ผลของสีพื้นหลังต่อความล้าทางสายตาจากการอ่านแท็บเล็ต

นางสาวแพรวพรรณ อยู่เย็น

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาเทคโนโลยีทางภาพ ภาควิชาวิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์
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EFFECTS OF BACKGROUND COLOUR ON VISUAL FATIGUE FROM READING ON TABLET

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งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของความล้าทางสายตาจากการอ่านหนังสือบนแท็บเล็ต เมื่อเปลี่ยนระดับความสว่างและสีของพื้นหลัง โดยที่ความระดับสว่างจะถูกแบ่งเป็น 6 ระดับคือ ความส่องสว่างเท่ากับกระดาษ (68 cd/m^2) ความส่องสว่างที่เพิ่มขึ้น15%, 30% และ 70% และลดลง 15% และ 30% จากความส่องสว่างของกระดาษ และสีพื้นหลัง 6 สีซึ่งควบคุมระดับความส่องสว่างให้เท่ากันกับกระดาษคือ สีขาว สีแดง สีฟ้า สีเขียว สีม่วง และสีเหลือง ผู้ทดสอบอ่านบทความจำลองที่มีความยาว 10 บรรทัด แบบตัวอักษรภาษาไทย 3 หน้า และภาษาอังกฤษ 3 หน้า บันทึกเวลาที่ผู้ทดสอบใช้ในการหาตัวอักษรที่แทรกอยู่ในบทความจำลองตามที่กำหนดถูกต้องและครบถ้วน พร้อมทั้งตอบแบบสอบถามการเกิดความล้าทางสายตาในระหว่างการอ่าน และแบบสอบถามทั่วไปซึ่งถามเกี่ยวกับความคุ้นเคยในการใช้งานแท็บเล็ตและความชอบสี กลุ่มผู้ทดลองเป็นนักศึกษามหาวิทยาลัยที่มีอายุระหว่าง 18-35 ปี จำนวน 50 คน พบว่า ความสว่างเป็นปัจจัยหลักที่ทำให้เกิดความล้าทางสายตา โดยที่สื่อไม่มีผลต่อระดับความล้าทางสายตาเมื่อความส่องสว่างเท่ากัน ระดับความส่องสว่างที่มีแนวโน้มการเกิดความล้าทางสายตามากที่สุดคือระดับความส่องสว่างที่เพิ่มขึ้น 70% จากระดับความสว่างที่เท่ากับกระดาษ และสีไม่มีผลต่อความล้าทางสายตา สีพื้นหลังที่เหมาะสมต่อการอ่านมากที่สุดคือพื้นหลังสีแดง

ภาควิชา	วิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์	ลายมือชื่อนิสิต .....
สาขาวิชา	เทคโนโลยีทางภาพ	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก .....
ปีการศึกษา	2556	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม .....

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PRAEWPAN YOUYEN: EFFECTS OF BACKGROUND COLOUR ON VISUAL FATIGUE FROM READING ON TABLET. ADVISOR: ASST. PROF. SUCHITRA SUEEPRASAN, Ph.D., CO-ADVISOR: PROF. TETSUYA SATO, Ph.D., 84 pp.

This study aimed to investigate the effect of visual fatigue from reading on a tablet when the background luminance and colour were changed. Six levels of background luminance were tested. They were the level with the same luminance as paper (68 cd/m^2), three levels with 15%, 30% and 70% increased, and two levels with 15% and 30% decreased from the paper luminance under the same lighting condition. Six background colours with the same luminance as paper were tested: white, red, green, blue, yellow and purple. Subjects read pseudo-text containing 10 lines per page. There were two types of pseudo-text: Thai and English; each had 3 pages. The time subjects spent finding the target letters that were randomly inserted in the pseudo-text was recorded. After the reading tasks, subjects rated the degrees of visual fatigue symptoms that possibly occurred during the tasks. They also answered the general questionnaire about the familiarity of using a tablet and colour preference. Fifty university students with 18 – 35 years of age took part in the experiments. The results showed that the main factor that affected visual fatigue was luminance. Reading media did not affect visual fatigue when the luminance was equal. The level of luminance that tended to cause visual fatigue was +70% from the paper luminance. Colour did not affect visual fatigue. Nevertheless, there was a tendency that red background was the most suitable for reading.

Department:	Imaging and Printing Technology	Student's Signature .....
Field of Study:	Imaging Technology	Advisor's Signature .....
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CONTENTS

Page

Page

LIST OF TABLES

PAGE

LIST OF FIGURES

PAGE

Chapter 1

INTRODUCTION

Electronic book (e-book) is becoming popular because of its costs and advantages over printed books. The price of e-books is lower than printed books due to the fact that producing e-books consumes fewer resources. Readers can conveniently read an e-book on any electronic media such as personal computer displays, e-paper and tablets. The use of a tablet as a reading device is ubiquitous because of its ease of use. In addition, reading on a tablet gives the similar feeling to reading on paper, at least more so than reading on a computer screen [1].

Much works have been done on comparing reading performance between computer screens and paper. Muter et al [2] found that reading on paper was 20-30% faster than reading electronic text. Wagner and Sterberg [3] found that reading on a computer screen resulted in more visual fatigue than reading on paper. Blanco and Reiros [4] found that the subjects in their study preferred reading on paper because its luminance was lower than the monitor screen. Brightness of a monitor gave negative effects for the brain and reduced the brain performance [5]. In Spencer's study[6], 71.8% of readers preferred reading on paper. One reason was that interactivity with a mouse was boring. Woody et al.[7] investigated the way to solve the physical

challenge imposed by e-book (visual fatigue, navigation and lumbar pain). They found that reading on tablet was effective to solve these problems. Yuwanakorn [8] investigated differences in visual stress and preference between reading on tablet and paper. The results showed that reading on tablet tended to give more visual stress. This was because the luminance of the tablet was much higher. The subjects felt too much light entering the eyes.

Colour affects human brain system and induces emotion. For example, people feel refreshed when seeing something yellowish, and relaxed when seeing blue[9]. The study by Wilkin et al. [10] showed that colour could reduce visual stress. They investigated the use of colour overlays to improve reading performance of visual stress sensitivity subjects. The overlays were multi-coloured cellophane sheets, which were put on document before reading. Their results showed that when the document background was changed by the overlay, the reading performance was improved.

Visual fatigue or eye fatigue is a part of visual stress. Eye fatigue is caused by any activity that requires intense use of the eyes, such as extended periods of reading. Exposure to bright light or straining to see in dim light can also cause eye fatigue. One of the most common causes of eye fatigue is staring for long periods at computer screens which have two types of display as reflective and transmissive display or any other digital displays. The symptoms of eye fatigue include dry or chronic ploblem,

irritated eyes, difficulty focusing, blurred vision, increased sensitivity to light, and pain in the neck, shoulders, or back [11]. These symptoms can reduce reading performance.

This study aimed to investigate the effect of background colour on visual fatigue from reading on the tablet. Firstly, the visual fatigue was compared between reading on tablet and paper, in which the background luminance of tablet and paper was set to the same level with the aim to investigate the effect of reading media without the influence from different luminance. The effect of luminance was investigated by varying the luminance of the tablet's display from the luminance that reflected from the paper and comparing the visual fatigue from reading on these mediums. Finally, the visual fatigue from different background colours of tablet was investigated. The colour backgrounds varied in hue, but all backgrounds had the same luminance.

1.1 Objectives

1. To compare difference in visual fatigue from reading between tablet and paper.
2. To investigate effects of background luminance when reading on tablet.
3. To investigate effects of background colour when reading on tablet.

1.2 Scope

The tablet used in this study was an Apple iPad4 with retina display. To determine the degree of visual fatigue, 50 university students performed reading tasks in which they read though a given document to find target letters. The reading documents were pseudo-text containing similar letters of the same language. They were in Thai and English. Size and spacing of text were of the same appearance on tablet and paper. Visual fatigue was determined by the speed of searching the target letters in the documents and scores of visual fatigue symptoms the subjects rated after the reading tasks.

Six luminance levels have been set. They were the backgrounds with the same luminance as paper (designated as a reference background), which fully controlled in this study was 68 cd/m_2, -15%, -30%, +15%, +30% and +70% from the reference background under the controlled viewing condition.

Six background colours: white, red, yellow, green, blue and purple, were tested. They all had the same luminance as the reference background.

1.3 Expected outcomes

1. The results of visual fatigue from reading on tablet and paper.
2. The results of visual fatigue from reading on different background luminance of tablet.

3. The results of visual fatigue from reading on different background colours of tablet.

1.4 Contents

This thesis contains five chapters. The first chapter provides the introduction to the study. Chapter 2 explains theories and literatures on the related work. Chapter 3 gives detailed explanations of experiments. Chapter 4 discusses the experimental results, and the conclusion is given in Chapter 5.

Chapter 2

THEORETICAL CONSIDERATIONS AND LITHERATURE REVIEW

2.1 Theoretical considerations

2.1.1 Colour perception

Vision is one of human perception. The process of the human visual perception has 3 components: the eyes, a light source and an object. In the process, light from the light source such as the sun strikes the object and reflects to the eyes, as shown in Figure 2-1.

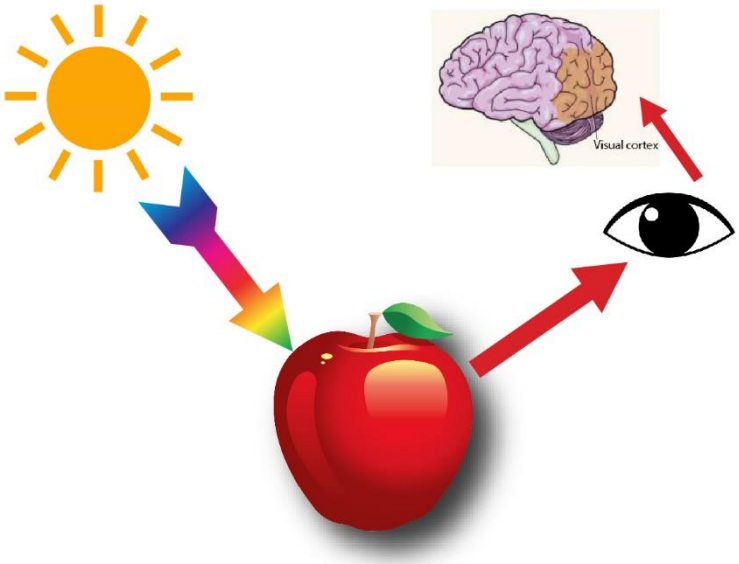

Figure 2-1 : Visual perception

White light consists of the combination of 400-700 nm of wavelengths. Each wavelength perceived as different colours, e.g. 400 nm perceived as blue. Based on colour perception, colour is caused by light from the light source reflection and absorption of the object. When light is incident on the object, the object absorbs

different amounts of colour light. The remaining light enters the eyes, the light that pass through the retina is converting into nerve signal to the visual cortex causing colour perception.

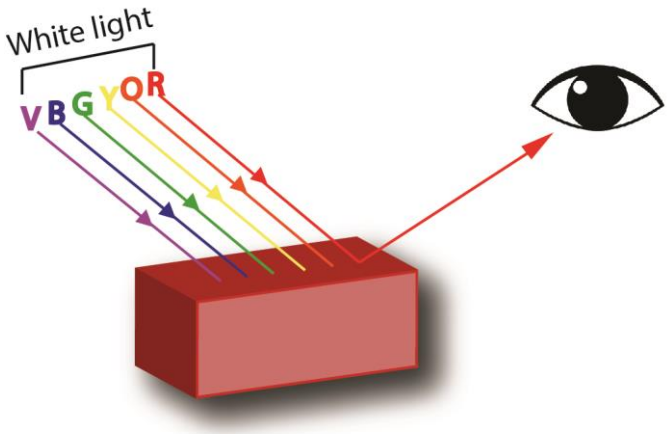

Figure 2-2: Colour perception

Figure 2-2 illustrates how a red object is perceived. When white light falls upon the red object, all colour light but red is absorbed, so only the red light reflects to the eyes. In the case of black objects, light at all wavelengths is absorbed. Conversely, white objects reflect light at all wavelengths, so the objects appear white.

- Luminance

Luminance is a part of photometry. The unit of luminance is candela per square meter (cd/m^2). It explains the intensity of light that passes through or is emitted from a particular area, and falls within a given solid angle. Luminance is the measurable quantity which most closely corresponds to brightness. The luminance indicates how much luminous power will be detected by an eye looking at the surface from a

particular angle of view. Luminance is an indicator of quantities of surface brightness (Figure 2-3)[12].

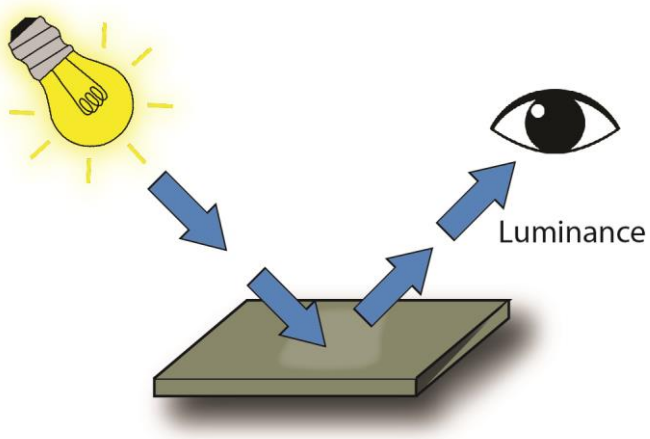

Figure 2-3: Luminance

- Brightness

Brightness is defined as an attribute of a visual perception according to which an area appears to emit, or reflect, more or less light. Brightness is a perceptual attribute, not a measure. It explains the intensity of light that human perceives, for example, dim or bright. The response to brightness is non-linear and complex. It is the sensitivity of rod cells and cone cells on the retina, which is the luminous energy per unit of time impinging on them[12, 13].

2.1.2 Contrast

Contrast is sensitivity of human that define the difference between two or more parts of a field seen. Contrast can be divided into many types such as brightness

contrast, lightness contrast, colour contrast, simultaneous contrast, successive contrast, etc. In this study two types of contrast were used in data analyses.[14]

2.1.2.1 Luminance contrast

The luminance contrast is the ratio between the higher luminance and the lower luminance that define the feature to be detected. The luminance contrast in this study refers to the luminance difference between the target and background, rather than to the overall luminance levels.

Weber contrast was used to compare the differences of each background luminance in the experiment. Weber contrast formula is commonly used in cases of small targets presenting on a large uniform background. The Weber contrast equation is shown in Equation 2-1. For background luminance lower than the text, Weber contrast is positive. On the other hand, for dark text on a light background, Weber contrast is negative. This equation will be used in the later section.[14]

$$C_{Weber} = \frac{(L_{target} - L_{Background})}{L_{Background}} \quad (2\text{-}1)$$

L_{target} = luminance of the target

$L_{background}$ = luminance of the background

Another definition of contrast is Michelson contrast. This formula is commonly used for simple periodic patterns that have bright and dark area alternating as shown in Figure 2-4[15].

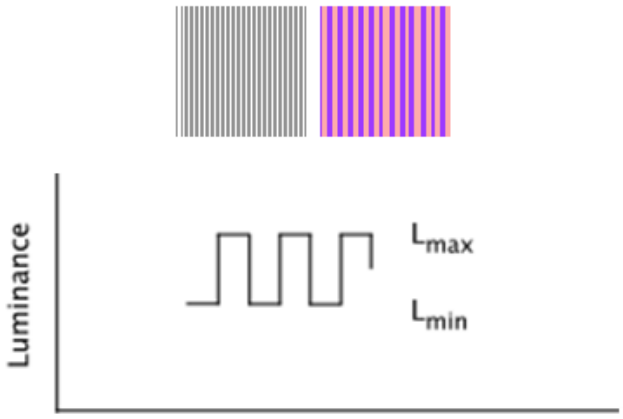

Figure 2-4: Periodic patern[15]

Michelson contrast is defined as:

$$C_{\text{Michelson}} = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \quad (2\text{-}2)$$

L_{max} = maximum luminance

L_{min} = minimum luminance

2.1.2.2 Colour contrast

Colour contrast is the difference between two colours or more in the same field seen. In this study six background colours could be of equal luminance, but their colour (chroma) is different such colour contrast can be described by a distance in any

colour spaces and a colour difference. The colour contrast can be described by a distance in a suitable chromaticity system. Figure 2-4 shows the distance between two colours in CIELAB colour space, indicating the colour difference. The International Commission on Illumination (CIE) uses (ΔE^*_{ab}) to refer to the difference between two colours. Delta (Δ) means difference, and E refers to “Empfindung” in German, which means "sensation". The formula to calculate ΔE^*_{ab} value is given in Equation 2-3.

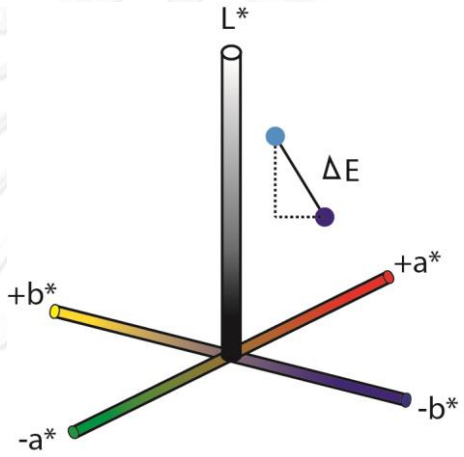

Figure 2-5 : Distance of two colours in CIELAB colour space (ΔE_{ab})

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \quad (2\text{-}3)$$

L_1^* = L* value of sample 1

a_1^* = a* value of sample 1

b_1^* = b* value of sample 1

L_2^* = L* value of sample 2

a_2^* = a* value of sample 2

b_2^* = b* value of sample 2

Table 2-1: The following delta E values are valid universally

Delta E value	Meaning
0 – 1	A normally invisible difference
1 – 2	Very small difference, only obvious to a trained eye
2 - 3.5	Medium difference, also obvious to an untrained eye
3.5 – 5	An obvious difference
More than 6	A very obvious difference

2.1.3 Visual Fatigue

Fatigue means tiredness of the body, which reduces the body effectiveness. Hence, the visual fatigue refers to all of the uncomfortable symptoms that occur after the eyes getting tired, e.g. sore eyes, dry or irritated eyes, blurred vision, etc. Visual fatigue is a part of visual stress. The main cause of visual fatigue is the eye muscles. When looking at small or unclear objects, the ciliary muscle stretches or shrinks for a long time in an attempt to focus the images onto the retina, causing the muscular spasm (sudden muscular contraction) [11].

Symptom of visual fatigue

Most people who suffer from visual fatigue are office workers. They use computers for a long time per day. Visual fatigue refers to reading difficulty. The

symptoms include dry and irritated eyes, sore eyes, blurred vision, doubling of vision, slow refocusing, and neck & backache.

- Dry and irritated eyes

This symptom is caused from tears, which has functions to moisten and clean off the eye surface by blinking of the eyelids. When concentrating on working tasks, the blinking rate is slower and the eye movement is in a narrow range, resulting in an increased rate of tear evaporation.

- Sore eyes

Sore eyes are an unpleasant sensation in or around one or both eyes. Sore eyes are a side effect of dry and irritated eyes. When the conjunctiva is dry, the next symptom a person will experience is sore eyes.

- Blurred vision

Figure 2-6 shows an example of blurred vision. A person who experiences this symptom sees unclear pictures or text, especially at the edges of object. When looking at very small letters, the letters cannot be distinguished.

Figure 2-6: Blurred vision

- Doubling of vision

This symptom is different from blurred vision, in which the text or picture is not unshaped but doubled (Figure 2-7). A person who suffers from this symptom sees two pictures overlapping.

Figure 2-7: Doubling vision

- Slow refocusing

When blurred vision and doubling vision occur, the visual system is trying to make the pictures look clear. Thus, refocusing is slower than normal viewing.

- Neck & Backache

Vision is the most important sensation of human. Hence, when the visual system is malfunctioning, the body will adjust to be compatible with the visual system, for example leaning closer or moving away from screens. When the body is stuck in uncomfortable postures for a long time, it causes neck and backache.

2.1.4 Reading test

To investigate visual fatigue, the symptoms of visual fatigue must be recorded. The basic method of recording the data is a visual fatigue questionnaire that asks about the level of symptoms occur. To do so, a situation in which the visual fatigue occurs must be simulated. The popular situation is a reading test. Many studies created various reading tests to measure the visual fatigue level.

- Wilkins' rate of reading test®

This reading test aims at studying the reading performance of children with poor reading ability [10]. This test consists of simple words commonly found in children's reading books. The words are placed to form a paragraph that has 10 lines. Each line has 15 words, which is meaningless, as shown in Figure 2-8. The reading task is to read aloud as rapidly and correctly as possible. The reading time is recorded.

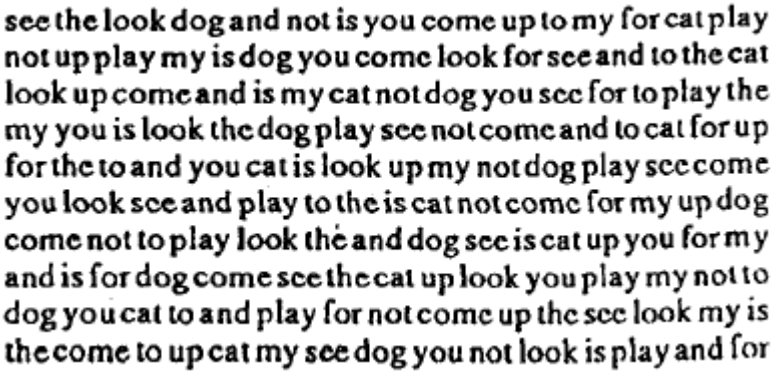
see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
look up come and is my cat not dog you see for to play the
my you is look the dog play see not come and to cat for up
for the to and you cat is look up my not dog play see come
you look see and play to the is cat not come for my up dog
come not to play look the and dog see is cat up you for my
and is for dog come see the cat up look you play my not to
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for

Figure 2-8: Wilkins' rate of reading test®[10]

- Visual stress screener

The visual stress screener [16] is similar to word games. The reading task is to locate a three-letter word such as "HAD", "FIT" that is randomly hidden in the word

matrix (Figure 2-8). The reading test is divided into 2 types: one for primary school children and the other for secondary school children. The difference between the tests is the matrix size. For primary school children the matrix size is 18x15 letters, and for secondary school children the matrix size is 21x26 letters. The letter matrix is put on different backgrounds: visually unstressful and visually stressful backgrounds. The visually unstressful background is a grey background, as shown in Figure 2-8 (left). The visually stressful is a black and white horizontally striped background, as shown in Figure 2-9 (right). The target word is shown above the matrix. The search time is recorded.

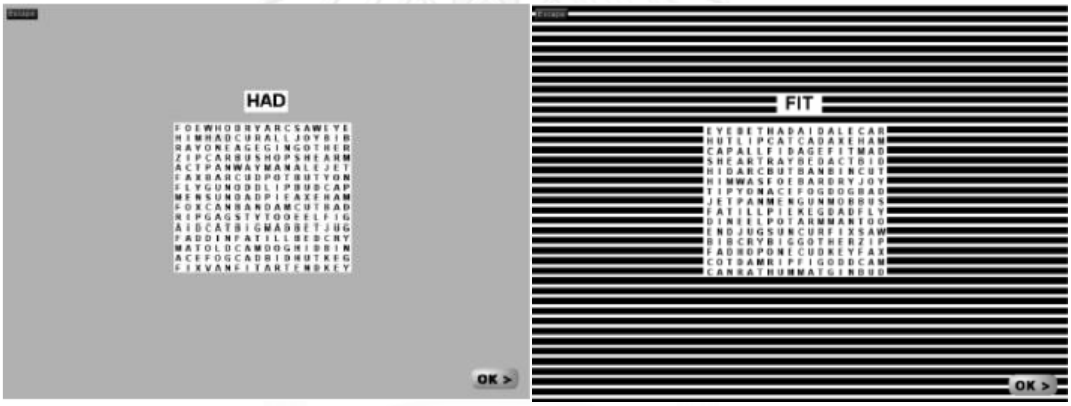

Figure 2-9: Visual stress screener test[16]

2.2 Literature review

Previous studies investigated the effects of visual fatigue from reading on various reading media such as paper, computer displays, electronics paper and tablets. Lin et al. [17] studied about visual fatigue from reading on simulated flexible electronic paper under various surface treatments and ambient illumination conditions. In the reading test, the subjects' task was to search for the target letters on pseudo-text under various conditions. The factors of surface treatments consisted of 3 surfaces: anti-glare, anti-reflection and non-treatment surface. The factors of bending curvature consisted of 3 different radii of curvature: -10 cm, plane and +10 cm. There were 3 factors of illumination level: 200 lux, 1500 lux and 8000 lux. The reading task was to find the letter "A", "X" and "Y" on pseudo-text as quickly and correctly as possible. The results of ANOVA showed that the suitable reading condition was anti-glare surface under ambient lighting of 1500 lux. The curvature did not affect visual fatigue. The results also showed that the amount of light entering the eyes during reading was the main factor. The subjects performed best with glare-free surface under the medium illumination level.

Yuwanakorn [8] investigated the differences in visual stress and preference in reading between tablet and paper. In the reading task, subjects were asked to find misspelled words from 3 types of reading documents: information, news and tale. Each document contained 7 misspelled words. The subjects' task was to read through the document and search for the misspelled words. The results of reading times and scores of visual stress symptoms showed that reading on tablet tended to have higher visual stress than reading on paper. The luminance of the tablet was much higher than paper

luminance. Thus, it was possible that the difference in luminance caused the difference in visual stress.

Wilkins et al. [10] found that the background colour could reduce visual stress. They changed the background colour of the reading document by colour overlays. The overlays were multi-coloured cellophane sheets, which were put on document before reading. They conducted the reading tests on 77 children in year 4, 5 and 6 in primary school. The speeds of reading with and without overlays were compared. The results showed that when the background colour was changed by the use of overlays, the reading performance improved, with the reduction of visual fatigue.

Chapter 3

METHODOLOGY

3.1 Apparatus

3.1.1 Laser printer

Model:	Brother HL-110
Toner :	TN-1000
Printing Resolution :	300 dpi

3.1.2 Paper

Thickness:	106 mil
Basis weight:	82.67 gsm
Opacity:	96.92
ISO brightness:	101.27%

3.1.3 E-book reader

Model:	iPad generation 4
Storage:	16 GB (WiFi+3G)
Display:	9.7 inch
Colour bit depth:	24-bits
Display resolution:	2048x1536 pixel at 264 ppi

3.1.4 Spectroradiometer

Model:	Konica Minolta CS-1000A

Lens :	Standard lens
Wavelength range:	380-780 nm
Spectral bandwidth:	5 nm
Display wavelength bandwidth: 1 nm	
Wavelength resolution:	0.9 nm/pixel
Wavelength precision:	±0.3 nm
	(Median wavelength: 546.1)
Luminance accuracy:	±2%, ±1 digit
Chromaticity accuracy:	x±0.0015, y±0.001
Luminance range:	1 – 8,000 cd/m^2
Luminance repeatability:	±0.1%, ±1 digit
Colour gamut:	Shown in Appendix A

3.1.5 Software Application

Adobe Photoshop:	Version CS6
Adobe Illustrator:	Version CS6
Adobe Acrobat Reader:	Version 10.4.3(69879)
Microsoft Excel:	Version 2013

3.2Method

In this study, the influence of background colour and luminance on visual fatigue caused by reading on tablet was investigated. To this end, subjects were asked

to perform visual tasks in which their speeds of searching target letters were recorded and degrees of visual fatigue were rated. The details of the experimental method are given in this section. The method is divided into three parts: experimental preparation (Section 3.2.1), experimental procedure (Section 3.2.2) and data analysis (Section 3.2.3).

3.2.1 Experimental preparation

Before subjects conducting visual tasks, experimental device and documents need to be prepared. This section describes about preparation of questionnaires used for obtaining subjects' information and tendency of visual fatigue after the visual tasks (Section 3.2.1.1). It also includes the preparation of documents for the visual tasks (Section 3.2.1.2). Finally, the preparation of reading mediums (paper and tablet) whereby colour and luminance of background were set up is explained in Section 3.2.1.3.

3.2.1.1 Questionnaire

Two types of questionnaires were used in this study. They were a general questionnaire and a visual fatigue questionnaire.

- General questionnaire

The general questionnaire was designed to obtain information about life style of the subjects in respect of familiarity of using tablet and/or e-book reader and

preference background colour for reading. The purpose of general questionnaire was to know the subjects' familiarity with respect of reading on tablet or other electronic reading device to avoid the difference of search time between the subjects who familiarity with reading on tablet and the subjects who unfamiliarity. Each part of general questionnaire that asking about colour preferences, this part was to compare the result of search time on various background and result of favorite colour, dislike colour to avoid the bias of color preference. This questionnaire was given to every subject before the visual experiments was conducted. An example of general questionnaire can be found in Appendix B.

- Visual fatigue questionnaire

The visual fatigue questionnaire was used to evaluate the degree of visual fatigue occurred after each visual experiment. It was given to subjects after completing each of background colour/luminance for the given experiment. In this questionnaire, subjects were asked to rate the degree of six possible visual fatigue symptoms including dry and irritated eyes, sore eyes, blurred vision, slow refocusing, neck and backache and doubling of vision. The rating scale ranged from 0 to 5, representing the degree of each symptom as follows:

0 represented "no, not at all"

1 represented "yes, a little"

2 represented “yes, quite a few”

3 represented “yes, moderate”

4 represented “yes, rather”

5 represented “yes, very much”

An example of the visual fatigue questionnaire is given in Appendix C.

3.2.1.2 Reading documents

In order to evaluate visual fatigue caused by reading, subjects need to perform a reading task for a certain period. However, instead of using actual text, pseudo-text that was formed with the same letters was used. The pseudo-text contained 10 lines of similar letters. Each line had 37 letters and was 108 mm in length. The font type was Cordia new, 16 points. The space between each line was set to 1.5 of line spacing, making the height of the 10-line text of 60 mm. The pseudo-text was categorized according to language – English and Thai. Both types were created with the same concept, that is at first glance, the pseudo-text looks like it containing only the same letters arranged in a line (Figure 3-1). In addition, 10 other letters, designated as target letter, having similar shape to the main letter were randomly inserted in the text. For English pseudo-text, the letter M was the main letter, and N was the target letter (Figure 3-1a). For Thai pseudo-text, the letter ค was the main letter, and ด was the target letter (Figure 3-1b). The concept of pseudo-text was employed to simulate the reading task. The subjects read through the text to locate all 10 target letters. In so

doing, the boredom of having to read actual text that is not of interest to the subjects can be avoided, and it can keep the subjects' attention during the experiments.

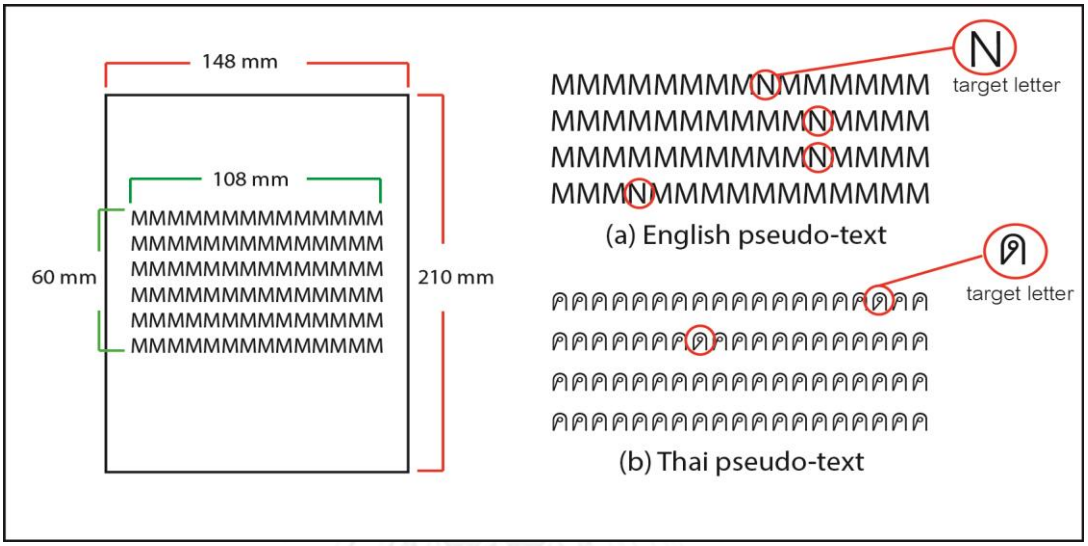

Figure 3-1 : Examples of reading documents.

One set of reading documents consisted of three pages of pseudo-text. The positions of target letters were randomized and varied for each page. Moreover, different sets of reading documents were prepared for varying backgrounds of tablet, so that the subjects would not be able to locate the target letters from their memory. Thus, 12 sets of reading documents were prepared for 11 backgrounds of tablet and one background of paper. Each page of the reading documents on tablet was presented in the centre of the display screen. In the case of paper, the pseudo-text was presented in the centre of A5-sized paper, which is approximately the same size as the tablet screen.

3.2.1.3 Reading medium

This study investigated the effect of background against which text is presented on visual fatigue when reading on tablet in comparison with when reading on paper. The background of tablet was varied from paper in two aspects: luminance and colour. In order to do this, firstly, we need to measure the luminance of the white paper as a reference luminance using a spectroradiometer under a controlled viewing condition (to be explained in Section 3.2.2.2). Note that the type of paper used in the experiment was photocopy paper commonly used in office. This type of paper contains fluorescent dye and is slightly bluish white. The mesured luminance of the paper was 68.00 cd/m^2. The background of tablet was then set up to have the same luminance as paper within ±1% tolerance. This was done by adjusting pixel values (RGB values) of a page background in Photoshop and saving it as PDF to open with Acrobat Reader on the tablet. Figure 3-2 illustrates the measuring configuration of tablet luminance. It is worth noting that the position of tablet and paper when measured and when subjects preforming a reading task was the same. For calculation of Weber's luminance contrast, the colour of text need to measure. Hence, the black squares that have the same pixel value as text was simulate and adjusted on various background to measuring.

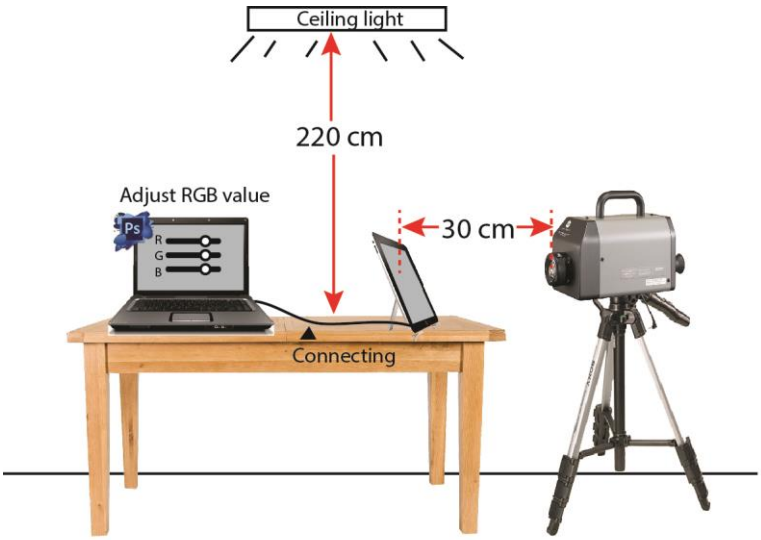

Figure 3-2: Measuring configuration.

- Luminance of background

Six levels of luminance of tablet background were investigated in this study. They were the levels that had the same luminance as paper, three levels of increased luminance: 15%, 30% and 70% from the paper, and two levels of decreased luminance: 15% and 30%. Table 3-1 shows the luminance values, along with colour values, of paper and tablet backgrounds. To achieve the desired luminance (all within ±1% error), RGB values were adjusted to the same number, so that all backgrounds would appear as white with different luminance. Figure 3-3 shows the background and text colours in xy chromaticity diagram.

Table 3-1: Colour values of backgrounds varying in luminance.

	Luminance (cd/m^2)	X	y	R	G	B
1. Paper	68.00	0.2980	0.3395			
2. Tablet						
■ the same luminance as paper	67.54	0.2933	0.3211	205	205	205
■ +15% from luminance of paper	78.70	0.2937	0.3215	220	220	220
■ +30% from luminance of paper	87.84	0.2941	0.3218	230	230	230
■ +70% from luminance of paper (Max)	113.11	0.2962	0.3231	255	255	255
■ -15% from luminance of paper	56.86	0.2933	0.3212	190	190	190
■ -30% from luminance of paper	47.86	0.2936	0.3212	175	175	175

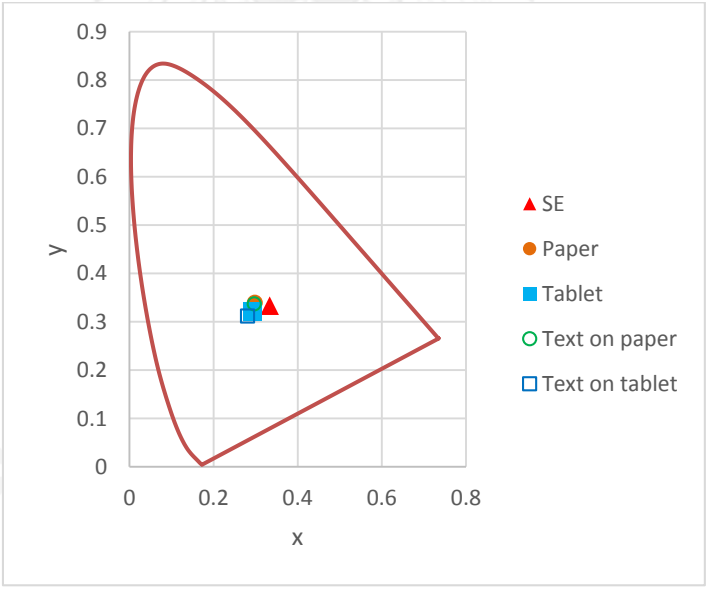

Figure 3-3: Colour of background and text on tablet and paper in chromaticity diagram.

- Colour of background

To investigate the effect of background colour, the RGB values were adjusted such that all colour backgrounds had the same luminance levels (68.00 ± 0.68, i.e. ±1% tolerance of paper luminance) but were different in hue. Six backgrounds under study were white, red, green, blue and purple, and their colour values can be found in Table 3–2.

In summary, there were 11 different backgrounds of tablet (stimuli) under investigation, as shown in Figure 3-4.

Table 3-2: Colour values of backgrounds varying in colour.

Luminance	Luminance (cd/m^2)	x	y	R	G	B	L*	a*	b*	colour
1. White	68.00	0.2933	0.3211	205	205	205	85.78	-5.76	-5.83	
2. Red	68.63	0.3447	0.3246	250	190	190	86.32	16.59	3.86	
3. Green	68.00	0.2896	0.4435	134	228	134	86.01	-51.72	31.55	
4. Blue	67.39	0.2603	0.2673	200	200	250	85.70	3.56	-30.72	
5. Purple	68.14	0.2792	0.2568	230	190	255	86.08	20.16	-32.36	
6. Yellow	67.38	0.3708	0.4469	210	210	100	85.70	-19.40	48.93	

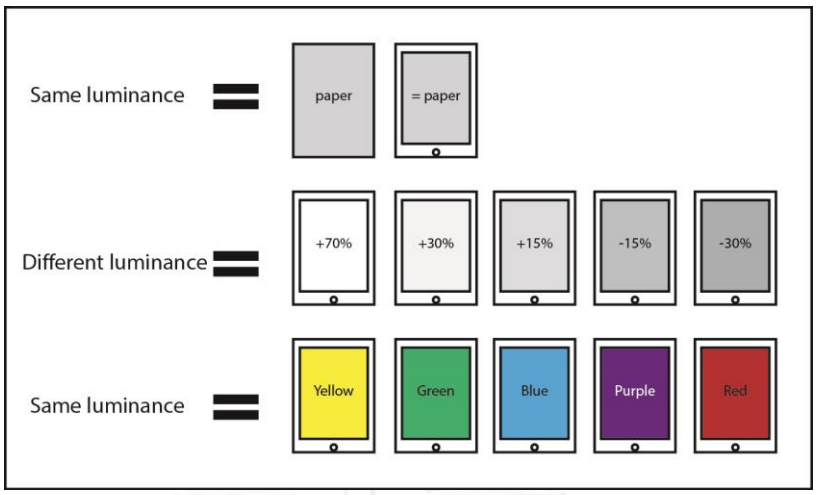

Figure 3-4: Summary of backgrounds used in the experiments.

3.2.2 Experimental procedure

Visual experiments in which subjects read through a series of pseudo-text to find target letters were carried out to investigate subjects' tendencies towards visual fatigue with changing backgrounds. The level of visual fatigue was analyzed by means of questionnaire and search time. This section provides demographic information of subjects (Section 3.2.2.1), details of viewing conditions for the visual experiments (Section 3.2.2.2) and the procedure of visual experiments (Section 3.2.2.3).

3.2.2.1 Subjects

Fifty university students (25 males and 25 females) participated in the visual experiments. The age of subjects ranged from 18-35 years old with an average of 26 years and a standard deviation of 2.5 years. They all had normal colour vision and were a regular reader.

3.2.2.2 Viewing condition

To simulate the lighting condition that tablet users normally use for reading, the present study set up an experimental room where the room lights were lit, and the light sources were cool white fluorescent tubes. This setting was different from the previous study [8] in which the visual experiments were conducted in a darkened room, and the reading tasks were performed in a viewing cabinet under D65 simulators. Hence, the viewing condition in this study was more natural to the subjects. During the reading tasks, subjects held the tablet/paper in a way that its plane was approximately 20 degrees to the surface plane (Figure 3-5), whereby the gloss reflection was not observed. The incident light from the ceiling on the tablet/paper plane had illuminance of 400.8 lux. The viewing distance approximately 50 cm. The subjects were allowed to wear visual aids (reading glasses or contact lens) as they usually do for reading.

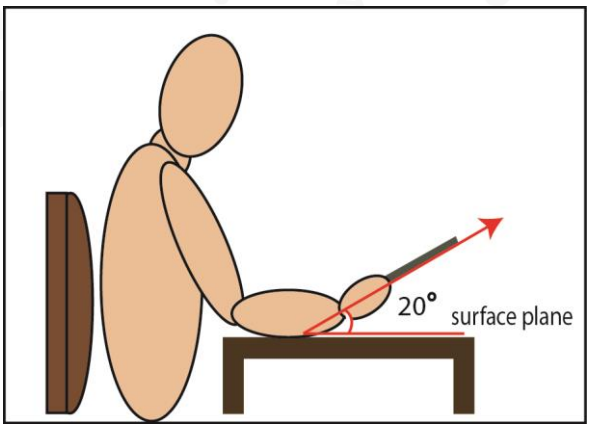

Figure 3-5: Viewing angle.

3.2.2.3 Visual experiment

In visual experiments, the subjects' task was to search the target letters in the reading documents on tablet and paper. Figure 3-6 shows an overview of the experimental process. Firstly, subjects filled in the general questionnaire asking about the familiarity of tablet, lifestyle and colour preference. This questionnaire was given to the subjects just once before the reading task commenced. Having done so, the subjects were trained how to use tablet for the reading task. After that, the subjects could begin the reading tasks.

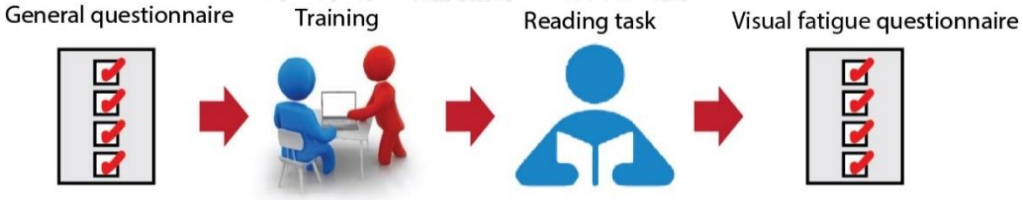

Figure 3-6: Overview of the experimental process.

- Reading task

In the reading tasks, subjects looked for the target letters in the pseudo-text, which was mentioned in Section 3.2.1.2. The process of reading tasks is summarised in Figure 3-7. First, subjects needed to adapt their eyes to the experimental room for at least 5 minutes. After that, one set of reading documents (consisting of 3 pages of Thai pseudo-text and 3 pages of English pseudo-text) on one particular background was

given to the subjects. The subjects read through the text to find 10 target letters on each page. Once the target letter was found, it had to be circled with a stylus pen. After completing for each page, the search time was recorded. Subjects had to finish the reading tasks on one background in one session and then answered the visual fatigue questionnaire, asking about symptoms of visual fatigue. Before continuing the reading tasks on another background, the subjects must rest their eyes for at least 15 minutes. However, the subjects were not allowed to do the reading tasks for more than 3 backgrounds per day. Every subject started the reading tasks on paper, whereas the sequence of tablet backgrounds was randomised for each subject.

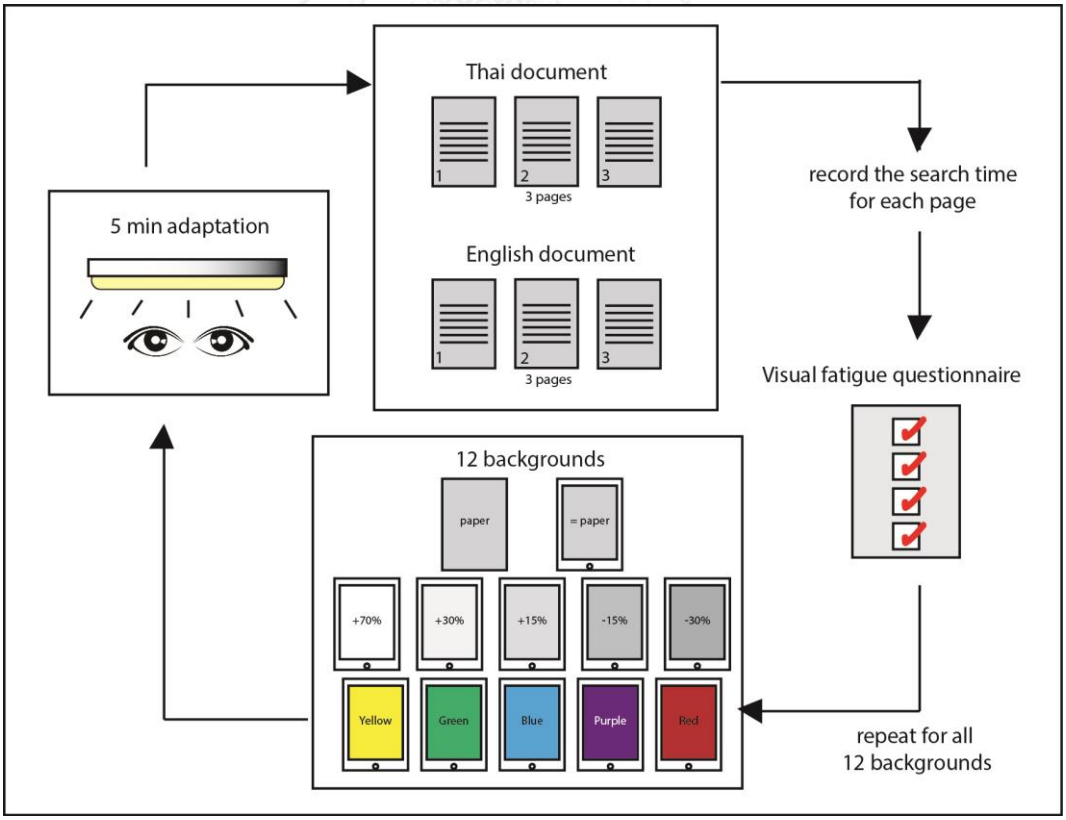

Figure 3-7: Reading task process.

3.2.3 Data analysis

1. One-way analysis of variance (ANOVA) was employed to determine significant differences of search time between different reading media.

2. One-way analysis of variance (ANOVA) was employed to determine significant differences of search time between different background luminance.

3. One-way analysis of variance (ANOVA) was employed to determine significant differences of search time between different background colour.

4. The average of visual fatigue symptoms were investigated from 50 subject.

5. From the general questionnaire, percentage of familiarity with tablet and colour preference and other information about the subjects' opinion were investigated from 50 subjects.

Chapter 4

RESULTS AND DISCUSSIONS

This study investigated the visual fatigue when reading on paper and different tablet backgrounds. When reading, subjects' task was to find the target letters hidden in the text. After completing the task, subjects rated the degree of visual fatigue symptoms that occurred during the task. Hence, the results of visual fatigue are determined by search time and score of visual fatigue.

- Comparing the results of search time from different document types

In the reading task, subjects read two types of document: Thai and English texts. Subject read three successive pages of one type of document, and the search time was recorded when finishing each page. The time subjects used to search for the target letters in the text was taken as an indicator of visual fatigue. If the subjects spent long time in searching the target letters, it is likely that the subjects experienced some forms of visual fatigue, which slow down the speed of reading. Thus the results of search time were averaged from all 50 subjects for both Thai and English documents. Table 4-1 shows the average of search time on paper. Note that these results were search times of 3 pages combined.

From Table 4-1, it can be seen that the search time for Thai text was much higher than that for English text. This is possibly because the target letter in Thai text is much more similar to the main letter than the English text, making it more difficult for the subjects to distinguish between the letters. Since the subjects spent distinctively longer time on Thai text, it is likely that they were more inclined to experience visual fatigue from reading Thai text than English text. Hence, the analysis of visual fatigue results from search time is separated for Thai and English text.

Table 4-1: Search time on paper

Reading document	Search time (second)
Thai	444
English	273

- Comparing the results of search time on each page

Each page of the document (both Thai and English pattern) contained 10 target letters. Once all 10 target letters were found, the search time was recorded. The averages of search time from 50 subjects for the first, second, and third page were calculated and compared. This was done under an assumption that the long reading time causes visual fatigue; thus, the search time should increase from the proceeding page. Figure 4-1 shows the differences of search time on paper for each page, $\Delta T1$

means the different of search time between first page and second page, ΔT2 means the different of search time between second page and third page It was found that, the differences between each page were very small. Therefore, One-way ANOVA, which is a hypothesis test, was employed to investigate the significance of search time between each page. The Hypotheses were as follows:

H_0: The search times of each page are not different.

H_1: The search times of each page are different.

The level of significant difference in which the null hypothesis is rejected is 0.05. Therefore, the null hypothesis will be rejected if F-value is higher than F-critical with 95% confidence. The results are shown in Table 4-2.

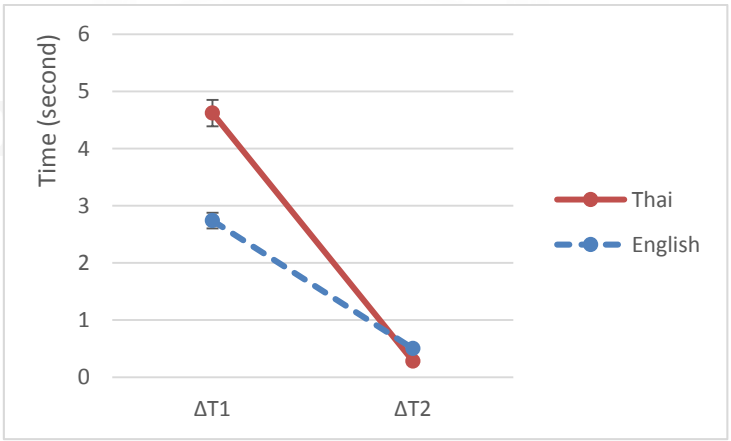

Figure 4-1: The differences of search time between each page. The error bars indicates the 95% confidence interval.

Table 4-2: One-way ANOVA of search time between each page.

Reading document	df	F	F critical	P - value
Thai	2	0.13	3.06	0.88
English	2	0.06	3.06	0.94

The results from One-way ANOVA showed that the search times between each page were not significantly different for both document types. This could be because the reading times for each page were not long enough to cause significant degrees of visual fatigue. Even for Thai document that subjects spent around 2 minutes to search for the target letters while spending around 1 minute for English document for the first page, the time was not long enough, so the search times for the subsequent pages were not affected by increasing degrees of visual fatigue.

Based on the results of search time on paper, which showed that the search times for Thai and English documents were significantly different, and the search time between 3 pages were not, the results for the following sections are analysed according to the document types, and the total search times (combined from 3 pages) are used.

4.1Effect of reading media on visual fatigue

4.1.1 Results of search time

This section compares differences in visual fatigue between reading from tablet and paper. The two reading media were controlled to have the same luminance for background (68± 0.68 cd/m^2). However, the colour of background and the luminance and colour of black text on media white background were natural to the characters of the reading media. The CIE L*a*b* values of background and text on tablet and paper, together with contrast (colour difference in this case) between background and text, are given in Table 4-3

Table 4-3: L*a*b*and contrast values of tablet and paper.

	Background			Text			Colour
	L*	a*	b*	L*	a*	b*	contrast
Paper	86.01	-11.52	1.15	28.20	-4.68	0.00	58.22
Tablet	85.78	-5.76	-5.83	21.54	-2.79	-4.08	64.33

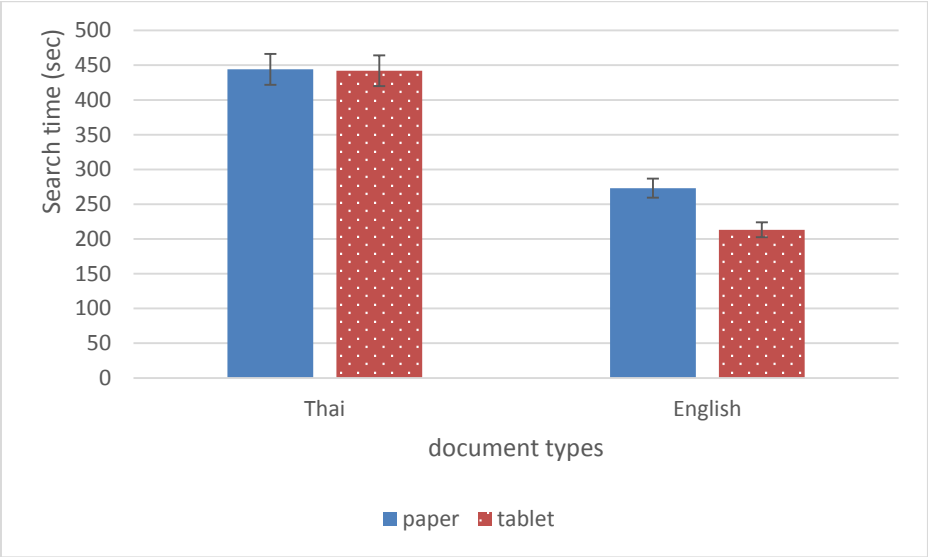

Figure 4-2: Search time on paper and tablet.

From Figure 4-3, the results show that the search time for Thai document reading on tablet (442 seconds) was almost the same as on paper (444 seconds). On the other hand, the search time on tablet for English document was noticeably lower (213 seconds) than on paper (273 seconds). In other words, the subjects spent less time in searching the target letters on tablet than on paper for English but spent about the same time for Thai. In addition, the search time for Thai was about twice as much as the search time for English. This is possibly because English patterns are easier to distinguish than Thai patterns. Thus, when searching for Thai target letters, the reading media had little influence, compared to the influence of the reading task. In contrast, the reading media had an impact on the search time when the reading task was easy. Some characteristics of tablet would help speeding up the search time. Some subjects commented that the text on paper was not as clear as the text on tablet. However,

the text on paper was printed with a laser printer at 300 dpi from a PDF file, while the text on tablet was displayed at 264 ppi from the same type of file. Therefore, the text on both media must be of the same quality. The reason why the subjects found the difference in clearness of text between paper and tablet could be from the contrast between text and background. The contrast on tablet (64.33) was higher than on paper (58.22), which possibly resulted in clearer and sharper text. With the clearer text, the subjects could identify the target letters more easily. Nevertheless, when the target letters were very hard to find, as in the case of Thai document, the slightly cleaner text could not make a difference.

To investigate the significance of the difference of search times between tablet and paper, one-way ANOVA was employed (Table 4-4). The result indicated that the search times on paper and tablet were not significantly different at a 95% confidence level for Thai reading document, but for English reading document the result was significantly different at a 95% confidence level. Since the background luminance of paper and tablet were equal, there was little difference in terms of the amount of light entering the eyes. The significance difference of search time for English document revealed that contrast was another factor that could affect visual fatigue, as the long search time could result from an inclination to visual fatigue.

Table 4-4: One-way ANOVA of search time between paper and tablet.

Reading document	df	F	F critical	P - value
Thai	1	0.00	3.94	0.94
English	1	6.27	3.94	0.01*

Note: *significantly different

4.1.2 Results from visual fatigue questionnaire

The questionnaire was the order tool to determine a tendency of visual fatigue. After the reading task, the subjects rated the degree of visual fatigue symptoms, including dry and irritated eyes, sore eyes, blurred vision, slow refocusing, neck and backache and doubling of vision. Each symptom had 6 levels of a sensitivity scale, i.e. levels 0–5, which 0 represented “no, not at all”, and 1-4 represented an increasing degree, until 5 representing “yes, very much”.

Figure 4-4 shows the scores of visual fatigue symptoms, averaged from 50 subjects when reading on tablet and paper. It was found that 2 out of 6 symptoms showed no difference between reading on tablet and paper. They were slow refocusing and sore eyes. It could be that the reading time, no more than 12 minutes, was not long enough to yield any difference between the two reading media in these symptoms.

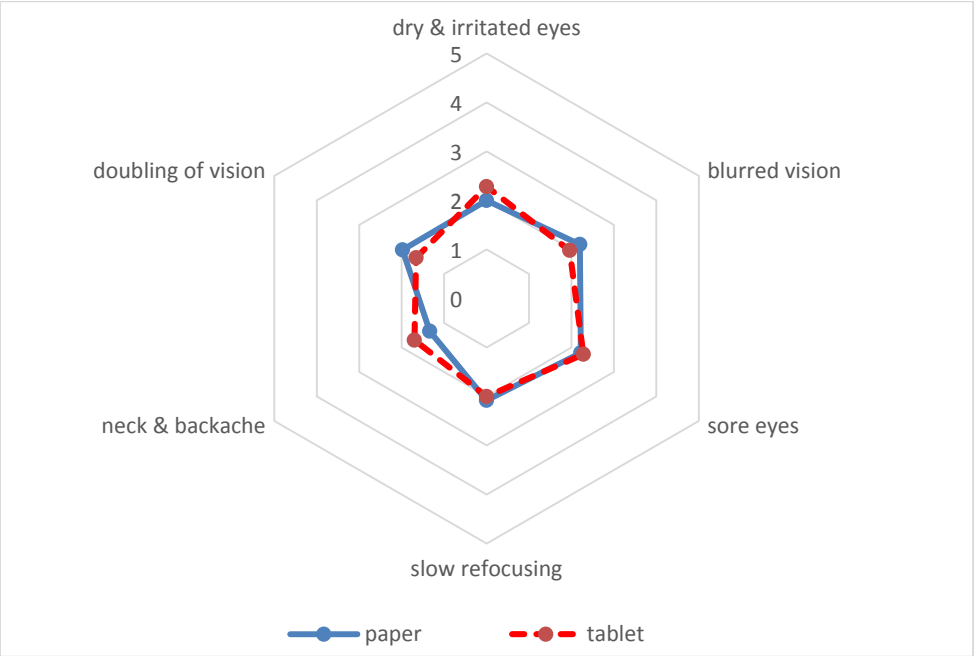

Figure 4-3: Scores of visual fatigue symptoms.

Reading on tablet had higher scores than reading on paper in two symptoms. They were dry and irritated eyes and neck and backache. However, the scores of dry and irritated eyes for tablet and paper were only slightly different. This is possibly because the amount of light entering the eyes was equivalent. In the case of neck and backache, the difference was more pronounced. It is possibly because of weight. The subjects had to hold the tablet and paper during the reading task. Since tablet is heavier than paper, the subjects could feel this effect on neck and backache.

Doubling of vision and blurred vision were the two symptoms that reading on paper had higher scores than tablet. These results conform with the results of search time, in which paper gave longer search time. Nevertheless, the overall scores of all

symptoms were not high, approximately 2 from the maximum score of 5, which might be because the reading time was too short to cause severe symptoms.

4.2 Effect of background luminance on visual fatigue

Previous studies comparing reading performance and visual fatigue between paper and displays showed that paper was a superior reading media [2, 8]. However, the results from previous sections in this study showed that when paper and tablet had the same luminance of text background, they provided little difference regarding reading performance and visual fatigue. Therefore, to further investigate the effect of background luminance, the background of tablet was varied and the results of search time and visual fatigue scores for different background luminance were compared.

4.2.1 Results of search time

The tablet background that the same luminance as paper was set as a reference background (68 ± 0.68 cd/m^2). The other backgrounds under study had luminance of 15%, 30%, and 70% increased from the reference, and 15% and 30% decreased from the reference. Thus, there were 6 levels of background luminance under study. The results of search time averaged from 50 subjects are shown in Figure 4-5.

Table 4-5: Luminance and contrast of varying background luminance.

	-30%	-15%	Ref	+15%	+30%	+70%
Background luminance	48.08	58.38	67.54	78.70	89.28	113.11
Text luminance	2.98	3.10	3.39	3.44	3.31	3.31
Luminance Contrast (Weber's)	-0.9380	-0.9469	-0.9498	-0.9563	-0.9629	-0.9707

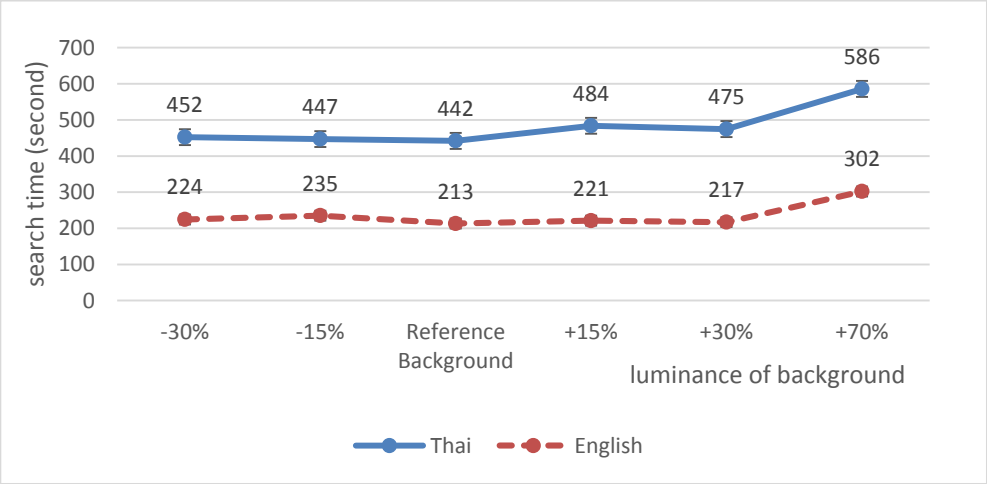

Figure 4-4: The averages of search time for different background luminance.

- Thai reading document

From Figure 4-5 the background that had the fastest search time was the reference background, followed by -15% and -30% luminance, respectively. Note that,

for Thai reading document, the search time of the reference background was not significantly different from that of paper with the same luminance. The results in Figure 4-5 showed the tendency that the backgrounds with luminance deviated from the reference gave longer search times for both decreasing and increasing luminance directions. Nevertheless, the subjects tended to spend longer time to search for the target letters when the background luminance increased than when it decreased. The luminance contrast (Weber contrast, Equation 2.1) was in ascending order from low luminance to high luminance background (Table 4-5). This means that both luminance and contrast affected the speed of finding the target letters. The subjects spent less time on searching with low luminance background, but the luminance should not be too low to cause low contrast between text and background. This is because low contrast background will make the text hard to distinguish from the background. The subjects spent the most time with +70% luminance of background (maximum luminance). It is possible that there was too much light entering the eyes, which irritated the subjects' eyes and reduced the speed of reading.

- English reading document

From Figure 4-5, it was found that the results for English reading document also showed a similar trend to Thai document: the background that gave the fastest search time was the reference background. The subjects spent more time to search for the

target letters on brighter backgrounds. When the background luminance was at maximum (+70%), the subjects spent the longest time.

Even though both Thai and English document showed the trend of increasing search time with increasing background luminance and the changing of contrast, the results were not much different between backgrounds, except for the maximum luminance background. To investigate the significance of search time, one-way ANOVA was employed. The results are summarised in Tabel 4-6.

Table 4-6: One-way ANOVA of search time between different background luminance.

Reading document	df	F	F critical	P - value
Thai	5	6.86	2.24	0.00*
English	5	4.95	2.24	0.00*

Note: *significantly different

The results from one-way ANOVA for search time between different background luminance were significantly different at a 95% confidence for both Thai and English reading documents. That means luminance of backgrounds affected search time. Hence, the next section will investigate which backgrounds are different from the other backgrounds.

4.2.2 Comparing the search time between each background luminance.

Each background was paired with the other backgrounds to find the backgrounds that gave the different search time. The independent t-test, which is a hypothesis test for means between two datasets was employed. The hypotheses are as follows:

H_0: The search times from two different backgrounds are equal.

H_1: The search times from two different backgrounds are not equal.

The level of significance difference in which the null hypothesis is rejected is 0.05. The null hypothesis will be rejected if t-value is more than t-critical with 95% confidence. The results are shown in Table 4-7.Note that only the pairs of backgrounds that showed significance difference are shown in Table 4-7. The absent pairs, for example the reference background against +30% background, had the same search time (or not significantly different) on both backgrounds. For furthur information. Rest of the results are shown in Appendix D.

Table 4-7: The independent t-test of search time between each background.

Reading document	t-value	t critical	Sig. (2tail)
Thai reading document			
1. +70% and -30%	5.24	1.98	0.00*
2. +70% and -15%	5.45	1.98	0.00*
3. +70% and reference background	5.64	1.98	0.00*
4. +70% and +15%	3.91	1.98	0.00*
5. +70% and +30%	3.94	1.98	0.00*
English reading document			
1. +70% and -30%	4.04	1.98	0.00*
2. +70% and -15%	3.93	1.98	0.00*
3. +70% and reference background	4.53	1.98	0.00*
4. +70% and +15%	4.49	1.98	0.00*
5. +70% and +30%	4.34	1.98	0.00*

Note: *significantly different

The results from the independent t-test showed that the maximum luminance background gave the different search time for the other backgrounds for both Thai and English reading document. The other backgrounds did not give significantly different search times between one another. This reveals that the luminance was the main factor of visual fatigue. The subjects spent significantly longer time to search for the target letters on the high luminance background, indicating the possible inclination to

visual fatigue. Contrast also had some contribution to visual fatigue, but not as strong as the background luminance.

4.2.3 Results from visual fatigue questionnaire

The subjects gave the same score for each symptom of visual fatigue, and the results were averaged from 50 subjects for each background luminance (Figure 4-6). The highest scores of all visual fatigue symptoms were found for +70% luminance from the reference background (the maximum luminance background). Moreover, the highest scores, approximately 3, was found for dry and irritated eyes. This symptom could be caused by too much light from the background.

The subjects felt the least dry and irritated eyes when reading on -15% of background luminance. For blurred vision, they felt the minimum when reading on the reference background. In the case of sore eyes and slow refocusing, reading on -30% of background luminance gave the lowest scores. The subjects gave the lowest scores of neck and backache and doubling of vision for +15% of background luminance. These results showed that no trend was found for background luminance that would cause the least visual fatigue. In addition, apart from maximum luminance background, the other backgrounds had the visual fatigue scores of mostly no more than 2, indicating a little degree of visual fatigue symptom. This is possibly because of the short experimental time.

Figure 4-5: Scores of visual fatigue from different background luminance.

4.3Effect of background colour on visual fatigue

4.3.1 Results of search time

The subjects also performed the reading tasks on 6 different colours of tablet background. All colour backgrounds are white, red, green, blue, yellow and purple, had the same luminance as paper (68.00 cd/m^2 ±0.68). Figure 4-7 shows the averages of search time from 50 subjects for different background colours.

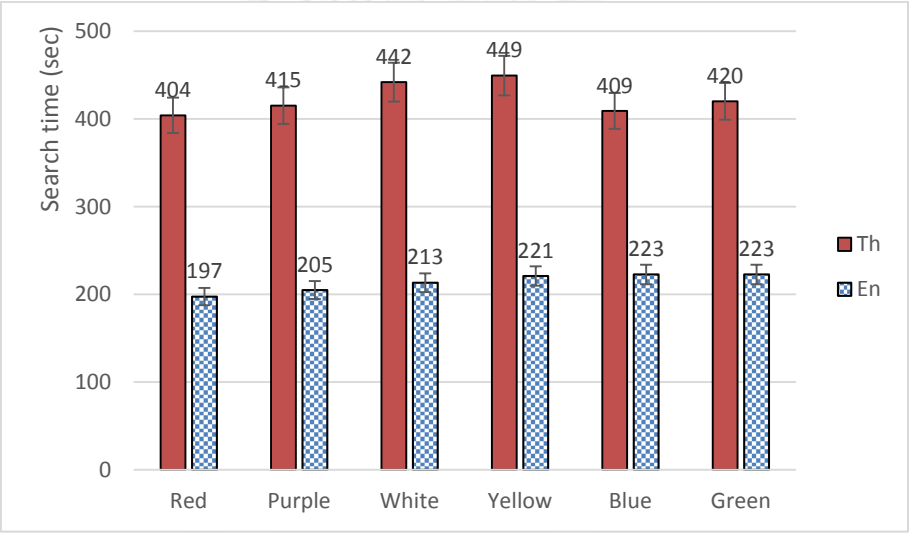

Figure 4-6: The averages of search time for different background colours.

- Thai reading document

The results showed that the shortest search time was obtained from red (404 seconds) background, while the longest was yellow (449 seconds). The difference between the longest and the shortest times was 15 seconds.

- English reading document

Figure 4-7 shows that red was the best background because the subjects could complete the reading task with the shortest time (197 seconds). The background that gave the longest search time to was green and blue (223 seconds). The difference between the longest and the shortest times was 26 seconds.

Even though red background gave the best search time for both Thai and English documents, the sequence of background colours from the best to worst search time was different between Thai and English documents. In order to investigate the correlation between search time and background colour, colour contrast between text and background and hue-angle values of background were plotted against search time, as shown in Figures 4-8(a) and (b), respectively.

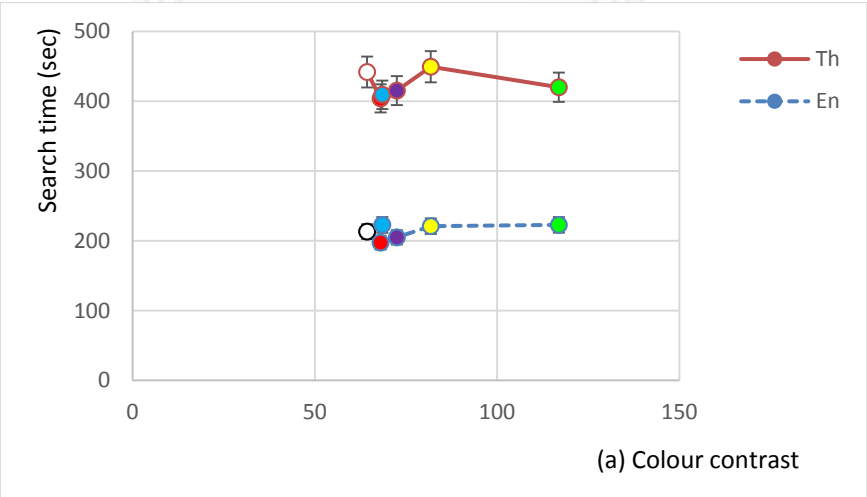

Figure 4-7: Relationships between search time and (a) colour contrast, and (b) hue angle.

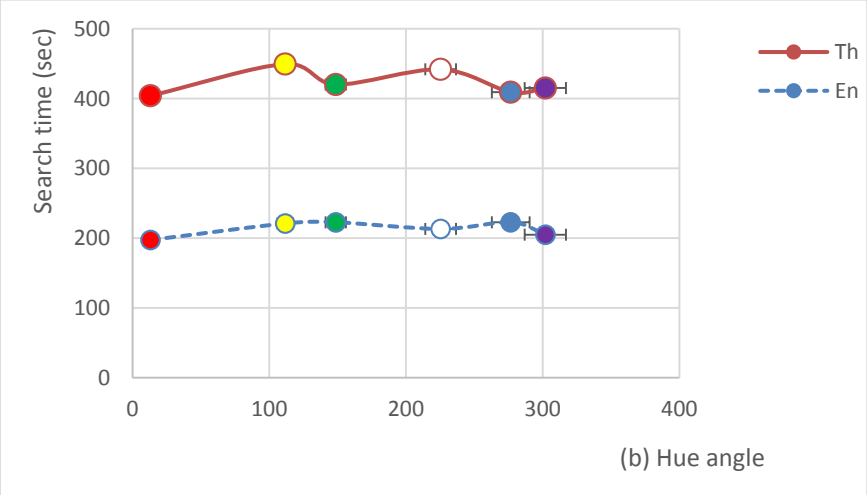

Figure 4-7 : Relationships between search time and (a) colour contrast, and (b) hue angle.

From Figure 4-8, no trend was found for colour contrast and hue for both Thai and English documents. White background gave the lowest contrast, and green background gave the highest. However, both backgrounds had longer search time than red backgrounds. This reveals that the search time could not be predicted by colour contrast. The changing of colour expressed by hue angle also could not predict the change of search time, as no pattern of search time was found with increasing hue angle.

Table 4-8: One-way ANOVA of search time between different background colours.

Reading document	df	F	F critical	P - value
Thai	5	0.87	2.24	0.50
English	5	0.37	2.24	0.86

The differences in search time between different background colours were statistically tested with one-way ANOVA, and the results are shown in Table 4-8. It was found that the search times between background colours were not significantly different for both Thai and English reading documents at a 95% confidence. Since all backgrounds had the same luminance, this could mean that the main factor that affected visual fatigue was luminance, with contrast and colour playing a smaller role. These findings support the study by [10]. In their study, the use of colour overlay could improve the reading performance of students because the overlay reduced the amount of light entering the eyes. The students chose the colour overlay according to their preference, which infer that any colour would help so long as it reduces the glare from white paper.

4.3.2 Results from visual fatigue questionnaire

Figure 4-8 shows the scores of visual fatigue symptoms averaged from 50 subjects and arranged from low to high scores of different backgrounds for each symptom.

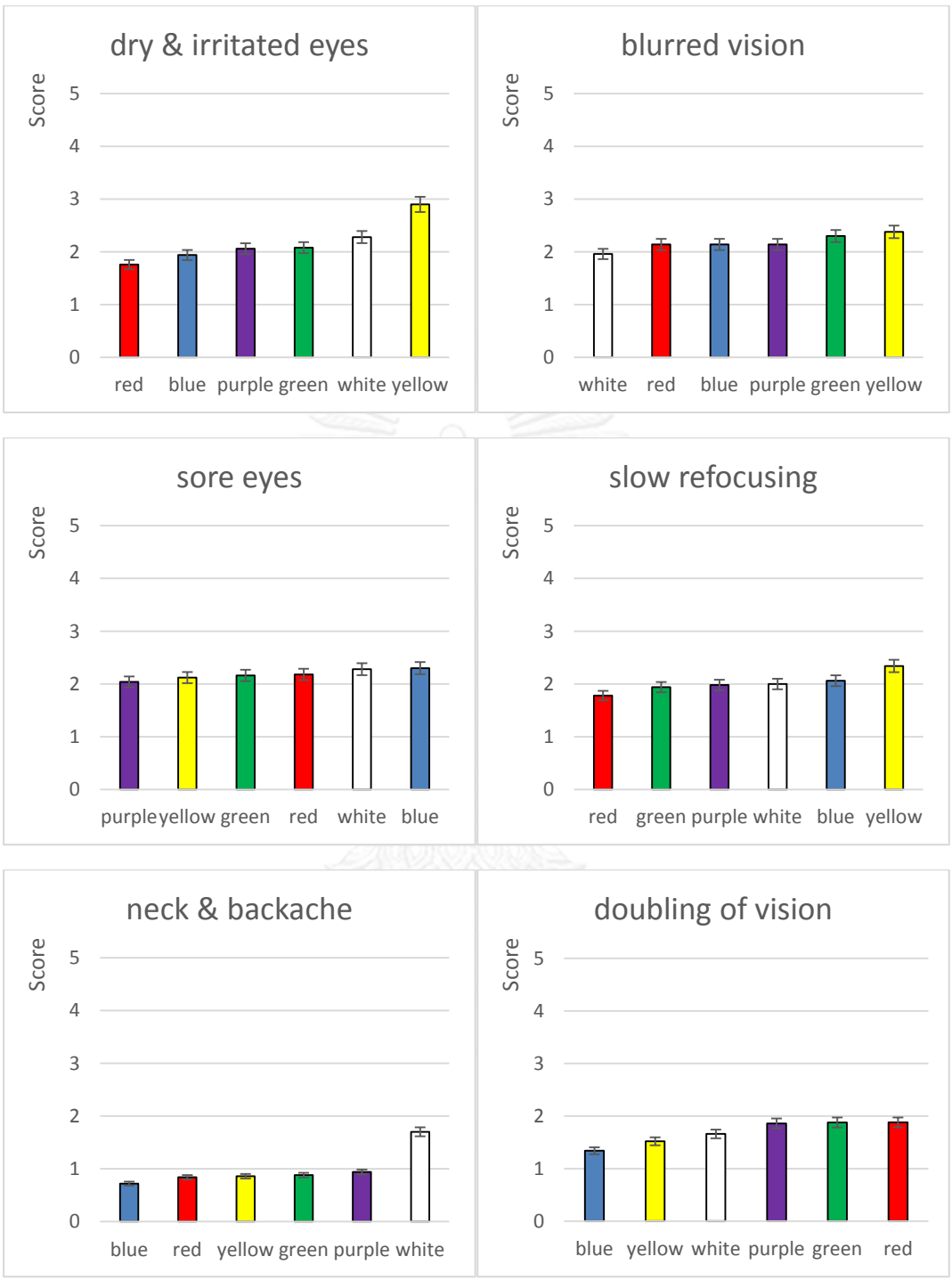

Figure 4-8 : Scores of visual fatigue from different background colours.

From Figure 4-8, for dry and irritated eyes red background scored the least, and yellow the most. The other backgrounds had scores of around two, indicating the low degree of this symptom. As for blurred vision, the results showed the similar scores when reading on various background colours. However, reading on yellow background gave the highest scores. This is also the case for the symptom of slow refocusing. In the case of sore eyes, blue background gave the highest score; however, the other backgrounds had very similar scores.

When reading on white background, the subjects felt neck and backache the most, while the other backgrounds had markedly lower scores and not more than one. It is possible that because white background had the lowest colour contrast between text and background (Figure 4.8 a), the subjects had to concentrate more and closer in order to read, causing muscle tension in the neck and back. For doubling vision, the subjects gave the highest score when reading on purple, green and red backgrounds and the lowest score on blue background. However, all backgrounds had the score lower than two.

Overall, the subjects answered that yellow background had the highest scores for 3 out of 6 symptoms. One of them which is dry and irritated eyes, scored the highest of all symptoms and had the score of approximately 3, indicating that the subjects felt moderate degree of that symptom. The symptom of dry and irritated eyes

could be the cause of blurred vision and slow refocusing, which probably explains why yellow background had the highest scores for these symptoms. Moreover, red background had the lowest scores in dry and irritated eyes and slow refocusing and ranked the second place in blurred vision.

Based on the results of search time and visual fatigue score, red was the best background colour for reading. Albeit it not showing significant difference, red background gave the fastest search time for both Thai and English document. Some subjects also commented that red was the most visual comfort background, compared with the other backgrounds.

4.4 Results from general questionnaire

The general questionnaire was given to 50 subjects before the reading task. It was designed to obtain the subjects' information about their familiarity with tablet and colour preference.

4.4.1 Familiarity of using tablet

Figure 4-9 shows the percentages of activities that the subjects usually did when using tablet. The results showed that 60% of subjects used tablets for social

network, and 32% for playing games. A small number of subjects used tablets to read e-book (4%), listen to music (2%) and 2% surf the internet for information (2%).

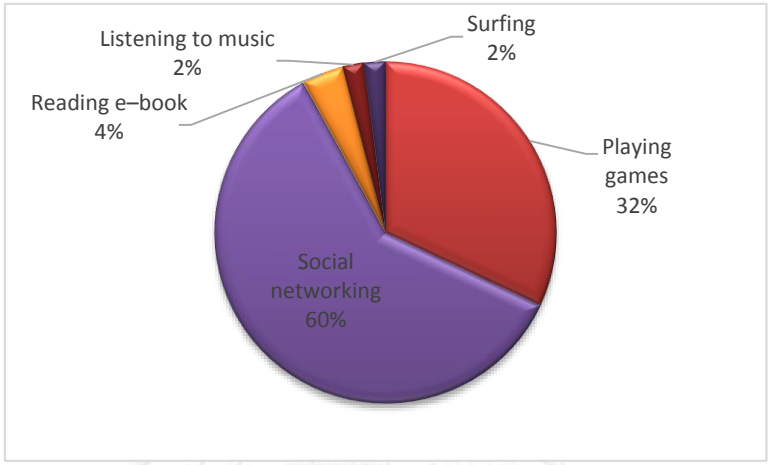

Figure 4-9 : Percentage of favourite activities when using tablet.

Figure 4-10 shows the frequency of the subjects' favourite activities on tablet. The subjects answered the question about how long they spent time on their favourite activities. It was found that 68% of subjects spent everyday, 16% used 3-5 times per week and 10% used 1-2 times per week. The small number of subjects answered "a few time per month". The results showed that the majority of subjects were very familiar with using tablet.

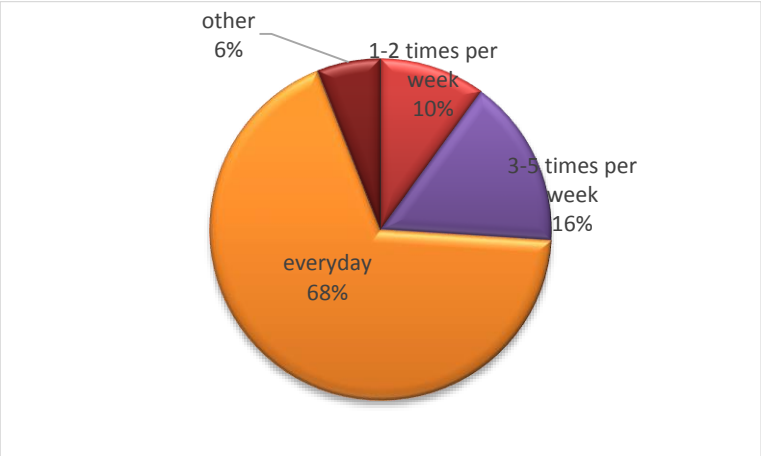

Figure 4-10: Percentage of frequency of usage.

The above results showed the frequency of using tablet to do any activities, which used to study about subjects' familiarity of using tablet. However, the use of tablet for reading e-book and/or long information such as news has different nature from reading. Thus, to learn the familiarity of reading on tablet, the subjects answered about the frequency of their using tablet for reading. Figure 4-11 shows these results. It was found that 44% of subjects read on tablet 3-5 times per week, 24% read every day, and 20% of subjects read 1-2 times per week. In addition, 6% never read on tablet and 6% answered a few times per month. The results showed that the majority of subjects were very familiar to reading on tablet, so the results would not be biased by the unfamiliar use of tablet.

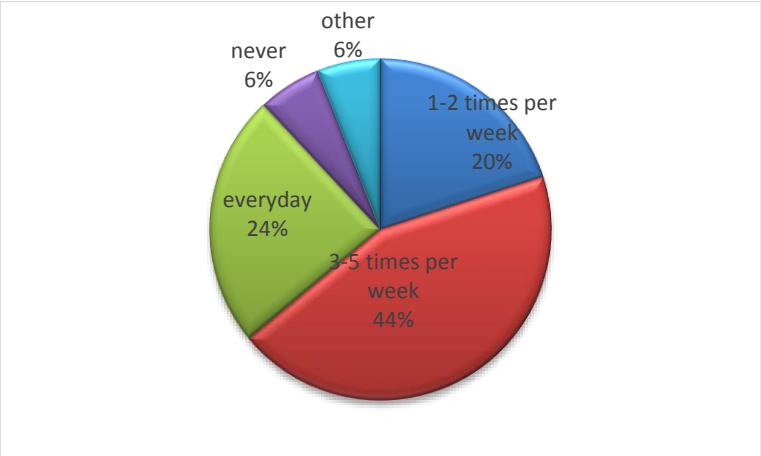

Figure 4-11: Percentage of frequency of using tablet for reading.

4.4.2 Colour preference

In the general questionnaire, the subjects were asked about their favourite and dislike colour. Moreover, they answered about which colour they thought would be comfortable and uncomfortable to the eyes when used as a background for reading. This was done to learn whether preference colour influenced the reading performance and/or visual fatigue. The results were expressed as percentages of subjects answering that colour and are given in Figure 4-12 for favourite colour and Figure 4-13 for dislike colour. The most preferred colours were light blue (16%) and green (16%), followed by pink (14%), black (14%) and orange 14%.The results showed that the most dislike colour was green (16%), 14% of the subjects disliked pink, and light blue, black and green had the same percentage of 12%. These results showed that preference colour did not affect the results from the reading task and visual fatigue questionnaire, as the

best colour for background was red, which was not found in the top ranks of favourite and dislike colour.

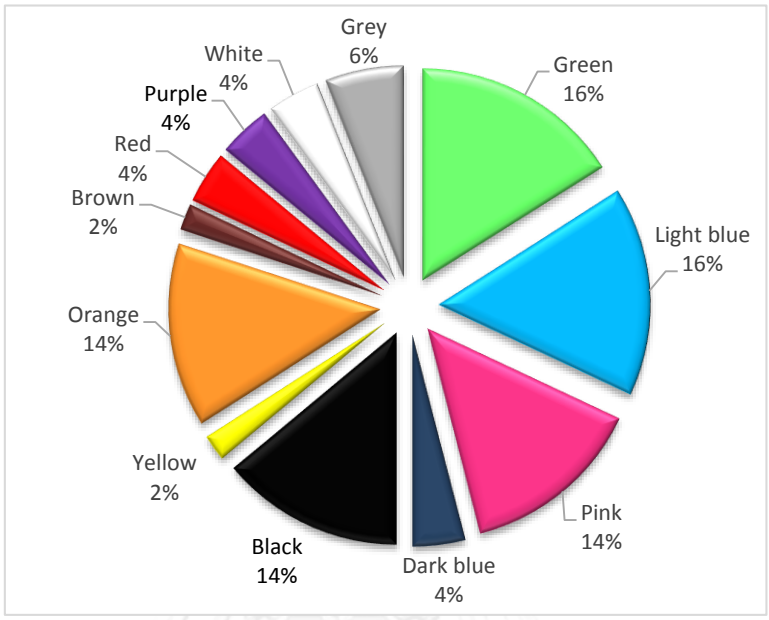

Figure 4-12: Percentage of favourite colour.

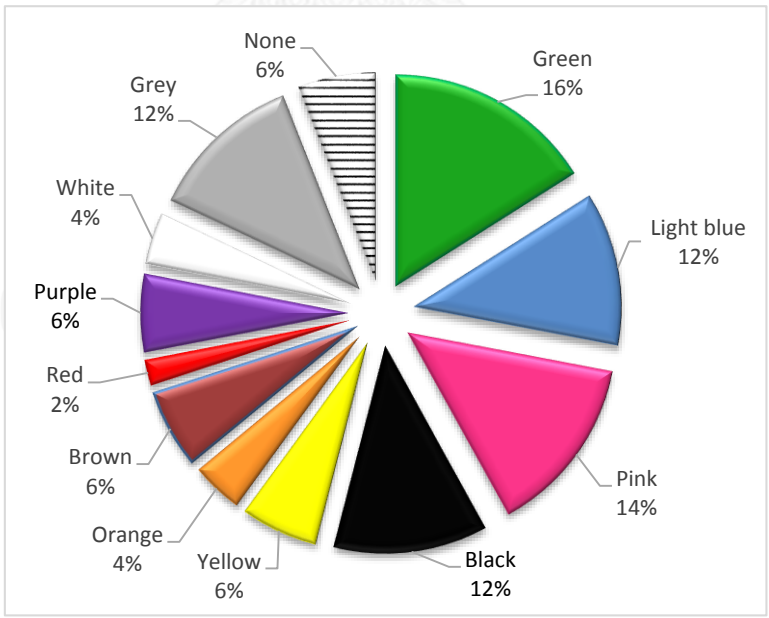

Figure 4-13: Percentage of dislike colour.

Figures 4-14 and 4-15 show the percentages of colours that the subjects thought were comfortable and uncomfortable as a background for reading, respectively. It was found that 24% of subjects answered light blue, followed by green with 20%. These two colours are cool tone. On the other hand, colour that the subjects answered as an uncomfortable background were orange (26%) and red (20%), which are warm tone.

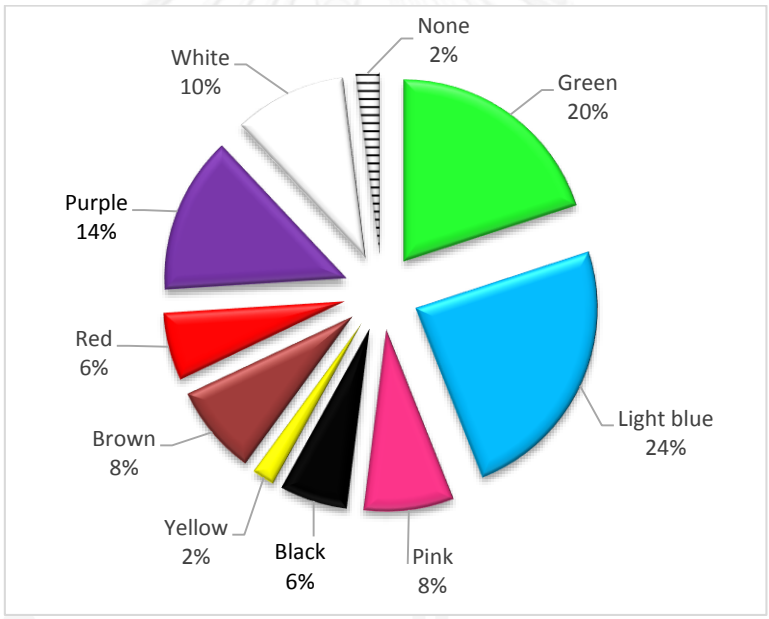

Figure 4-14: Percentage of visual-comfort colour.

The subjects chose cool tone colours as a visual comfort background. Conversely, they performed best on red background, which is warm tone colour. Red background also showed promising results for visual fatigue scores. The discrepancy between these results probably came from the given colour name. When provided

with basic colour terms, such as red, one often thinks about unique hues, which are pure and saturate. Hence, the colour in the subjects' mind were not the same as the background colour used in the reading tasks.

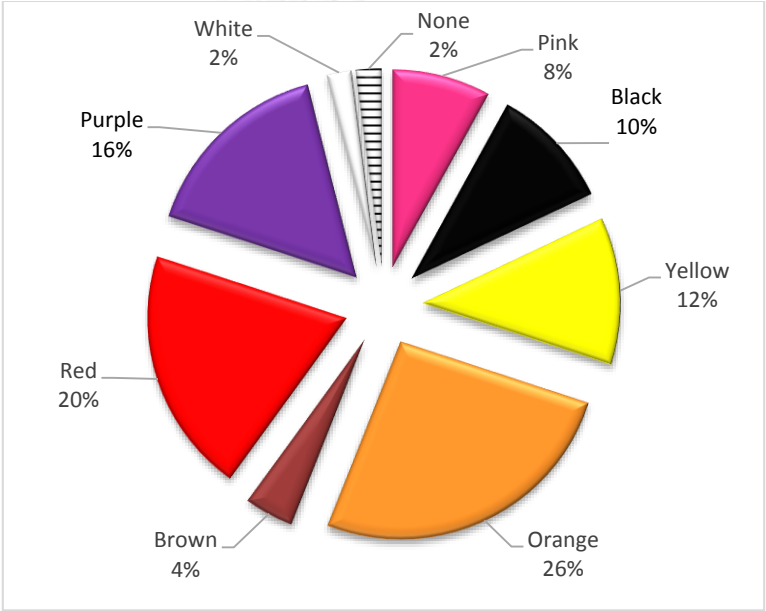

Figure 4-15: Percentage of colour uncomfortable to the eyes.

Chapter 5

CONCLUSIONS

5.1Conclusions

This study aimed to investigate the effects of background luminance and colour on visual fatigue from reading on tablet. This was done by means of reading tasks, whereby subjects read through Thai and English pseudo-text to find hidden target letters, and questionnaires about a sign of visual fatigue that the subjects experienced during the reading tasks. Fifty subjects who were a regular reader and familiar with using tablet for reading participated in the experiments. The search time and scores of visual fatigue symptoms were exploited as an indicator of visual fatigue. The results were compared between different backgrounds having various luminance and colours.

To compare the effect of reading media between paper and tablet, the background of the tablet was set to have the same luminance as the paper. The results showed that the search times on tablet for both Thai and English text were faster than those on paper, which indicated that reading on tablet tended to cause a lower degree of visual fatigue. Nevertheless, the significant difference was found only in English text. The search time for Thai pseudo-text was approximately twice as long as the search time for English pseudo-text. This is because Thai patterns are more difficult to distinguish. This revealed that the reading media had an effect on an easy

reading task. One possible factor contributing to this effect was the luminance contrast between text and background. Even though the background luminance of tablet and paper was equal, the contrast on the tablet was higher, making the text on tablet appear clearer and sharper. This also indicated the effect of image quality on an easy reading task: the clear text will shorten the reading time, so the reader has not yet felt visual fatigue. The results from questionnaire also showed that reading on paper tended to cause higher degrees of doubling vision and blurred vision. Nevertheless, the scores of these two symptoms were approximately two, signifying a mild feeling.

To investigate the effect of background luminance, the background luminance of the tablet was varied in six levels: 15% and 30% increased and decreased from the luminance of a reference background, luminance of 68 cd/m_2 (the paper luminance) as the reference background and 70% increased from the reference background (the maximum luminance of tablet under the given viewing condition). The luminance contrast between text and background varied from low to high according to the luminance levels of background (i.e. from -15% to +70%). The results showed that the search time on the reference background was the fastest. When the luminance decreased and increased, the search time tended to be longer, and the search time on the background with maximum luminance was the longest. However, only the search time on the maximum luminance background was significantly different from the other backgrounds. This revealed that luminance was the main factor causing

visual fatigue. The background luminance should be at certain levels for comfortable reading: lower luminance from these levels will yield low contrast and make the text hard to read, while higher luminance will yield too much light and irritate the eyes.

The background with maximum luminance caused the moderate symptom of dry and irritated eyes. The moderate degrees of visual fatigue symptoms were also found in blurred vision and slow refocusing for the maximum luminance background, while the other backgrounds yielded mild feelings in all symptoms. The feeling of dry and irritated eyes are the first sign of visual fatigue. When the fatigue is more severe, the readers will experience other symptoms with various degrees of severity. The subjects in this study did not experience severe degrees of any symptoms, which was possible that the reading time was not long enough.

The effect of background colour was investigated using six backgrounds varied in hue: white, red, yellow, green, blue and purple. All six backgrounds had the same luminance. Statistically, no difference in search time between the backgrounds was found. However, red background seemed to be the best background for comfortable reading, as it gave the fastest search time and had the lowest scores in two symptoms: dry and irritated eyes and slow refocusing. On the other hand, yellow background was the worst, as it caused a moderate feeling of dry and irritated eyes and also received the highest scores in blurred vision and slow refocusing.

No relationships were found between visual fatigue and colour contrast, and hue-angle. White background did not outperform most other colour backgrounds in both search times and visual fatigue scores. There was a tendency that a certain hue performed better than the others. This revealed that luminance was the most important factor affecting visual fatigue, while contrast and colour (or hue) played a smaller role. Colour background could improve visual comfort for reading. However, the suitable colour may not be the same as the readers' favourite colour.

5.2 Suggestions

The results of this study revealed the tendency of hue and contrast effects on visual fatigue, although the statistical tests did not show significant differences. This might be because the reading time was not long enough to actually cause visual fatigue. Thus, increasing the reading time by extending the reading tasks might help to achieve the significance of the results. Moreover, as pseudo-text was used in this study, the future study could use the actual passages in the reading tasks. In the visual experiments, more levels of luminance such as ±5%, ±10% until the max level could be included to find the optimal results.

The background colours of tablet that were investigated in this study varied only in five hues; thus, the future study could also include other background colours that are available on e-book applications, for example, sepia background. However,

there are other potential factors such as chroma and contrast between text and background. The exposed area of background, text size, image quality, and lighting conditions could also have an effect on visual fatigue and are worth investigating in future studies. Moreover, the tablet screen should be calibrated for ensuring accurately colours.

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research (MNREAD acuity charts) were presented at the aforementioned conference. 2007. Lawrence Erlbaum Associates Publishers.

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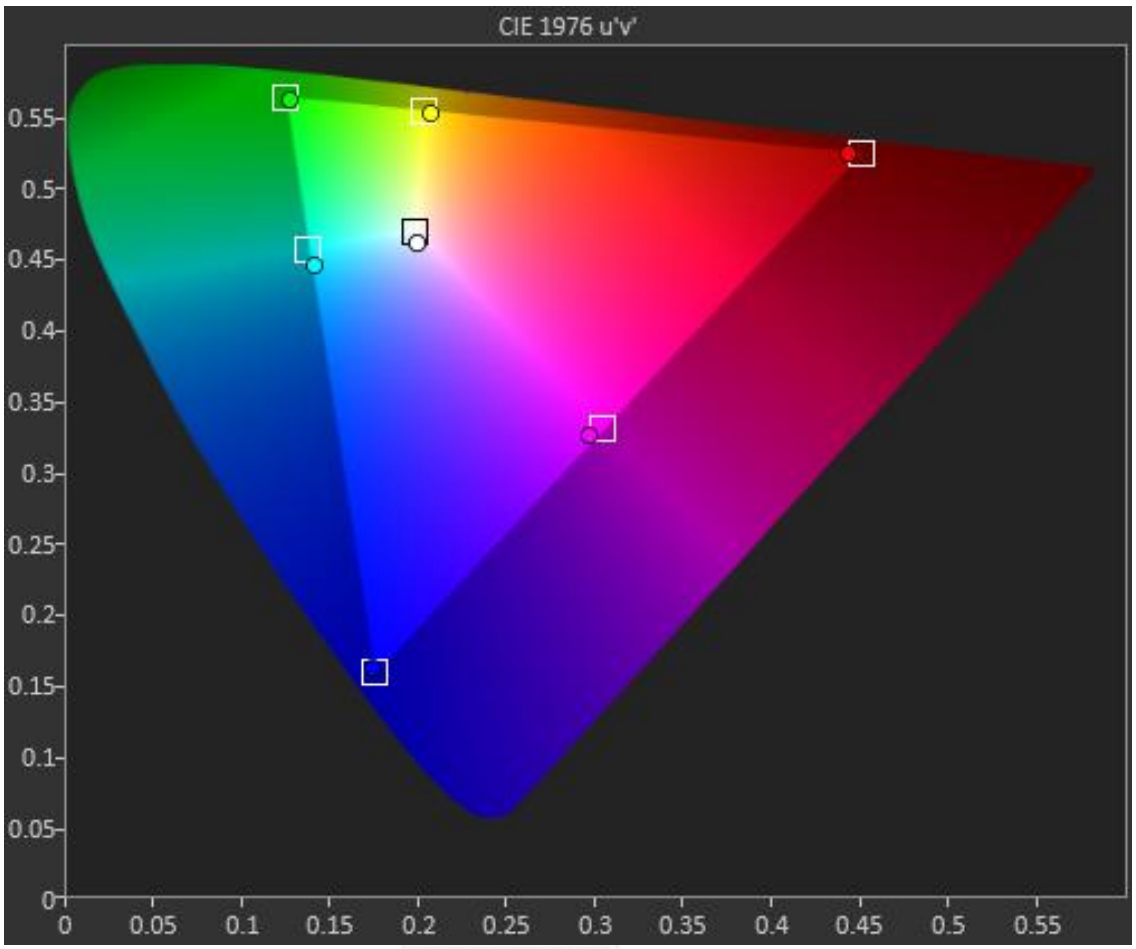
APPENDIX

Appendix A
Colour gamut of iPad generation



Colour gamut of iPad generation 4.[18]

Appendix B
General questionnaire

ชื่อ_____

นามสกุล _____

อายุ_____ **เพศ**_____

เบอร์โทรศัพท์_____

วันที่_____**เวลา**_____

---

1. โปรดเลือกคำตอบที่ตรงกับความจริงมากที่สุด

1.1 ท่านเคยใช้แท็บเล็ตหรือไม่

( ) เคย ( ) ไม่เคย

1.2 ท่านมีแท็บเล็ตเป็นของตัวท่านเองหรือไม่

( ) มี ( ) ไม่มี

1.3 ในอนาคตอันใกล้ ท่านวางแผนที่จะซื้อแท็บเล็ตหรือไม่

( ) คิด ( ) ไม่คิด

1.4 โดยส่วนใหญ่ท่านใช้แท็บเล็ตทำกิจกรรมใดดังต่อไปนี้(เรียงลำดับจากกิจกรรมที่ทำบ่อยสุดไปถึงกิจกรรมที่ทำน้อยที่สุด)

( ) เล่นเกมส์

( ) social network

( ) อ่านข่าวหรือนิตยสาร

( ) ชมภาพยนตร์

( ) อ่าน e–book

( ) ทำงานเอกสาร

( ) ฟังเพลง

( ) หาข้อมูล

( ) อื่นๆ_____

( ) อื่นๆ _____

1.5 ความถี่ของกิจกรรมที่ท่านทำบ่อยเป็นอันดับที่ 1

( ) 1-2 ครั้งต่อสัปดาห์

( ) 3-5 ครั้งต่อสัปดาห์

( ) ทุกวัน ( ) อื่น ๆ _____

1.6 ความถี่ของการใช้แท็บเล็ตเพื่อการอ่าน เช่น บทความ, ข่าว, e-book

( ) 1-2 ครั้งต่อสัปดาห์

( ) 3-5 ครั้งต่อสัปดาห์

( ) ทุกวัน ( ) อื่น ๆ _____

1.7 ท่านเคยอ่าน e - book หรือไม่

( ) ไม่เคย ( ) 1-2 ครั้งต่อสัปดาห์

( ) 3-5 ครั้งต่อสัปดาห์ ( ) ทุกวัน

( ) อื่น ๆ _____

1.8 ถ้าเคย โดยส่วนใหญ่ท่านอ่าน e-book จากสื่อชนิดใด

( ) สมาร์ทโฟน ( ) แท็บเล็ต

( ) e-paper ( ) คอมพิวเตอร์

( ) อื่น ๆ _____

2. คำถามเกี่ยวกับความชอบสี

2.1 สีที่ท่าน**ชอบ**คือ

( ) สีม่วง ( ) สีเขียว ( ) สีฟ้า

( ) สีชมพู ( ) สีเหลือง ( ) สีส้ม

( ) สีน้ำตาล ( ) สีขาว ( ) สีเทา

( ) สีดำ ( ) อื่น ๆ _____

2.2สีที่ท่าน**ไม่ชอบ**คือ

( ) สีม่วง ( ) สีเขียว ( ) สีฟ้า

( ) สีชมพู ( ) สีเหลือง ( ) สีส้ม

( ) สีน้ำตาล ( ) สีขาว ( ) สีเทา

( ) สีดำ ( ) อื่น ๆ _____

2.3 ในความคิดของท่านสีใดต่อไปนี้ให้ความรู้สึก**สบายตา**

( ) สีม่วง ( ) สีเขียว ( ) สีฟ้า

( ) สีชมพู ( ) สีเหลือง ( ) สีส้ม

( ) สีน้ำตาล ( ) สีขาว ( ) สีเทา

( ) สีดำ ( ) อื่น ๆ _____

2.4 ในความคิดของท่านสีใดต่อไปนี้ให้ความรู้สึก**ไม่สบายตา**

( ) สีม่วง ( ) สีเขียว ( ) สีฟ้า

( ) สีชมพู ( ) สีเหลือง ( ) สีส้ม

( ) สีน้ำตาล ( ) สีขาว ( ) สีเทา

( ) สีดำ ( ) อื่น ๆ _____

ขอบคุณค่ะ

Name_____

Surname _____

Age_____ Sex_____

Telephone number_____

Date_____Time_____

1. Please select the answer that best fits you.

1.1 Have you ever use tablet?

( ) Ever ( ) Never

1.2 Do you have your own tablet?

( ) Yes ( ) No

1.3 Do you have any plans to buy tablet?

( ) Yes ( ) No

1.4 What your favorite activities when using tablet?

( ) Playing games

( ) social networking

( ) Reading news/ magazine

( ) Watching the movies

( ) Reading e–book

( ) Working with document

( ) Listening to music

( ) Surfing

( ) Other_____

( ) Other _____

1.5 How often do you activate your activities that you answer in above question?

( ) 1-2 times per week

( ) 3-5 times per week

( ) everyday ( ) other _____

1.6 How often do you use tablet for reading? (text, news, e-book)

( ) 1-2 times per week

( ) 3-5 times per week

( ) everyday ( ) other _____

1.7 Have you ever read e-book?

( ) never ( ) 1-2 times per week

( )) 3-5 times per week

( ) everyday ( ) other _____

1.8 If you ever read, what medium do you often to read?

( ) smart phone ( ) tablet

( ) e-paper ( ) computer

( ) other _____

2. Colour preference questions.

2.1 What your favorite colour?

( ) Purple ( ) Green ( ) Blue

( ) Pink ( ) Yellow ( ) Orange

( ) Brown ( ) White ( ) Grey

( ) Black ( ) Other_____

2.2 What your dislike colour?

( ) Purple ( ) Green ( ) Blue

( ) Pink ( ) Yellow ( ) Orange

( ) Brown ( ) White ( ) Grey

( ) Black ( ) Other_____

2.3 In your opinion, what colour is comfortable to read?

( ) Purple ( ) Green ( ) Blue

( ) Pink ( ) Yellow ( ) Orange

( ) Brown ( ) White ( ) Grey

( ) Black ( ) Other_____

2.3 In your opinion, what colour is uncomfortable to read?

( ) Purple ( ) Green ( ) Blue

( ) Pink ( ) Yellow ( ) Orange

( ) Brown ( ) White ( ) Grey

( ) Black ( ) Other_____

Thank you

Appendix C
Visual fatigue questionnaire

ชื่อ_____**นามสกุล** _____**อายุ**_____

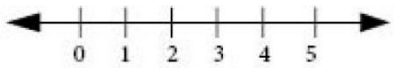
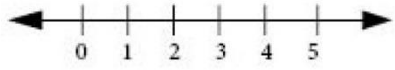
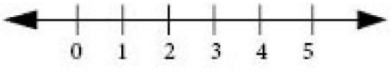
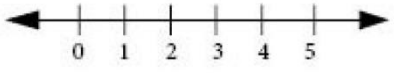
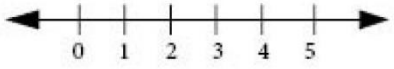
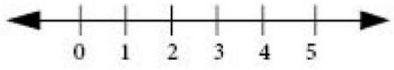
เพศ_____**เบอร์โทรศัพท์**_____

ระดับการศึกษา_____

กรุณาวงกลมล้อมรอบระดับของอาการเหล่านี้ โดยที่

0= ไม่เกิดเลย	3=เกิดปานกลาง
1=เกิดน้อยมาก	4= เกิดค่อนข้างมาก
2=เกิดค่อนข้างน้อย	5=เกิดมาก

สี

1. **แสบตาหรือระคายเคืองตา**	
2. **ตัวอักษรเบลอ**	
3. **ปวดตา**	
4. **โฟกัสสายตาช้าลง**	
5. **ปวดบริเวณคอ หลัง หรือไหล่**	
6. **มองเห็นเป็นภาพซ้อน**	

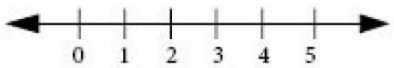
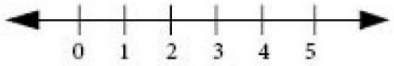
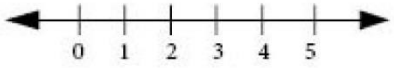
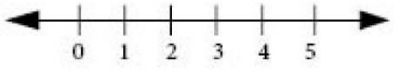
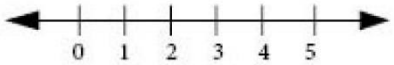
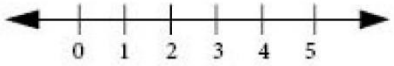
Name_____Surname _____Age_____

Sex_____Telephone number_____

Please circle around the most correct answer.

Background

0 = no, not at all.	3 = yes, moderate.
1 = yes, a little.	4 = yes, rather.
2 = yes, quite a few.	5 = yes, very much.

1. Dry and irritated eyes	
2. Blurred vision	
3. Sore eyes	
4. Slow refocusing	
5. Neck and backache	
6. Doubling of vision	

Appendix D

The independent t-test of search time between each background.

Table D1: The independent t-test of search time between each background on English reading document.

	-30%	-15%	ref	+15%	+30%	max
-30%		0.61	0.62	0.88	0.74	0.00*
-15%			0.3	0.48	0.39	0.00*
ref				0.71	0.87	0.00*
+15%					0.85	0.00*
+30%						0.00*
max						

Table D2: The independent t-test of search time between each background on Thai reading document.

	-30%	-15%	ref	+15%	+30%	max
-30%		0.85	0.72	0.28	0.47	0.00*
-15%			0.86	0.2	0.37	0.00*
ref				0.15	0.29	0.00*
+15%					0.77	0.00*
+30%						0.00*
max						

Note: *significantly different

VITA

Ms. Praewpan Youyen was born on 10 Dec, 1988 in Bangkok, Thailand. She received a Bachelor's Degree in Printing technology from Rajamagala University of Technology Thanyaburi University in 2010. She entered the Department of Imaging and Printing Technology, Faculty of Science, the Graduate School, Chulalongkorn University in 2012.