 0.05 therefore also rejecting $H_0 2$. Based on the results from subjective preference test experiment, it is reveals that, subjects do feel, the difference between the positive (M=2.74 ± 0.844) and negative (M=2.46 ± 1.058) colour combinations polarity. A closer look at the mean values on subjective preference test experiment reveals that some of the colour combinations pairs have statistically significant differences and some do not.

Black background with White text (M=3.31) and White background with Black text (M=2.89) have been found to have no significant difference. While Green background with White text (M=1.65) is not recommended colour combinations are statistically significance difference with White background with Green Text (M=2.75), which is the most recommended colour combinations based on legibility test experiments. In the legibility test experiment, the difference between any pair of colour combinations is too small therefore difficult to see the difference.

After taking into considerations the difference between positive (M=83.42%) and negative (M=80.11%) is only 3.31%, and hardly see differences between any pair of colour combinations (refer Table 4.18) as discussed earlier, it is certainly concluded that the difference is statistically significant different but not in practicality.

4.4.1.2 Legibility Analysis of Different Colour Combinations on High Resolutions

On high resolutions, the results from ANOVA on legibility test experiment reveals a p-value (less than 0.001) lower than 0.05, therefore rejecting the $H_0$1.

Table 4.23: Mean and SD values of all colour combinations on legibility test experiment on high resolution

Colour Combinations	Mean (%)	Std. Deviation
Yellow on Black	85.48	12.301
White on Green	93.89	11.159
White on Red	88.40	13.150
White on Blue	87.70	13.162
Blue on White	87.06	12.390
White on Black	87.73	13.224
Black on Yellow	85.95	13.767
Red on White	85.22	11.873
Green on White	85.27	16.178
Black on White	87.44	11.670
Yellow on Red	85.53	12.767
Red on Green	78.46	16.589
Green on Red	85.44	14.440

Based in Table 4.24, White background with Green text (93.89% ± 11.159) is the best colour combination, while Red background and Green text (78.46% ± 16.589) is the most not recommended colour combination. A further analysis on homogeneity test of all colour combinations tested, reveals, Red background with Green text proved to be the most not recommended colour combination while White background with Red text (M=88.30% ± 13.208) proven to have equal legibility performance with White background with Green text which is the best colour combinations. Table 4.25 shows the results from the homogeneity test.

Table 4.24: Homogeneity test of mean values of all colour combination on legibility test experiment on high resolution

Colour Combinations	**Subset for alpha = 0.05**		
	1	**2**	**3**
Red on Green	78.46		
Red on White		85.22	
Green on White		85.27	
Green on Red		85.44	
Yellow on Black		85.48	
Yellow on Red		85.53	
Black on Yellow		85.95	
Blue on White		87.06	
Black on White		87.44	
White on Blue		87.70	
White on Black		87.73	
White on Red		88.40	88.40
White on Green			93.89

On subjective preference test experiment, the result reveals a p-value (less than 0.001) less than 0.05, thus rejecting the $H_0$1. Table 4.25 shows the mean and SD value of each colour combinations.

Table 4.25: Mean and SD of all colour combinations on subjective preference test experiment on high resolution

Colour Combinations	Mean	Std. Deviation
Yellow on Black	2.92	0.664
White on Green	2.87	0.666
White on Red	2.73	0.720
White on Blue	2.83	0.611
Blue on White	2.80	0.808
White on Black	2.90	0.595
Black on Yellow	2.79	0.763
Red on White	2.43	0.690
Green on White	2.00	0.912
Black on White	3.14	0.664
Yellow on Red	2.63	0.613
Red on Green	2.20	0.833
Green on Red	2.43	0.750

Based in Table 4.25, it is recommended to use black background with white text (M=3.14 ± 0.664) while try to avoid using a Green background with White text (M=2.0 ± 0.912), which is not recommended.

A homogeneity test was done to see the significance different between each colour combinations.

Table 4.26: Homogeneity test of all colour combination on subjective preference test experiment on high resolution

Colour Combinations	Subset for alpha = 0.05				
	1	2	3	4	5
Green on White	2.00				
Red on Green	2.20	2.20			
Green on Red		2.43	2.43		
Red on White		2.43	2.43		
Yellow on Red			2.63	2.63	
White on Red			2.73	2.73	
Black on Yellow				2.79	
Blue on White				2.80	
White on Blue				2.83	2.83
White on Green				2.87	2.87

Table 4.26: Continued

Colour Combinations	Subset for alpha = 0.05				
	1	2	3	4	5
White on Black				2.90	2.90
Yellow on Black				2.92	2.92
Black on White					3.14

Table 4.26 shows the homogeneity results of all colour combinations. The result reveals that Red background with Green text (M=2.20 ± 0.833), Green background and Red text (M=2.43 ± 0.750) and Red background with White text (M=2.43 ± 0.690) are not recommended. The most recommended colour combination is Black background and White text.

Based on the result from both experiments, the conclusive result is shows in Table 4.27.

Table 4.27: Legibility performance for each colour combination on high resolution

Colour Combinations		
Red on Green Red on White Green on White Green on Red	Not recommended colour combinations	Less legible colour combinations
Yellow on Black Yellow on Red Black on Yellow Blue on White Black on White White on Blue White on Black White on Red White on Green	Recommended colour combinations	Most legible colour combinations

A further analysis was done to study on the different types on colour combinations polarity, the legibility test experiment, result reveal a p-value (less than 0.001) less than 0.05, therefore $H_0 2$ is rejected.

Table 4.28: Mean and SD values of colour combinations polarity on high resolution

Performance Measured		Positive Polarity	Negative Polarity
Legibility test experiment (%)	Means	87.70	84.88
	SD	13.168	14.169
Subjective preference test	Means	2.76	2.56
experiment (Likert scale)	SD	0.681	0.872

Based in Table 4.28, the legibility test experiment reveals positive polarity (M=87.70% ± 13.168) has statistically significant advantage over negative polarity (M=84.88% ± 14.169). Subjective preference test experiment also reveals a p-value (less than 0.001) smaller than 0.05 thus rejecting the $H_0 2$ set earlier. Based in Table 4.28 the result reveals positive polarity (M=2.76 ± 0.681) has statistically significant advantage over negative polarity (M=2.56 ± 0.872).

As a conclusion, based on the results, there is significant different between the two colour combinations polarity. However, based on the results the small number of difference on legibility test mean values (2.82%) and hardly to see any significance difference on colour combinations legibility test experiment (refer Table 4.26) makes it difficult to see the difference in practicality.

4.5 COLOUR CONTRAST RATIO LEGIBILITY EXPERIMENT

Legibility analysis was done to analyse the different levels of colour contrast and its effects on legibility on different resolutions. On colour contrast legibility analysis, the colour combination used is fixed to White background with Black text. The font used is also set to Verdana and with font size 14pt.

The dependent variables for this analysis will be the 5 level of colour contrast as define in chapter three. Identical with fonts and colour combinations analysis, the resolution used is same for low and high resolution and the same 24" VDT.

4.5.1 Legibility Analysis of Different Colour Contrast Ratio

The legibility of colour contrast will be assessed using the results from legibility task experiment and subjective preference test experiments. ANOVA will be used to analyse data from both experiments. This sub-section will be focused on analysis of five level colour contrast ratio as defined in chapter three. A hypothesis has been defined for colour contrast analysis as follows:

$H_0$1: All colour contrasts have the same or equal legibility performance.

4.5.1.1 Legibility Analysis of Different Colour Contrast Ratio on Low Resolutions

On low resolutions the task-based experiments reveals the p-value (less than 0.001) smaller than 0.05 thus rejecting the $H_0$1. Table 4.29 reveals the results for legibility test experiment.

Table 4.29: Mean and SD values of different colour contrast levels on legibility test experiment on low resolution

Colour Contrast Ratio	Mean (%)	Std. Deviation
1.37:1	68.50	31.179
2.35:1	84.96	15.260
3.32:1	82.79	14.919
4.54:1	83.25	13.518
6.90:1	82.31	21.550

The result reveals that colour contrast level 1.37:1 (M=68.50% ± 31.179) is the most not recommended while 2.35:1 (M=84.96% ± 15.260) is the best colour contrast level for this analysis. A further homogeneity analysis was done to see the significant difference between all colour contrast levels.

Table 4.30: Homogeneity test of all colour contrast levels on legibility test on low resolution

Colour Contrast Ratio	Subset for alpha = 0.05	
	1	2
1.37:1	68.50	
6.90:1		82.31
3.32:1		82.79
4.54:1		83.25
2.35:1		84.96

Based in Table 4.30, the homogeneity test reveals that colour contrast ratio 1.37:1 is significant difference compared to other colour contrast ratio levels. The result also reveals that, colour contrast ratio 6.90:1, 3.32:1, 4.54:1 is not statistically significant difference with colour contrast ratio 2.35:1.

On subjective preference test experiment, the result reveals a p-value (less than 0.001) smaller than 0.05 therefore also rejecting the $H_0$1. The result reveals colour contrast ratio 1.37:1 (M=1.51 ± 0.856) is the lowest while colour contrast ratio 6.90:1 (M=3.09 ± 0.750) is the best. Table 4.32 shows the results from homogeneity analysis.

Table 4.31: Means and SD values on subjective preference test experiment on low resolution

Colour Contrast Ratio	Mean	Std. Deviation
1.37:1	1.51	0.856
2.35:1	2.36	0.786
3.32:1	2.78	0.729
4.54:1	2.94	0.695
6.90:1	3.09	0.750

On subjective preference test experiment, result a further analysis was done to see the different of each colour contrast ratio. Table 4.32 shows the result from homogeneity analysis.

Table 4.32: Homogeneity analysis of all colour contrast ratio on subjective preference test experiment on low resolution

Contrast Ratio	Subset for alpha = 0.05		
	1	**2**	**3**
1.37:1	1.51		
2.35:1		2.36	
3.32:1			2.78
4.54:1			2.94
6.90:1			3.09

Based in Table 4.32 it has been revealed that, clearly colour contrast ratio 1.37:1 is the most not recommended followed by colour contrast ratio 2.35:1 while colour contrast ratio 6.90:1 which is the best has proven no significant difference with 4.54:1 and 3.32:1.

As a conclusion, colour contrast ratio 2.35:1 (M=84.96%) might be the best on legibility test experiment but it is proven the subjects require extra effort thus subject rate the experience less comfortable compared to 3.32:1, 4.54:1 and 6.09:1. Considering the results from both experiments, it is recommended to use colour contrast ratio at least 3.32:1, same as recommended by ANSI (3:1) for optimum legibility. Table 4.33 shows the recommended colour contrast ratio for low resolution.

Table 4.33: Recommended colour contrast ratio for low resolution

Colour Contrast Ratio		
1.37:1	Not recommended colour contrast ratio	Less legible colour contrast ratio
2.35:1		
3.32:1	Recommended colour contrast ratio	
4.54:1		
6.90:1		Most legible colour contrast ratio

4.5.1.2 Legibility Analysis of Different Colour Contrast Ratio on High Resolutions

On high resolution the legibility test experiment results reveal a p-value (0.004) smaller than 0.05 therefore rejecting the $H_0$1. Table 4.34 shows the mean and SD values for each colour contrast ratio.

Table 4.34: Mean and SD value for each colour contrast ratio on legibility test experiment on high resolution

Colour Contrast Ratio	Mean (%)	Std. Deviation
1.37:1	82.00	17.424
2.35:1	87.52	16.597
3.32:1	88.90	12.475
4.54:1	90.35	11.076
6.90:1	92.08	12.681

Based on the result shows in Table 4.34, it has been revealed that the most not recommended colour contrast ratio is 1.37:1 (M=82.59% ± 16.878) while 2.35:1 (M=91.01% ± 11.618) is the best contrast ratio.

Table 4.35 shows the result from homogeneity test of all colour contrast ratio on legibility test experiment on high resolution

Table 4.35: Homogeneity test of all colour contrast ratio on legibility test experiment on high resolution

Colour Contrast Ratio	Subset for alpha = 0.05	
	1	2
1.37:1	82.00	
2.35:1		87.52
3.32:1		88.90
4.54:1		90.35
6.90:1		92.08

Table 4.35 shows the homogeneity test for all colour contrast ratio. Based on the results it has been revealed that colour contrast ratio 6.91:1 is the best but have no statistically significant difference with colour contrast ratio 4.54:1, 3.32:1 and 2.35:1. However, colour contrast ratio 1.37:1, which is the most not recommended, is found to be statistically significant different compared to the other colour contrast ratios.

A further analysis on subjective preference test experiment, the result reveals a p-value (less than 0.001), which is smaller than 0.05 thus again rejecting the $H_0$1. Table 4.36 show the mean and SD values for each colour contrast ratio.

Table 4.36: Mean and SD values for each colour contrast ratio on subjective preference test experiment on high resolution

Colour Contrast Ratio	Mean	Std. Deviation
1.37:1	2.08	0.874
2.35:1	2.66	0.687
3.32:1	2.90	0.565
4.54:1	2.99	0.570
6.90:1	2.99	0.645

Based in Table 4.36 it has been revealed that 1.37:1 (M=2.08 ± 0.874) is the most not recommended colour combination while 4.54:1 (M=2.99 ± 0.570) is the best colour contrast ratio. A homogeneity test was done to investigate the significance different for each colour contrast ratio.

Table 4.37: Homogeneity test of all colour contrast ratio on subjective preference test experiment on high resolution

Colour Contrast Ratio	Subset for alpha = 0.05		
	1	2	3
1.37:1	2.08		
2.35:1		2.66	
3.32:1		2.90	2.90
6.90:1			2.99
4.54:1			2.99

Based on the result in Table 4.37, it has been revealed that colour contrast ratio 2.35:1 (rated normal on the liker scale) is the minimum colour contrast ratio recommended. While colour contrast ratio 1.37:1 (rated uncomfortable on the Likert scale) is the most not recommended colour contrast ratio thus not recommended.

In conclusion, after considering the results from both experiments it is concluded that it is recommended to use contrast ratio at least 2.35:1, which is a bit lower compared to recommendation by ANSI (3:1). It is also concluded that colour contrast ratio 1.37:1 and below should be avoided. Table 4.38 show the recommended colour contrast ratio for high resolution.

Table 4.38: Recommended colour contrast ratio for high resolution

Colour Contrast Ratio		
1.37:1	Not recommended colour contrast ratio	Less legible colour contrast ratio
2.35:1 3.32:1	Recommended colour contrast ratio	↓
4.54:1 6.90:1		Most legible colour contrast ratio

4.6 RECOMMENDED LEGIBILITY GUIDELINES HIGH RESOLUTIONS VERSUS LOW RESOLUTIONS AND DISCUSSIONS

In sections 4.2.1.1 and 4.2.1.2, a detail analysis of different typefaces on high and low resolutions has been presented. Based on the results it is concluded that both type of resolution results almost identical.

However deeper analysis reveals the difference between the two resolutions. On low resolution, the difference between fonts design for printed (M=74.44%) and fonts designed for on-screen viewing (M=78.11%) is only 3.67%. While on high resolution, the difference between fonts design for printed (M=76.38%) and fonts designed for on-screen viewing (M=87.19%) is increase to 10.81%. This leads to two findings: 1) The higher screen resolution does increase legibility due to increase in percentage for both type of fonts. 2) The recommended fonts type includes fonts designed for on-screen viewing due to larger difference of mean values and the mean values does increase for

both type of fonts compared between the resolutions tested. Figure 4.1 illustrates the comparison of both types of fonts on high and low resolutions.

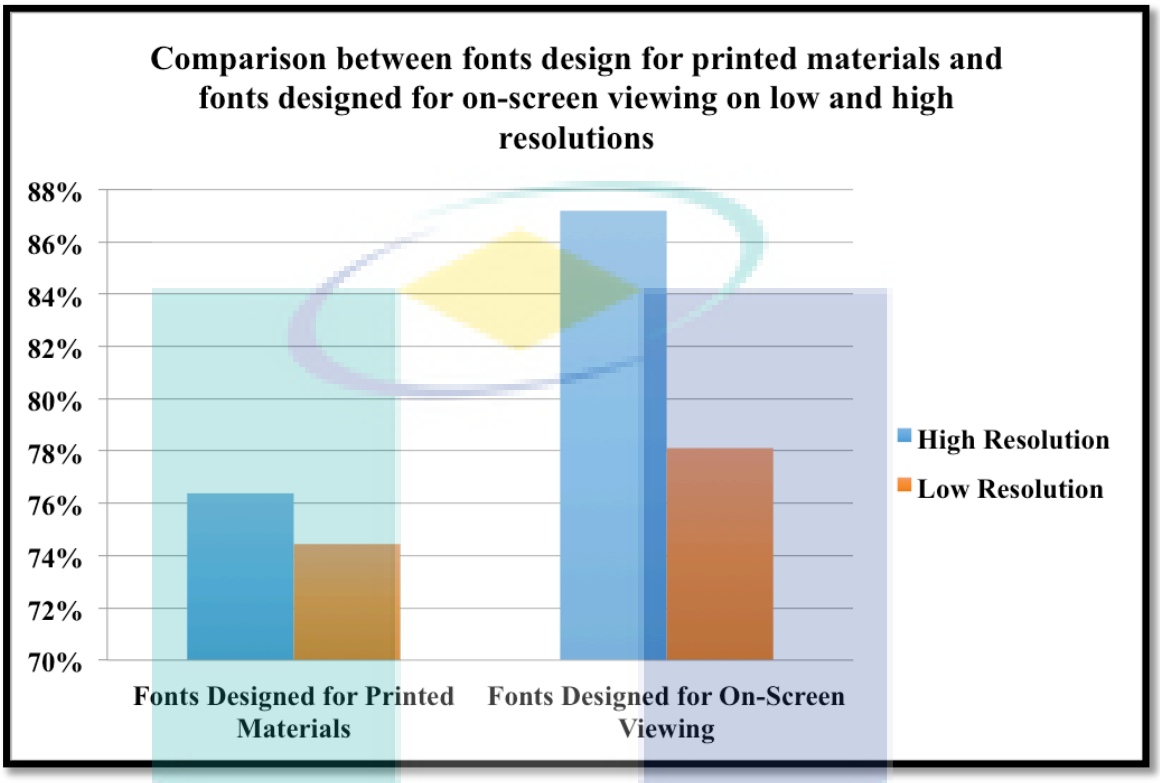


Figure 4.1: Comparison between both type of fonts on high and low resolutions

Serif versus sans serif font results reveals that for low resolution, the difference is 12.49% for serif (M=70.35%) and sans serif (M=82.84%). On high resolution, the differences increase to 14.65% for serif (M=74.49%) and sans serif (89.14%). This can only concluded that both resolutions recommended sans serif fonts for optimal legibility. Figure 4.2 shows the difference between serif and sans serif fonts on high and low resolutions.

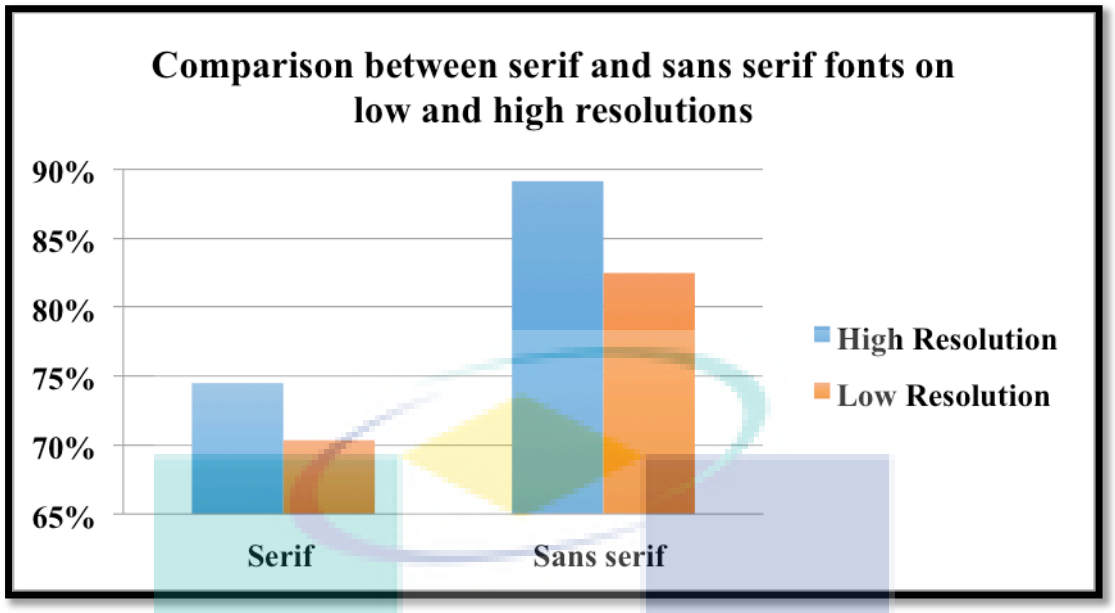


Figure 4.2: Serif versus sans serif on high and low resolutions

On detailed analysis for each type of fonts reveal that, on high resolutions, which have almost double the amount pixels per-inch, have the advantages over the low resolution in terms of legibility performance. Figure 4.3 illustrates the difference for all type of fonts on both resolutions. Based on the details of the results, Georgia font has seen an improvement on high resolution. This has led to the recommendation of Georgia for high resolution but not low resolution.

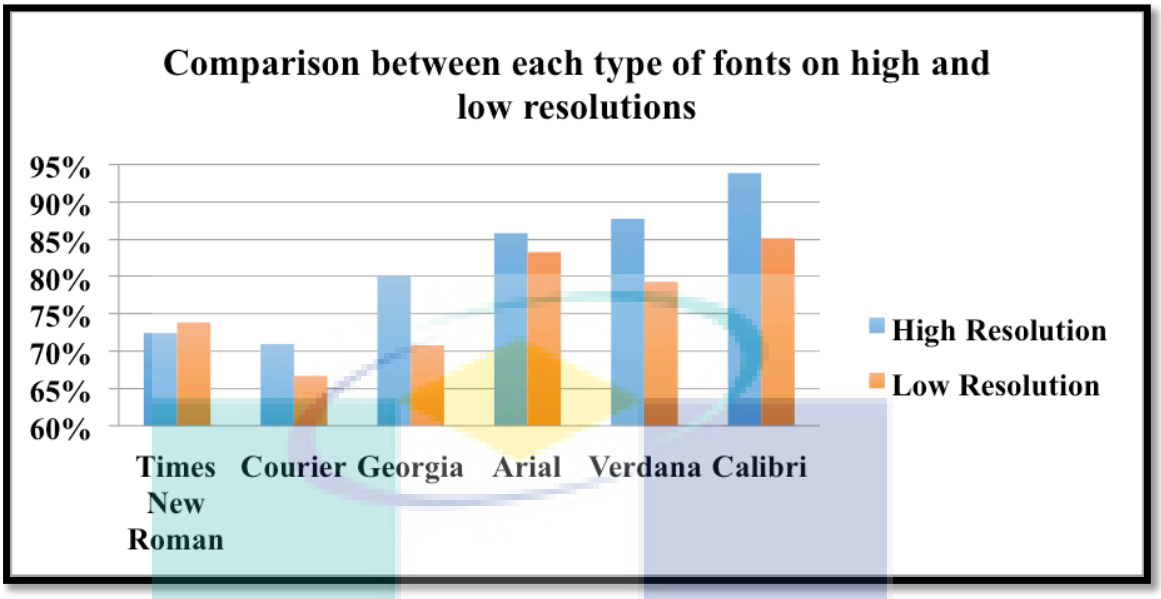


Figure 4.3: Comparison between all fonts on high and low resolutions

In sections 4.3.1.1 and 4.3.1.2 detail analysis of all colour combinations tested on high and low resolution have been presented. Figure 4.4 shows the difference between high and low resolutions for all colour combinations.

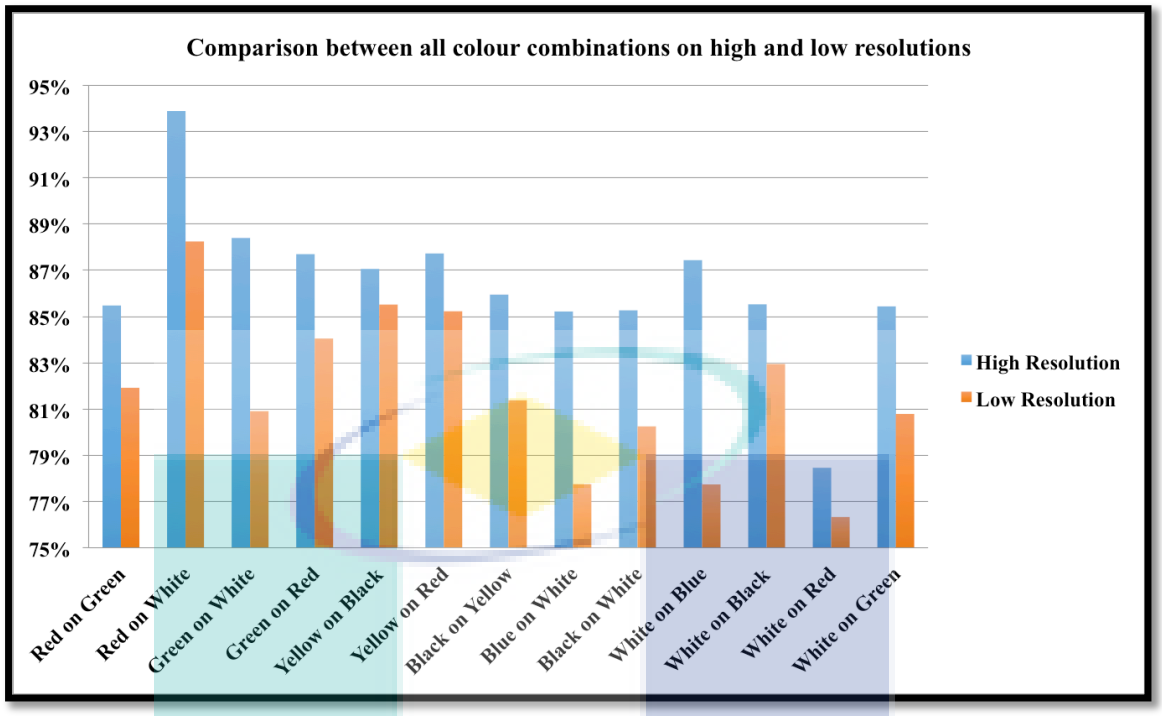


Figure 4.4: Comparison between all colour combinations on high and low resolution

For colour combinations, analysis on both resolution results is identical. The most recommended colour combination is White background with Green text. Both results also not recommended Red background with Green text colour combinations. However as illustrated in Figure 4.4, the higher the resolution does increase the legibility level for each colour combinations. This result has proved that increase in VDT resolution does increase legibility.

For colour combinations polarity, on low resolution the result reveals that, there is a significant difference between the two types of colour combinations polarity. However by observing the results for each colour combinations, it is concluded that it is hard to see any differences between the two types of colour combinations polarity and therefore it is concluded that the difference is too small in practicality. On high resolution, the percentage is much higher compared to low resolutions. It is recommended to use any type of colour polarity since the null hypothesis is fails to be rejected. Figure 4.5 shows the result on colour combinations polarity on both low and high resolution.

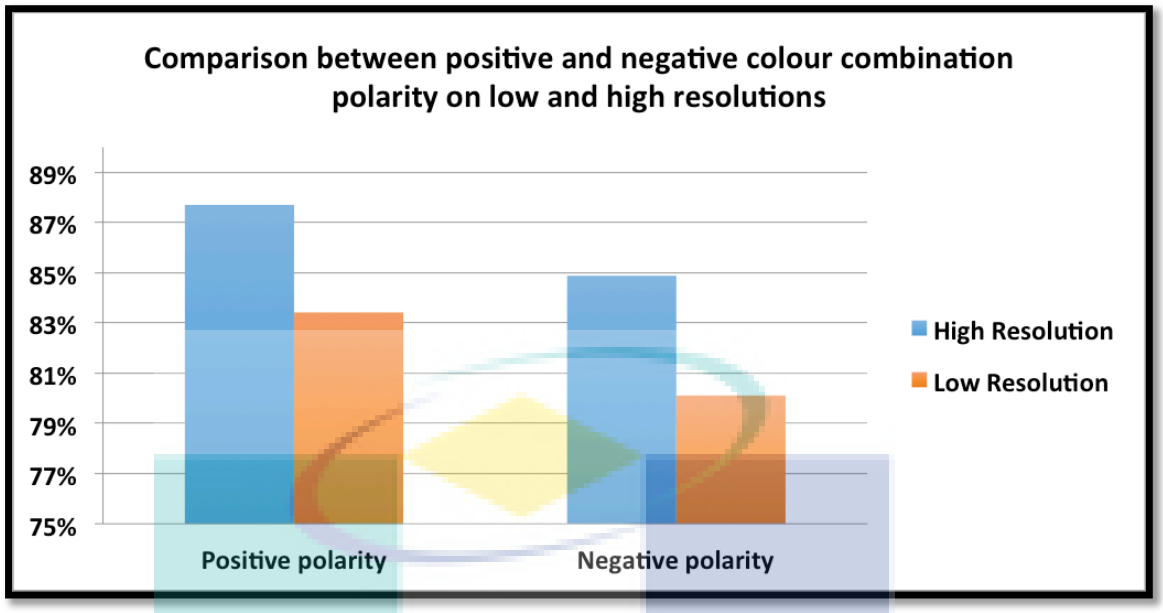


Figure 4.5: Comparison between positive and negative colour combination polarity for both high and low resolution

On the detail analysis in subsection 4.5.1.1 and 4.5.1.2 the result reveals that minimum colour contrast ratio for low resolution is 3.32:1, same as recommended by ANSI (3:1). However on high resolution the recommended contrast ratio is 2.35:1, which is a bit lower than recommended contrast ratio for low resolution. The results also reveal that on low resolution, colour contrast ratio 2.35:1 scores the highest legibility performance. However, further analysis reveals that the subjects did feel less comfortable while doing the legibility test experiment. Therefore the colour contrast ratio 2.35:1 is rejected as a minimum contrast ratio for low resolution. Figure 4.6 illustrates the comparison of all colour contrast ratio on high and low resolutions.

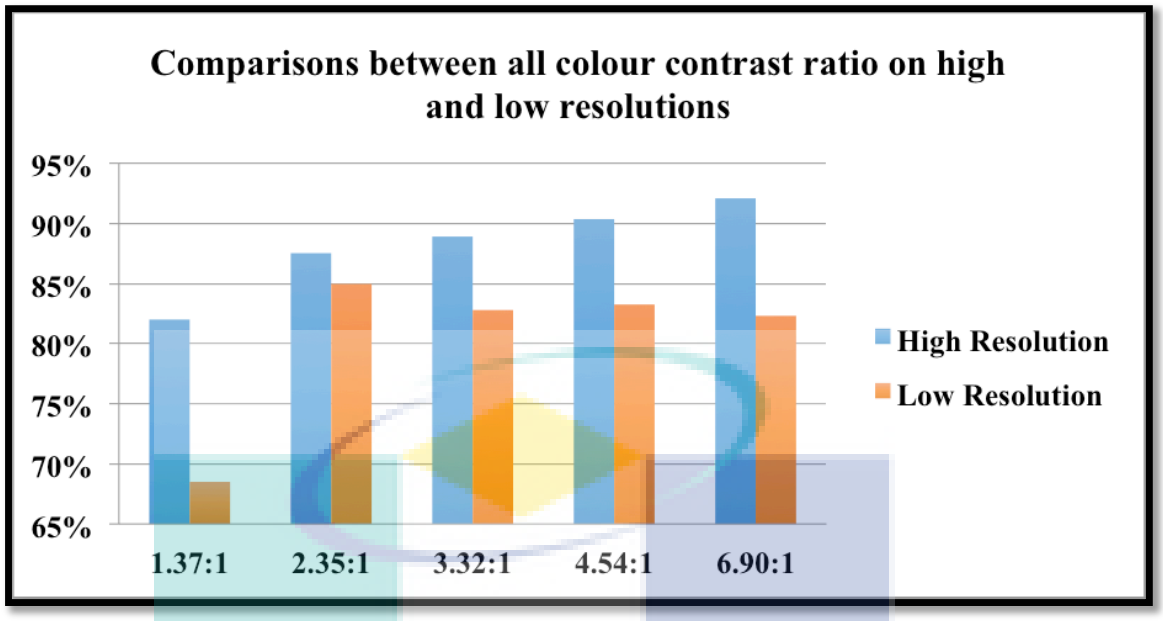


Figure 4.6: Comparison of all colour contrast ratio on high versus low resolution

The results observed have proved that resolution does influence legibility level in terms of colour contrast ratio. Figure 4.6 clearly indicates the legibility level does increase for all colour contrast ratio on high resolution compared to low resolution.

As a conclusion, based on the results from this study, the legibility performance for each dependent variables state in the scope in this study does influence by VDT resolution. The higher the resolution the higher the legibility level. Summary Table 4.40 below contains the legibility recommendations based on the result from this study. For complete LG refer to Appendix E.

Table 4.39: Recommendations based on the results from this study

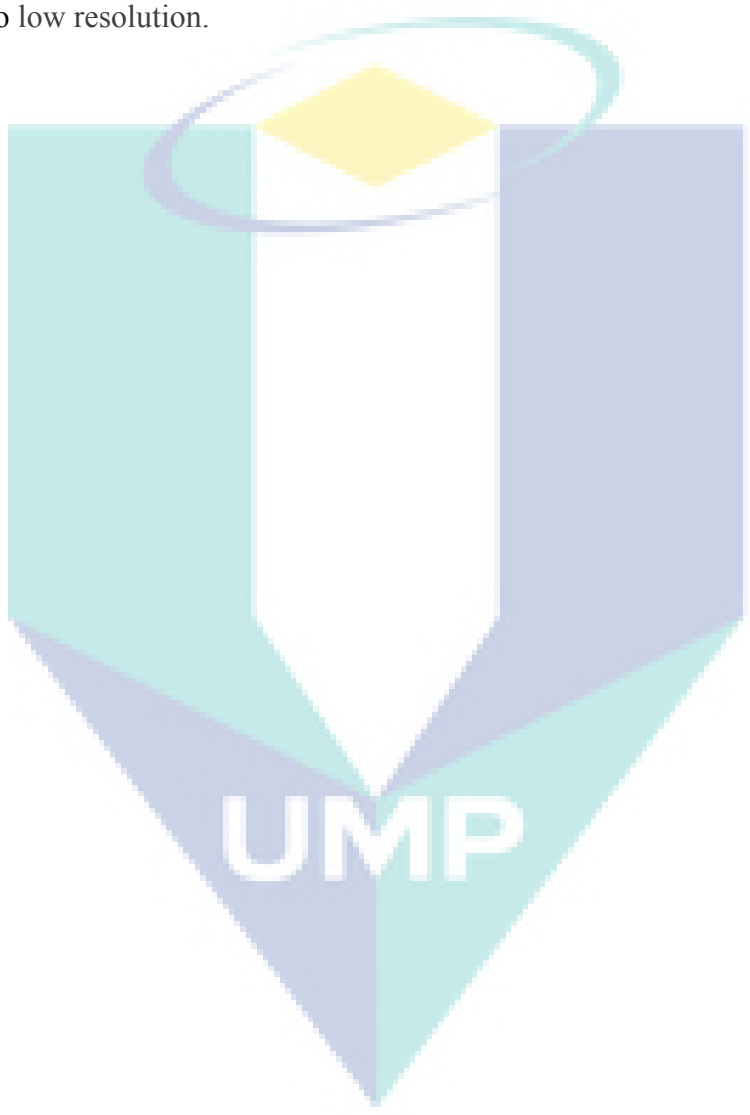
Dependant variables	**High Resolution**			**Low Resolution**		
Font size	Minimum 10 pt.			Minimum 10 pt.		
Font types	Courier Times New Roman Georgia Arial Verdana Calibri	Not recommended fonts Recommended fonts	Less legible fonts ↓ Most legible fonts	Courier Georgia Times New Roman Verdana Arial Calibri	Not recommended fonts Recommended fonts	Less legible fonts ↓ Most legible fonts
Fonts design for printed materials versus Fonts design for on-screen viewing	Recommended to use fonts design for on screen viewing			Recommended to use fonts design for on screen viewing		
Serif versus Sans Serif Fonts	Recommended to use sans serif fonts			Recommended to use sans serif fonts		

Table 4.39: Continued

Dependant variables	**High Resolution**			**Low Resolution**		
Colour Combinations	Red on Green Red on White Green on White Green on Red Yellow on Black Yellow on Red Black on Yellow Blue on White Black on White White on Blue White on Black White on Red White on Green	Not recommended colour combinations Recommended colour combination	Less legible colour combinations ↓ Most legible colour combinations	Red on Green Green on White Red on White Green on Red Black on White White on Red Black on Yellow Yellow on Black Yellow on Red White on Blue White on Black Blue on White White on Green	Not recommended colour combinations Recommended colour combination	Less legible colour combinations ↓ Most legible colour combinations
Colour Combinations Polarity	Positive polarity but no significance difference			Positive polarity but no significance difference		
Colour Contrast	1.37:1 2.35:1 3.32:1 4.54:1 6.90:1	Not recommended colour contrast ratio Recommended colour contrast ratio	Less legible colour contrast ratio ↓ Most legible colour contrast ratio	1.37:1 2.35:1 3.32:1 4.54:1 6.90:1	Not recommended colour contrast ratio Recommended colour contrast ratio	Less legible colour contrast ratio ↓ Most legible colour contrast ratio

4.7 CONCLUSION

This chapter represents detail experiments implementation and analysis for each dependents variable defined in the scope of this study. Two types of experiments and results have been analysed, compared and discussed in detail. The comparative results have shown that there is advantage in terms of legibility performance on high resolution compared to low resolution.



CHAPTER 5

LEGIBILITY ASSESSMENT TOOL

5.1 INTRODUCTION

The previous chapter has concluded the recommended guidelines to ensure the legibility of text in web pages. In this chapter, a prototype tool that has been developed using the newly found recommended legibility guidelines for high resolution based on this research will be explained in detail. Figure 5.1 shows the processes involved in creating the tools. The process starts with requirement analysis, which has been done in the previous chapter. In this chapter, the prototype tool design will be explained in detail starting with the tool architecture and proceed to show how the tools detecting the font properties. Then, the implementation of the prototype tool will be presented regarding how the font properties are being validated. Lastly, some selected test cases will be used in validating the prototype tool.

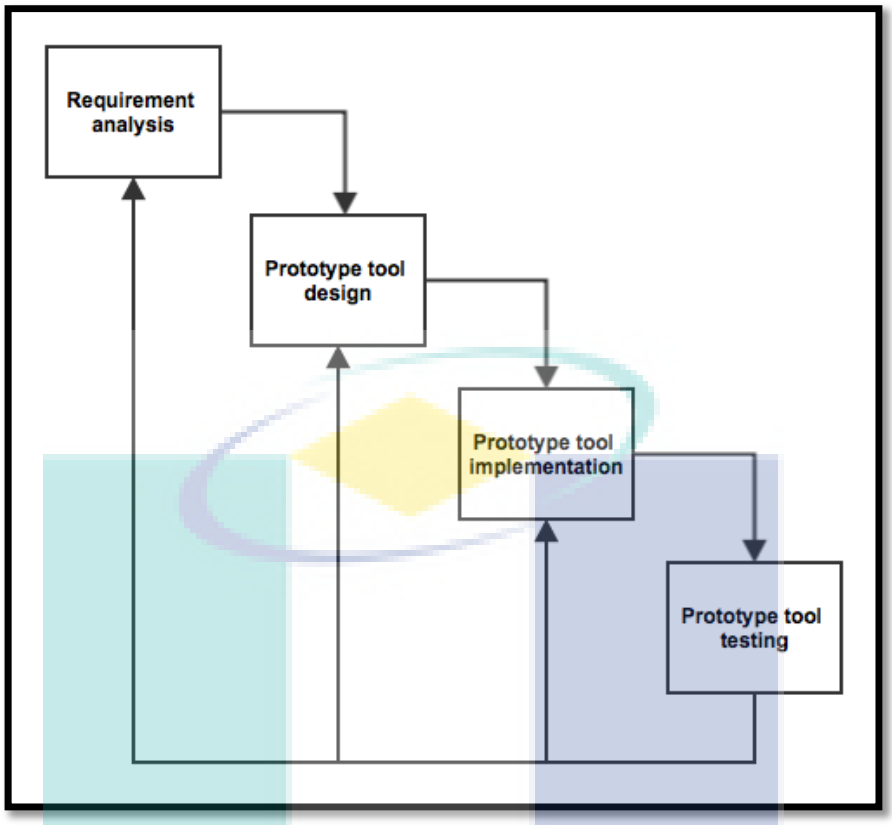


Figure 5.1: Process involved creating the prototype tools

5.2 TOOL ARCHITECTURE

The tool will be developed using JavaScript library (jQuery Version 1.11.1). The tool developed contains mainly two parts. The first part is the font characteristics detection. In this part, information about the colour of the font, the background colour, font size and type of font used are collected. The second part is the validation process. Fonts characteristics information collected in the first part will be validated against the proposed guideline. The recommendations, if any, will be then presented to the user.

5.3 FONTS CHARACTERISTICS DETECTION

The first part of the tool is detecting the characteristics of the fonts. The detection of the font properties will be done by inspecting the properties of CSS for the element. Figure 5.2 shows the part of the code used in detecting the font properties.

```
1  this.fonts = this.element.css('font-family');
2  this.size = this.element.css('font-size');
3  this.color = this.element.css('color');
4  this.backcolor = this.element.css('background-color');
```

Figure 5.2: Snippet of the code used to detect font characteristics

Based on Figure 5.2, the first line will collect the information about the type of font used in the element. The second line will be then collected the information about the size of the font used. The third line will collect the colour of the font, and the fourth line will collect the background colour of the font.

5.4 FONTS CHARACTERISTICS VALIDATION

Font characteristics information collected in the first part will be then validated against the new high-resolution legibility guideline. There are mainly four validation parts. The parts are as follows:

i. Type of font validation.
ii. Font size validation.
iii. Colour combination validation.
iv. Colour contrast ratio validation.

All validation parts will be using a common algorithm. Figure 5.3 shows the programming flows used in the validation process.

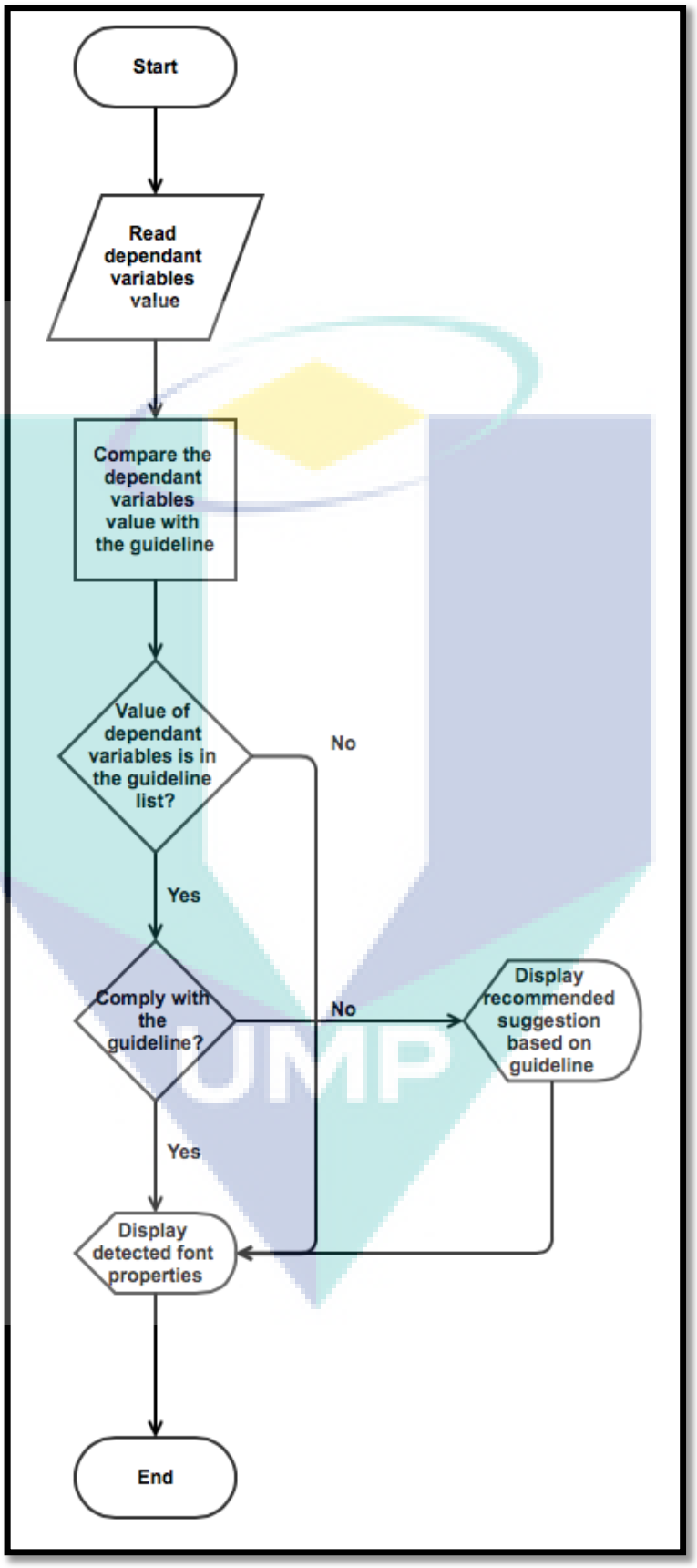


Figure 5.3: General validation process flow.

5.4.1 Type of Fonts Validation

The type of fonts validation process involves validating the active font displayed on the webpage by the browser used. After the font is detected, it will be then compared with the new legibility guideline. If the font is in the recommended list, the validation process will end immediately. If the font detected is not in the list, tools will recommend best guideline to choose font. If the font is in not recommended font list, an error message will be displayed and a suggestion will be provided.

5.4.2 Font Size Validation

Font size detected will be compared with the new legibility guideline. If detected font size is below recommended guideline, an error message will be displayed and minimum recommended font size be presented. If the font size detected complies with the guideline, the validation process ends immediately.

5.4.3 Colour Combination Validation

The colour combination validation process involves additional process before the common validation algorithm begins. The colour combination detected is the Red Green Blue (RGB) colour model. Since the guideline using a colour name (e.g. red, blue, yellow and so on) the colour detected must be first converted to colour names. Achieving this, the RGB colour code will be then converted to Hue Saturation Value (HSV) colour model. After the conversion, using the diagram like below (Figure 5.3), each colour will be classified into main colour names.

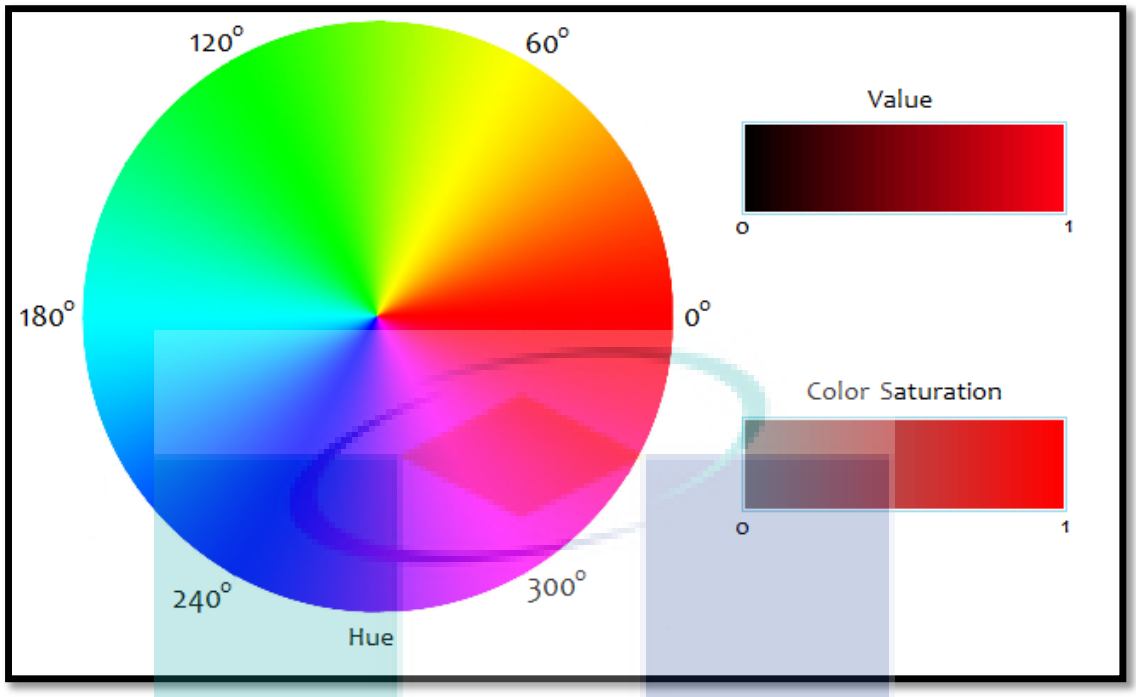


Figure 5.4: Colour hue, colour saturation, and value

Based on the diagram on Figure 5.4 and HSV value for background and text, the tools will be then calibrates to achieve the best result naming the colour names. Figure 5.4 shows the configuration rules used in this tool.

```
1   if(saturation < 4 && value < 85) {
2           return "Black";
3    }
4   else if(saturation < 11  && value >= 85) {
5           return "White";
6   }
7   else if(hue >= 0 && hue < 42) {
8           return "Red";
9    }
10  else if(hue >= 42 && hue < 70) {
11          return "Yellow";
12  }
13  else if(hue >=70 && hue < 175) {
14          return "Green";
15  }
16  else if(hue >= 175 && hue < 270) {
17          return "Blue";
18  }
19  else if(hue >= 309 && hue <= 360) {
20          return "Red";
21  }
```

Figure 5.5: Colour naming configuration rules

The value for saturation and value is using scale 0 to 100 to avoid using decimal value instead 0 to 1 used in Figure 5.4. Based on the rules, six-colour name is determined using the HSV values for text and background. The colour combination is then compared against the guideline and recommendation (if any) provided.

5.4.4 Colour Contrast Ratio Validation

Colour contrast ratio is calculated based on mathematical formulas from W3C WCAG 2.0. The first step is to calculate the relative luminance for each colour, background, and text.

$$L = 0.2126 \, x \, \boldsymbol{R} + 0.7152 \, x \, \boldsymbol{G} + 0.0722 \, x \, \boldsymbol{B}$$

where **R**,**G** and **B** are defined as follows:

i. if R_{sRGB} <= 0.03928 then R = R_{sRGB}/12.92 else R = ((R_{sRGB}+0.055)/1.055) ^ 2.4

ii. if G_{sRGB} <= 0.03928 then G = G_{sRGB}/12.92 else G = ((G_{sRGB}+0.055)/1.055) ^ 2.4

iii. if B_{sRGB} <= 0.03928 then B = B_{sRGB}/12.92 else B = ((B_{sRGB}+0.055)/1.055) ^ 2.4 (5.1)

and R_{sRGB}, G_{sRGB}, and B_{sRGB} are defined as:

i. R_{sRGB} = R_{8bit}/255

ii. G_{sRGB} = G_{8bit}/255

iii. B_{sRGB} = B_{8bit}/255

After the luminance contrast for each colour, background and text, the formula below will calculate the colour contrast ratio for the colour combination.

$$Colour\ Contrast\ Ratio = \frac{(L1 + 0.05)}{(L2 + 0.05)}, Where \quad (5.2)$$

i. L1 is the relative luminance of the lighter of the foreground or background colours, and

ii. L2 is the relative luminance of the darker of the foreground or background colours.

Colour polarity for each colour combination will also be determined using the formula 5.1 and 5.2. If the font colour relative luminance value is lower than the background, then the colour polarity is negative and vice versa.

5.5 TESTING AND RESULT VALIDATION

The tool has been tested for its accuracy detecting the font properties and the validation process using the proposed high-resolution legibility guideline. Results from the tool will be compared with Firefox Web Inspector (FWI) and Internet Explorer Developer Tool (IEDT). A few selected test cases have been used in the testing process.

5.5.1 Test Case 1 – Universiti Malaysia Pahang Website

Figure 5.6 below is a screenshot of a webpage used in this case study.

Figure 5.6: Universiti Malaysia Pahang webpage

In this case study, the results from the browsers and the LAT are presented in Table 5.1 below.

Table 5.1: Results from the test on Universiti Malaysia Pahang webpage

	IEDT	FWI	LAT	Result or Recommendation
Active Used fonts	Arial	Arial	Arial	None. Complies with the guideline

Table 5.1: Continued

	IEDT	FWI	LAT	Result or Recommendation
Background colour	N/A	N/A	#FFFFFF (White)	None. Complies with the guideline.
Font colour	rgb(51,51,51)	#333	#333333 (Black)	
Colour contrast ratio	N/A	N/A	12.63:1	None. Complies with the guideline.
Font size	11.93px	1.2 em (12px)	12px or 9pt	Font size 9pt is too small. Recommended to use font size at least 10 pt.

Figure 5.7 show the expected output from the tools when used on this selected test case web page.

Figure 5.7: LAT showing the results from test case 1

5.5.2 Test Case 2 – Maran Land And District Offices Website

Figure 5.8 below shows the screenshot of the web page used in this case study.

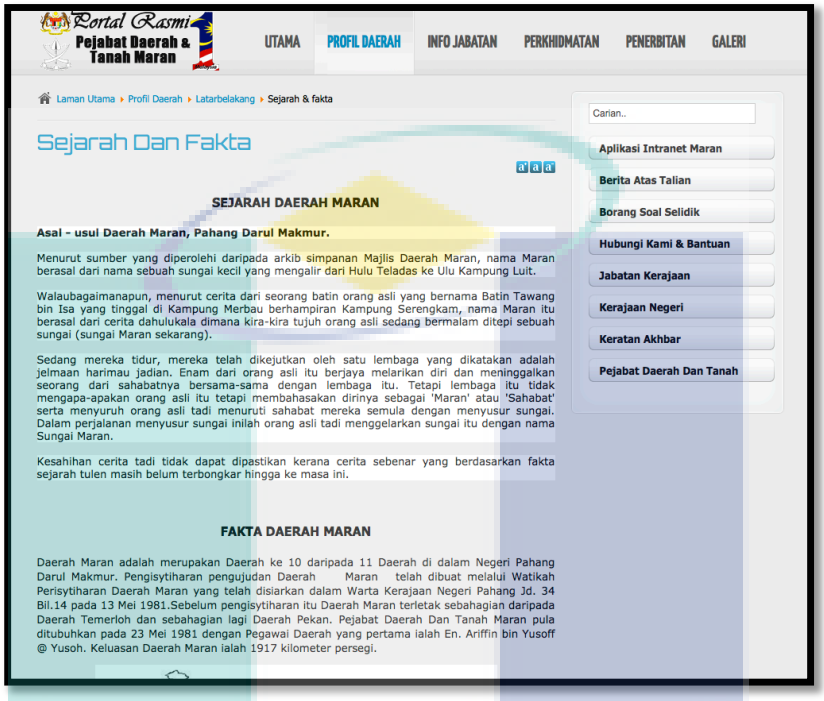


Figure 5.8: Maran Land and District Offices webpage

In this case study, the results from both tools are presented in Table 5.2 below.

Table 5.2: Results from the test on Maran Land and District Offices webpage

	IEDT	FWI	LAT	Result or Recommendation
Active Used fonts	Verdana	Verdana	Verdana	None. Complies with the guideline.
Background colour	rgb(255, 255, 255)	#FFF	#FFFFFF (White)	None. Complies with the guideline.
Font colour	rgb(0, 0, 0)	#000	#000000 (Black)	

Table 5.2: Continued

	IEDT	FWI	LAT	Result or Recommendation
Colour contrast ratio	N/A	N/A	21:1	None. Complies with the guideline.
Font size	12.8px	10 pt	13.3333px or 10 pt	None. Complies with the guideline.

Figure 5.9 show the expected output from the tools when used on this selected test case web page.

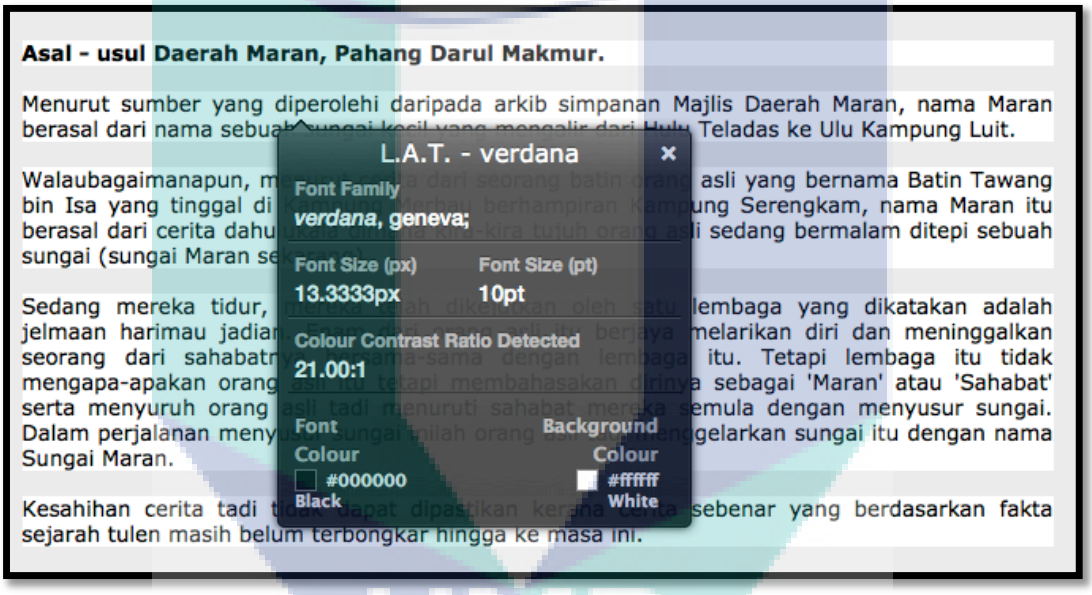


Figure 5.9: LAT showing the results from test case 2

5.5.3 Test Case 3 – Perak State Official Government Website

Figure 5.10 below shows the screenshot of the web page used in this case study.

Figure 5.10: Perak state official government webpage

In this case study, the results from browsers and LAT are presented in Table 5.3 below.

Table 5.3: Results from the test on Perak state official government webpage

	IEDT	FWI	LAT	Result or Recommendation
Active Used fonts	Verdana	Verdana	Verdana	None. Complies with the guideline.
Background colour		transparent	#FFFFFF (White)	None. Complies with the guideline.
Font colour	rgb (102, 102, 102)	#666	#666666 (Black)	

Table 5.3: Continued

	IEDT	FWI	LAT	Result or Recommendation
Colour contrast ratio	N/A	N/A	5.74:1	None. Complies with the guideline.
Font size	12.8px	10 pt	13.3333px or 10 pt	None. Complies with the guideline.

Figure 5.11 show the expected output from the tool when used on this selected test case web page.

Figure 5.11: LAT showing the results from test case 3

5.5.4 Test Case 4 – Simulated Webpage I

Figure 5.12 shows the simulated webpage with LAT displaying the result analysis.

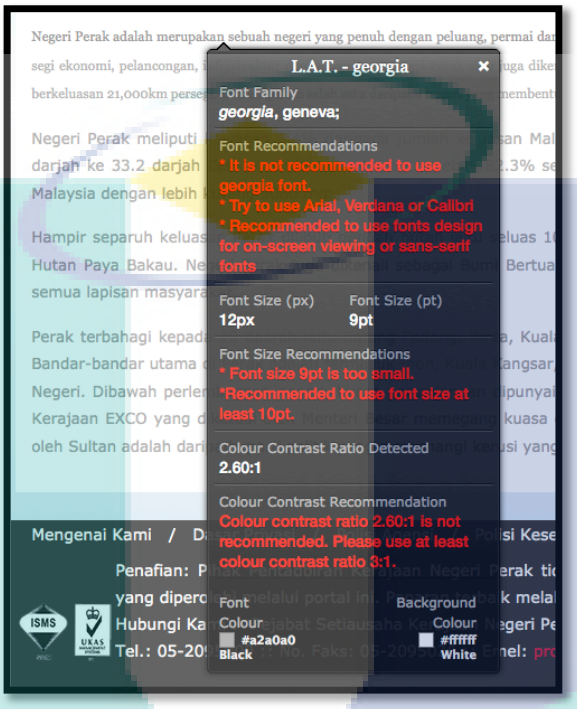


Figure 5.12: LAT showing the results from test case 4

In this case study, the results from browsers and LAT are presented in Table 5.4 below.

Table 5.4: Results from LAT tools and Firefox browser web inspector on simulated webpage I

	IEDT	FWI	LAT	Result or Recommendation
Active Used fonts	Georgia	Georgia	Georgia	It is not recommended to use Georgia font. Try to use Arial, Verdana or Calibri Recommended to use fonts design for on-screen viewing or sans serif fonts

Table 5.4: Continued

	IEDT	**FWI**	**LAT**	**Result or Recommendation**
Background colour	N/A	Transparent	#FFFFFF (White)	None. Complies with the guideline.
Font colour	rgb (162, 160, 160)	rgba (162, 160, 160, 1)	# A2A0A0 (Black)	
Colour contrast ratio	N/A	N/A	2.60:1	Colour contrast ratio 2.60:1 is not recommended. Please use at least colour contrast ratio 3:1.
Font size	11.93 px	9pt	12px or 9pt	Font size 9pt is too small. Recommended to use font size at least 10 pt.

5.5.5 Test Case 5 – Simulated Webpage II

Figure 5.13 shows the simulated webpage with LAT displaying the result analysis.

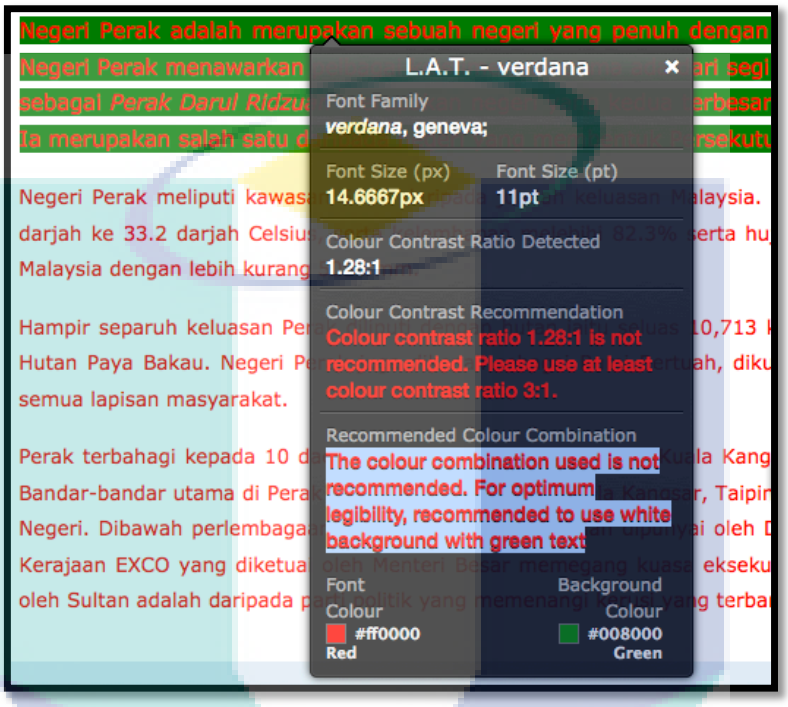


Figure 5.13: LAT showing the results from test case 5

In this case study, the results from browser and the LAT are presented in Table 5.5 below.

Table 5.5: Results from LAT tools and Firefox browser web inspector on simulated webpage II

	IEDT	**FWI**	**LAT**	**Result or Recommendation (output from LAT)**
Active Used fonts	Verdana	Verdana	Verdana	None. Complies with the guideline.
Background colour	rgb(0, 128, 0)	green	#008000(Green)	The colour combination used is not recommended. For optimum legibility, recommended to use white background with green text
Font colour	rgb(255, 0, 0)	red	#FF0000 (Red)	
Colour contrast ratio	N/A	N/A	1.28:1	Colour contrast ratio 1.28:1 is not recommended. Please use at least colour contrast ratio 3:1.
Font size	12.8 px	10 pt	13.3333 px or 10 pt	None. Complies with the guideline.

5.6 IMPLEMENTATION OF LAT

In previous subsection in this chapter, the how LAT works and software testing have successfully been presented. In this subsection we are going to review a few more website to evaluate its legibility level based on new improve LG. In this subsection, we are going to compare the recent version of a webpage with the older version of the same page. To achieve this, the archive version of the website will be retrieved from The Internet Archive. The Internet Archive is an organization that is non-profit, founded to build an Internet library. Its purposes include offering permanent access for researchers, historians, scholars, people with disabilities, and the general public to historical collections that exist in digital format (Internet Archive).

5.6.1 Case study 1: Pennsylvania State University

Pennsylvania State University (PSU) website is the website of one of the well known University in America founded in 1857. The (PSU) website below (Figure 5.14) taken from the archived snapshot dated 19th September 2002.

Figure 5.14: Old version of PSU main web page retrieved from the archived snapshot on 19th September 2002

Analysis on the website reveals that serif font is being used (refer Figure 5.15). This is not recommended based on improved LG. Due to the small size of the font. The legibility could be improved by using the sans serif fonts. The recent version of the website have improved. However the usage of the font size is still smaller than recommended minimum font size that is 10 pt. and should be improved to increase legibility. Figure below shows the different between the old and latest version of PSU website.

Figure 5.15: LAT analysis on old version of PSU main web page

The recent version of the website have improved (Figure 5.16). Based on the analysis, the font in use is Open Sans which is sans serif fonts (Google Fonts). However the usage of the font size is still smaller than recommended minimum font size that is 10 pt. and should be used to increase legibility.

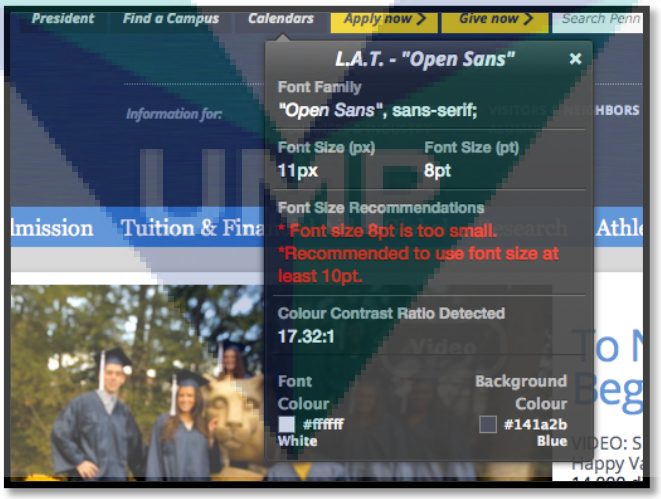


Figure 5.16: LAT analysis on latest version of PSU main web page

5.6.2 Case study 2: University Sains Malaysia

University Sains Malaysia (USM) is the second oldest university in Malaysia founded in 1969. The old version of a web is retrieved from the archived snapshot dated 18th march 2004.

Figure 5.17: LAT analysis on old version main webpage of USM

Based on the analysis. The main top menu link is using serif font, which is not recommended, and the contrast ratio is 2.13:1, which is less than minimum, recommend value, which is 2.35:1. Second analysis on the webpage content, which is displaying the latest news about USM, revealed that the font size in use is 8 pt., which is again less than minimum recommended value, which is 10 pt.

Figure 5.18: LAT analysis on latest version main webpage of USM

Based on the recent version of the webpage the legibility of the webpage have improved. The main top menu link is now using OpenSans font, which is sans serif font and larger font size too compared to old version of the same webpage (Figure 5.17). The legibility of the main content also has improved by the usage of DroidSanRegular font, which is sans serif fonts (Google Fonts) and larger font size, which is 11pt higher than old version of that same webpage and above the minimum recommended value. The improved legibility on the main webpage will assist users to easily navigate around the website and to read the summarised version of the news comfortably.

5.6.3 Case study 3: International Islamic University Malaysia

International Islamic University Malaysia (IIUM) is one of the first Islamic universities in Malaysia. The IIUM main webpage below (Figure 5.19) taken from the archive snapshot dated 20th may 2007.

Figure 5.19: Older version of IIUM main webpage taken from archive snapshot on 20th May 2007

One of the main content on this webpage is the announcement. Based on the analysis (refer Figure 5.20), the header of the content title is legible and users should be able to notice it at glance about what the content is all about. In terms of the contents, the legibility level could be improved by using much larger font size, which is minimum recommended 10 pt.

Figure 5.20: LAT analysis on old version of IIUM main webpage

On the newer version of the same IIUM webpage, the legibility level of the same content is greatly improved. Based on Figure 5.21, the font in use is Roboto Condensed is humanist serif font, which is an improved version of Roboto font (Google Fonts). The header of the content is greatly improved by the usage of much larger font (15 pt.) compared to the old version of the same webpage. The content also have improved by usage of larger font size (13 pt.) than minimum recommended font size.

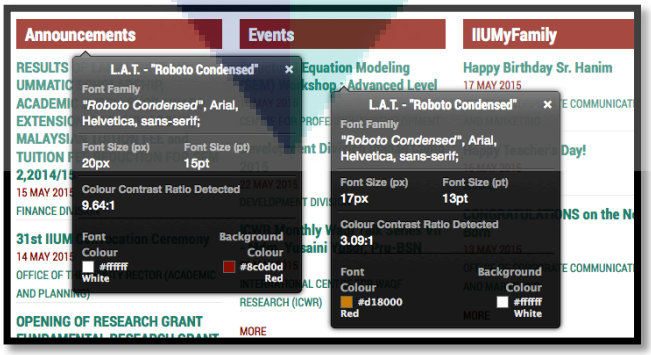


Figure 5.21: LAT analysis on new version of the same IIUM main webpage

5.6.4 Case study 4: National University Of Singapore

National University of Singapore (NUS) is the best university in Asia situated in Singapore. NUS main webpage on Figure 5.22 below retrieved from archived snapshot dated 1st march 2009.

Figure 5.22: Old version of NUS main webpage retrieved from archive snapshot dated 1st March 2009

Analysis on the old version of webpage reveal that, the main content of the webpage which is the news, do have less legibility level on the summarized content of the news. The font size in use is 8 pt. compared to the recommended, which is minimum 10 pt. Figure 5.23 shows the legibility analysis result.

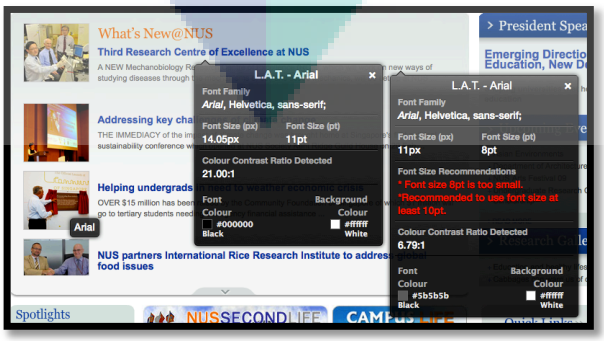


Figure 5.23: LAT analysis on the old version of NUS main webpage

Analysis on the newly improved webpage reveals that then legibility of the webpage is greatly improved. The font type in use is Helvetica Neue is a sans serif font. Based on the legibility analysis depicted on Figure 5.24, the new and latest design of the main NUS webpage is legible compared to old version compared in this legibility analysis.

Figure 5.24: LAT analysis on the latest version of NUS main webpage

5.6.5 Case study 5: Singapore Polytechnic

Singapore Polytechnic (SP) is one of higher education institution in Singapore. The SP webpage on Figure 5.25 is webpage retrieved from archived snapshot dated 15th January 2008.

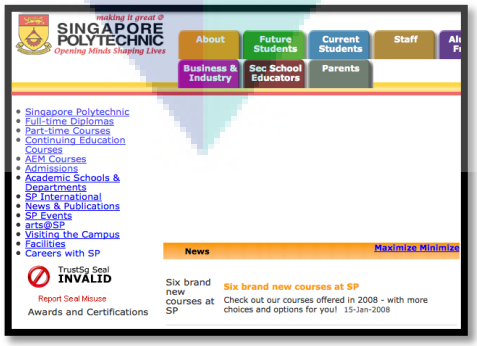


Figure 5.25: Old version of SP main webpage retrieved from archived snapshot dated 15th January 2008

Analysis on the old SP webpage shows that on the content that shows the news is not in optimal legibility level. Based on Figure 5.26, the title of the news is using font size 9 pt. below the minimum recommended font size. The colour contrast ratio is use 2.09:1 also lower than recommended contrast ratio level. The usages of not recommended font size and colour contrast ratio not just lead to legibility problem but also produce uncomfortable reading activity experience.

Figure 5.26: Legibility analysis on old version of SP main webpage

Analysis on the latest SP webpage on reveals a lot of improvement. All parts of the webpage is exceed minimum recommended value thus make it legible and comfortable to be read. Figure 5.27 shows the legibility analysis of the webpage.

Figure 5.27: LAT analysis on new SP main webpage

In this subsection, it is concluded that legibility of a webpage is getting improved from old to a new version of a webpage. Based on the analysis also, fonts selected for the font family configuration in all selected webpage style in this analysis are also among the recommended fonts in the improved LG. The font size used in latest or new webpage design for each website selected in this analysis also indicate towards legibility improvement, same with colour contrast and colour combination.

5.7 CONCLUSION

This chapter has discussed the detail architecture of LAT. The results from test case used have been presented. A detailed performance evaluation has been shown as well. The comparative result indicates that LAT managed to accurately retrieved active settings for each test case and validate them with the proposed LG guideline. On the implementation, a few case studies have been discussed. There are evidence the webpages in discussed, improved from old version compared to newer version. However with the bigger VDT getting cheaper and with higher resolution available, it would be good if all components on webpage can be at the optimum legibility level. This is where the LG through LAT can assist the web designer or developer to enhance their web design in terms of legibility level.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 INTRODUCTION

This research has addressed legibility issues caused by the use of different VDT resolution. On this research, a guideline has been developed for high and low resolutions selected in this research. This research has also introduced the LAT that applies the newly found knowledge on this research, the new legibility guideline for high resolution. In this chapter, the important findings from the research will be discussed and the future work that might lead to significant findings will also be presented.

6.2 CONCLUSION

On this research, the important factor that can help in improving the web design towards better legibility has been explored. There are a few areas that can be improved to have more legible text in web pages. The first is the typeface or fonts used. In chapter 2, we explored a few research projects in this area. These mostly have suggested that choosing the right font can leads to significant impact on legibility. Concurring with the results of this research, there are a few fonts that are can be clearly group as recommended and not recommended fonts. This research however has explored the effects of VDT resolution and the results also have proven improvement in terms of legibility level, but not significantly. Concurring with most of the previous researches, based on the detail type font analysis have proven that Verdana is the best font, and it is recommended to use font design for on-screen viewing and fonts without serifs.

Choosing the right font size also influence greatly on legibility. However, in this research, we have found out that the recommended minimum font size tested on fonts used is 10 pt for both resolutions tested. Previous research, however, has recommended the usage of font sizes between 10 to 14 pt.

Colour combination used as a text and background colour have been proven to cause greatly on the legibility of a text in web pages. Based on chapter 2, many researchers have proved some colour combination can significantly improve legibility and some are significantly making the text less legible. By considering basic features on improving legibility of a text in web pages, this research also concurs with this finding. This research however has demonstrated identical results for both resolutions, thus proving that colour combination might not be influence by VDT resolutions. Previous research has recommended black and white colour combinations; in this research, however, green text with white background colour combination has been found to be the best.

Colour contrast ratio has also been proven to have influence the legibility of a text in web pages. Recommendations have been made, and the minimum suggested is at least 3:1. In this research also concurred with the previous findings. However, a high resolution VDT that is capable of displaying sharper images has been proven to have an advantage, with a much lower recommended colour contrast ratio of 2.35:1.

Overall findings have proven that there is improvement on legibility of text in web pages in all scope or dependant variables studied on this research. However, the improvement is not significant to influence any changes to current guidelines, except for colour contrast ratio.

This research does provide significant contribution to the web design guideline. This first major contribution is, that the VDT resolution does influence the legibility of a text in web pages. It has been proven based on the analysis that VDT resolution is not significantly influence to make a changes to the current guidelines except colour contrast ratio, however it does improve the legibility. The second major contribution is the LAT. In this research, the results have proved that careful is still needed on

designing the text in web pages even when it is going to be displayed on higher resolution. LAT has been developed to provide better assistance to the web developers or web designers in evaluating their web design.

6.3 CONTRIBUTION TO THE KNOWLEDGE

This research has successfully proved that VDT resolution does influence legibility of a text in web pages. Due to higher densities of pixels on high resolution VDT, the image on the screen will appear sharper than a low VDT resolution. Based on this evidence special care needs to be taken when designing webpages to cater to different targeted resolutions.

6.4 FUTURE WORK

In this research, the new guidelines found in this research may be improved further, to enhance the legibility level of text in web pages. In this research we have explored a few variables on text in web pages design that have been proven to have an influence on legibility.

Currently, the guideline is only focused on the minimum requirement for each dependant variables studied to ensure legibility. This however can be improved to find suitable range of recommended values for each dependent variable by including a few more factors such as readability.

The typeface recommendation, however, may be improved by considering to aesthetics preference in the study, which in this not the focus of this research. Some fonts might display legibly and be aesthetically appealing in different resolutions.

The recommended font size can be further improved by considering the readability factor. Larger text will lead to better legibility; however, too large a font might decrease the readability level since the text might consist more lines and might needed to be scrolls to read the whole text. This might lead to increasing reading time and visual fatigue.

The colour combinations suggested in this research is focused on basic factors such as improving legibility. This, however, has led to basic conclusion that users see and are able to recognize and comfortably read the text. Since colour also influences the aesthetics factor, a study may be further enhanced by including preferences factors.

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APPENDIX A

LIST OF PUBLICATIONS

Hashim, A. A., & Abdul Majid, M. (2012), "***Guidelines for Making Web Text Legible on High Definition Display***", Presented at the National Conference of Postgrduate Research, Gambang, Pahang, Malaysia. **Status: Presented**

Hashim, A. A., & Abdul Majid, M. (2012), "***Guidelines and Assessment Tool for Making Web Text Legible on High Definition Display***", Presented at the International Conference of Computational Science Information Management, Medan, Indonesia. **Status: Published**

Hashim, A. A., & Abdul Majid, M. (2013), "***A Study on Colour Combination Guidelines for Text and Background in Web Legibility Perspective***", Presented at the International Conference on Software Engineering Computer Systems, Gambang, Pahang, Malaysia. **Status: Published**

Hashim, A. A., Abdul Majid, M., & A Mustafa, B. (2014), "***Legibility Of Web Page On Full High Definition Display***", Presented at the International Conference on Advanced Computer Science Applications and Technologies, Kuching, Sarawak, Malaysia. **Status: Published**

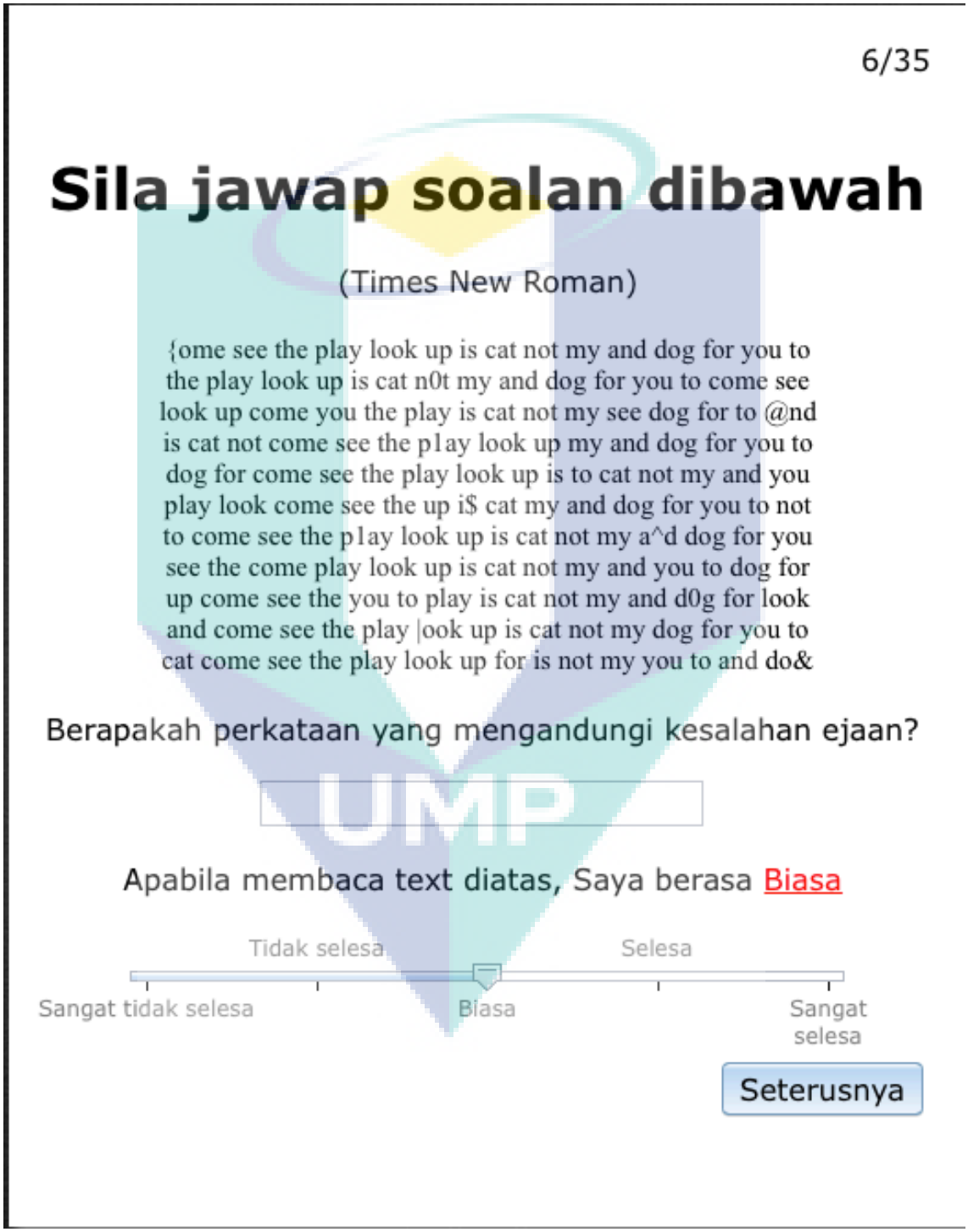
Hashim, A. A., & Abdul Majid, M., (2015) "***Effects Of Video Display Terminal Resolutions To the Legibility Of Text On A Web Page***", International Journal Of Software Engineering & Computer Sciences (IJSECS), ISSN: 2289-8522, Volume 1, pp.131-134, February 2015. **Status: Published**

APPENDIX B

SAMPLE QUESTIONAIRE QUESTION – FONT SELECTIONS

APPENDIX C

SAMPLE QUESTIONAIRE QUESTION – LEGIBILITY TEST



APPENDIX D

LEGIBILITY ASSESSMENT TOOL MANUAL

1) Download LAT from – http://bit.ly/lattool
2) To download the LAT drag the LAT link to your bookmark/favorites toolbar (Figure D.1).

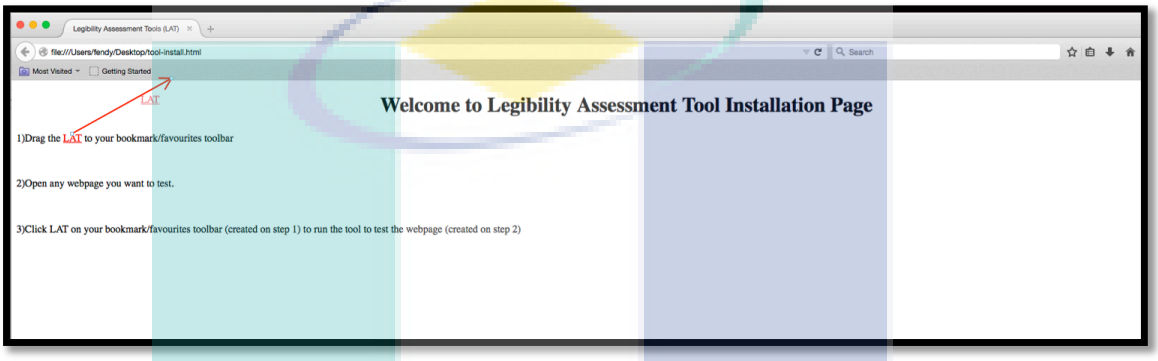


Figure D.1: LAT installation web page

3) Open any webpage you want to test.
4) Click the LAT on your bookmark toolbar (created on step 2) to run the tool to test the webpage (created on step 3).

APPENDIX E

LEGIBITY GUIDELINES

Introduction

These guidelines explain how to make Web content legible to users with normal or corrected to normal vision. These guidelines are intended for all web content developers and for developers of authoring tools. The primary goal of these guidelines is to promote legibility. Following these guidelines will help users read the text on the web comfortable and quickly find information.

Throughout this document, High resolution is referring to Video Display Terminal or computer screen that have 1920 horizontal pixels and 1080 vertical pixels and higher. While low resolution is any resolution that is below the higher resolution.

Legibility Guidelines

Guideline 1: Font type usage

Use fonts that are enhanced for on screen viewing.

Fonts design for on screen viewing are specifically designs and optimized to be use for text displayed on screen. It is also encourage using sans serif fonts compared to serif fonts. The sans serif fonts is proven to assist users in recognising characters displayed on screen therefore produce comfortable reading experienced.

It is not recommended to use Courier and Times New Roman fonts since it is proven not legible to be viewing on screen. Georgia font however is a serif font but designed for on screen viewing. The usage for Georgia font however only recommended for high resolution (1920x1080) or higher computer screen or Video Display Terminal.

Arial, Verdana and Calibri is proven to be legible and therefore recommended fonts. However usage of other fonts are recommended if among sans serif fonts family and designed for on screen viewing. Table 1, summarised the recommended font type usage.

Items	High Resolution	Low Resolution
Recommended fonts	Georgia Arial Verdana Calibri	Arial Verdana Calibri
Not recommended fonts	Courier Times New Roman	Georgia Courier Times New Roman
Recommended font by design	Recommended to use font design for on screen viewing	Recommended to use font design for on screen viewing
Serif versus sans serif	Recommended to use sans serif fonts	Recommended to use sans serif fonts

Guideline 2: Font size usage

Use font size at least 10 pt.

A certain trend among designers, believing that small text gives a Web page a sl eek appearance and provides more space per "page" for actual content, sometimes result s in the use of unreasonably small font sizes.

The problem here is a basic usability and accessibility issue: a good design should look good without requiring the user to enlarge or reduce the text size.

10 pt. is proven the minimum recommended font size regardless any resolution size use.

Guideline 3: Colour combination usage

Ensure that each of the text letters have at least 3:1 colour contrast ratio with the background.

Certain colour combination for text and background are proven to provided extra challenges to the user's reading activity.

Not recommended colour combination	
Colour for text	**Colour for background**
Red	Green
Red	White
Green	White
Green	Red

Table above shows the not recommended colour combination. However, if the not recommended colour combination is required to be use. Ensure that colour contrast ratio is at well above 3:1 or 2.35:1 for high resolution VDT.

To check the colour contrast ratio, procedures below are applied.

Procedure

1. Measure the relative luminance of each letter (unless they are all uniform) using the formula:

L = 0.2126 * **R** + 0.7152 * **G** + 0.0722 * **B** where **R**, **G** and **B** are defined as:

i. if $\mathbf{R}_{sRGB}$ <= 0.03928 then $\mathbf{R} = \mathbf{R}_{sRGB}$ /12.92 else
$\mathbf{R} = ((\mathbf{R}_{sRGB} + 0.055)/1.055)$ ^ 2.4

ii. if $\mathbf{G}_{sRGB}$ <= 0.03928 then $\mathbf{G} = \mathbf{G}_{sRGB}$ /12.92 else
$\mathbf{G} = ((\mathbf{G}_{sRGB} + 0.055)/1.055)$ ^ 2.4

iii. if $\mathbf{B}_{sRGB}$ <= 0.03928 then $\mathbf{B} = \mathbf{B}_{sRGB}$ /12.92 else
$\mathbf{B} = ((\mathbf{B}_{sRGB} + 0.055)/1.055)$ ^ 2.4

and $\mathbf{R}_{sRGB}$, $\mathbf{G}_{sRGB}$, and $\mathbf{B}_{sRGB}$ are defined as:

i. $\mathbf{R}_{sRGB} = \mathbf{R}_{8bit} /255$

ii. $\mathbf{G}_{sRGB} = \mathbf{G}_{8bit} /255$

iii. $\mathbf{B}_{sRGB} = \mathbf{B}_{8bit} /255$

The "^" character is the exponentiation operator.

Note: For aliased letters, use the relative luminance value found two pixels in from the edge of the letter.

2. Measure the relative luminance of the background pixels immediately next to the letter using same formula.

3. Calculate the contrast ratio using the following formula.

(**L1** + 0.05) / (**L2** + 0.05), where

i. **L1** is the relative luminance of the lighter of the foreground or background colors, and

ii. **L2** is the relative luminance of the darker of the foreground or background colors.

4. Check that the contrast ratio is equal to or greater than 2.35:1 for high resolution and 3:1 for low resolution.