Effect of tablet PC screen color combination on vision in bright and dark environments

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Abstract: With the advancement of computer technology and screen technique, reading with tablet PC has become a new trend. Since the light of the environment affects the reading when using tablet PC, the study is mainly focused on how the combination of text colors influences the sense of visual while reading with tablet PC in bright and dark environments. The whole experiment was divided into two sections; one is the legibility, and the other is the visual performance, subjective and objective visual fatigue affected by color combinations. Experimental result shows that no matter in bright and dark environment for legibility and visual fatigue, the worst combinations of colors are negative presentation (BK/W, BL/G, BK/G). Moreover, all the best color combinations in dark for visual fatigue are positive presentation (G/BL, W/BK). And in bright environment, the best combinations for objective experiments are both negative presentation (BK/W, BK/G). In summary, this study has discovered that there should be different combinations of colors while people are reading with tablet PC in the environment with different brightness levels. The conclusion has indicated that it is possible to ease the visual fatigue when reading the suitable combination of color.

Key words: Color Combination, Tablet PC, Legibility, Visual performance, Visual fatigue

1. Foreword

1.1 Research Background and Motivation

The spread of computerization technology -using the Internet, telephone, fax, scanners or text messaging -has opened up a new range of possibilities for reading everywhere at anytime. Nowadays, there is a trend toward integrating new technologies, such as documents, mails, video clips, and books in cloud computing. In these years, the tablet PC has taken the place of computer as an electronic computerization device, with the majority of the adult, teenager and even child. The tablet PC is portable and takes up little space. It can save ink production, paper and lumber consumption. The type, size and font on tablet PC are adjustable, and documents can be shared to many people at a time. Because of the reader-friendly tablet PC, people more eye strain over extended reading time. Especially in the environment with insufficient light, reading electronic displays may be more harmful to eyes.

Legibility is the degree to which individual characters or figures in text are understandable or recognizable based on appearance. It is greatly affected by the perceived contrast between target (words or figures) and background. Color perception is affected by many factors, including physiological factors such as aging and color-

blindness and environment factors such as display settings and room lighting. When designing elements that require clarity and definition—such as text, choosing colors for perceptibility and legibility above all other considerations to avoid using color combinations and makes it difficult for users to distinguish foreground from background (In-Chen, Chang1998).

In the past researches, not only the personal computer (with CRT or LCD screen) but also the laptop with LCD screen, there is an obvious effect upon the visual fatigue while reading different combination of colors on the screen (Chin-Chiuan, Lin 2000). And subjective preference and visual performance for color combinations were related (Matthews,1987).Color and typeface are two important factors of visual stimulus that may affect visual performance and visual fatigue (Shieh et al. 1997). Color can be a significant influence means to improve human-computer communication (Pastoor, 1990 ; Silverstein, 1997).

The studies in the past were mostly focused on the displays with PC and laptop, while there was only a few regarding tablet PC. Due to the portability of tablet PC, this study is mainly discussed how the combination of text colors influences the sense of visual while reading in bright and dark environments.

1.2 Research Purpose

The study is focused on how the combination of text colors (foreground and background) influences the sense of visual while reading with tablet PC in bright and dark environments.

(1) Effect of the legibility by color combination while reading with tablet PC in bright and dark environments.

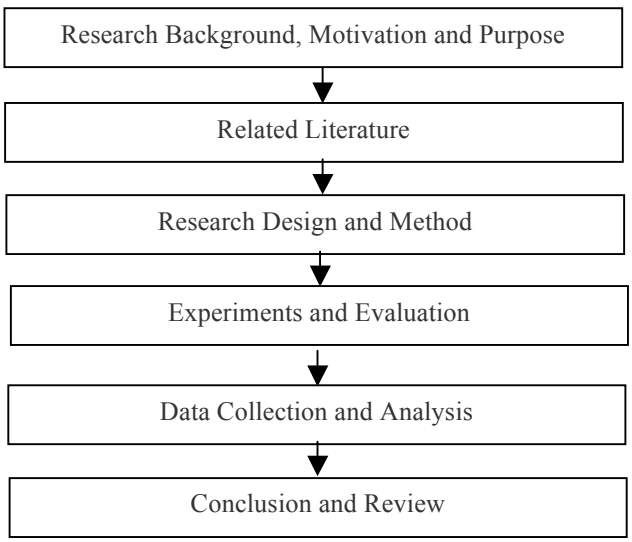
(2) Effect of the visual performance by color combination while reading with tablet PC in bright and dark environments.

(3) Effect of the visual fatigue by color combination while reading with tablet PC in bright and dark environments.

(4) The interrelation of legibility, visual performance and fatigue by color combination while reading with tablet PC in bright and dark environments.

1.3 Research Procedures

Table 1. Research flow chart



2. Related Literature

2.1 Color and Legibility

2-1.1 Physics of colors

Color derives from the spectrum of light interacting in the eye with the spectral sensitivities of the light receptors. (Kun-Fan, Lin 2011) Color is the visual perceptual property corresponding in humans' eyes to the categories called red, orange, yellow, green, blue, purple and others. Electromagnetic radiation is characterized by its wavelength intensity. When the wavelength is within the visible spectrum (the range of wavelengths humans can perceive, approximately from 380 nm to 780 nm), it is known as "visible light". Because perception of color stems from the varying spectral sensitivity of different types of cone cells in the retina to different parts of the spectrum, colors may be defined and quantified by the degree to which they stimulate these cells.

2-1.2 Legibility

Legibility is the degree of which individual characters in text are understandable or recognizable based on appearance. The legibility of a typeface is related to the ability to distinguish foreground from background. It is different from readability refers to entire words, sentences, and paragraphs. Legibility includes factors such as x-height, character shapes, stroke contrast, the size of its counters and weight.

Figure.1 Legibility of color

2-1.3 Legibility of words

Visual acuity assessment of Chinese readers is complicated by the spatial complexity of Chinese characters, but the fact that the Snellen E, which is the current national standard of acuity measurement in China, and Chinese characters showed similar dependence on optical defocus may indicate a potentially valid way to infer functional vision in Chinese readers with Snellen E acuity. (Jun-Yun, Zhang 2007) Therefore, the testing sample of experiment 1 is composed of Snellen E acuity.

2.2 Visual System and Formation

2-2.1 Visual Differences in Gender

Men and women are different in physiological structure. Salyer, Lnud, Fleming, Lephart, Horvath (2001) indicated that the retinal innate for male is thicker than female with mostly constituted by Magno, (M cells). M cells, they are primarily found in the periphery of the Rods which is more receptive to large center-surrounding field as well as receiving depth, indifferent color, moreover, it is adaptive rapidly to a stimulus; female retinal is thinner, and constitute by Parvo (P cells). P cells links in the cone cells with mostly concentrated in the fovea of the retina with major perception for the identification of color and texture to generate a difference in the direction of image recognition. Therefore, male favors visual-search space while female prefers image searching.

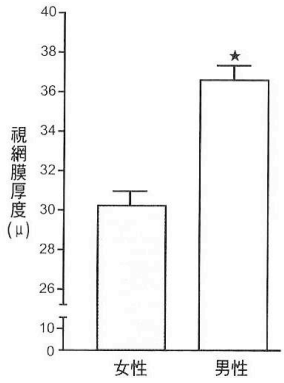


Figure.2 The thickness of retinal between males and females

2-2.2 Adaption of Visual

Eyes should be adapted to different brightness while the sight of people moves, in these moment, eye is temporarily reduce visibility until fully adapts to the new brightness. We called it “Temporary Adaptation (Transient Adaptation)”. It can be divided into Light and Dark scenarios. Light Adaption: From dark into the light, it will produce instant glare feelings. The adaptation usually takes 2 to 10 minutes; Dark Adaption: This process usually moves slowly; it takes about 10 to 20 minutes to adapt completely. The difference of visually adaption is affected by personal adjustment force and ambient brightness. The difference of visually adaption is affected by personal adjustment force and ambient brightness.

2-2.3 Visual Fatigue

According to the Institute of Labor Safety and Health, prolonged concentration work will cause high tension of the eye muscle that brings Atigue Suanse. Light is closely related to the pupil size changing. Eye adjustment will thus be adversely impacted which will produce a visual fatigue.

(1) Environmental factors: The burden on the eyes is related by light uneven distribution. No matter the ambient light is insufficient or too strong, flicker irregularly, or reading object is too small, too thin or unstable, it will become a burden on the eyes, leading to a visual fatigue.

(2) Physiological factors: When a body is weak, fatigue, or in some special conditions, such as menopause, pregnancy, and those suffering from diseases of hypertension, anemia, it may lead to the eye's disability.

(3) The eyes’ own factors: such as nearsightedness, farsightedness, astigmatism and other reflective errors are easy to cause visual fatigue; improper wearing glasses will also add the burden on the eyes.

Chi and Lin, 1998, mentioned in their assessment of visual fatigue wherein it divides into subjective and objective scenarios and grouped by the following four categories:

Table 2. Visual Fatigue and detection

Type of work	**Mechanism of Visual**	**Burden of Visual**	**Methods of detection**
Near visible range work	Lens	Adjustment mechanism	Accommodative micro fluctuation analysis program
Low luminance contrast work	Retinal	Retinal cell	Critical Fusion Frequency (CFF)
Dynamic target presentation	Pupil	Information Processing	Pupil Diameter

Table 3. Merit and Demerit of visual fatigue assessment

Methods of visual fatigue assessment	Merit	Demerit
Adjustment force of ciliary body	With a high sensitivity of concentration work	To raise a significant degree by Prolonged stimulation
Pupil size	Suitable for overall changes in visual function	To raise a significant degree by Prolonged stimulation
Critical Fusion Frequency (CFF)	With high sensitivity of Low luminance contrast work	To raise a significant degree by Prolonged stimulation
Subjective questionnaire	Implement easily with high face validity	Lack of objectiveness
Visual Performance	Show indirect visual fatigue	Results easy to influence by other factors. Lack of accurateness

2.3 Multi-touch Tablet Display

2-3.1 Polarity of Screen

The polarity of the text and images presented on the screen can be divided into Positive presentation and Negative presentation. (Dillon, 1992) mentions the dark words on the bright background (EX: black on white) is called “Positive presentation”; and bright words on dark background (EX: white on black) is called “Negative presentation.”

Bauer, D., Cavonius, CR (1980) indicated that different polarity of screen does affect reading performance. The Positive presentation (dark words on light background) of reading is faster than the Negative presentation (light words on dark background). Besides, reading error rate of Positive presentation is less than Negative presentation however there is no significant difference in reading comprehension while subjective visual fatigue for Negative presentation is better than Positive presentation.

Figure 3. Positive and Negative Presentation

2-3.2 Screen Brightness and Luminance

The screen brightness that means the luminance of surface generates physical quantity of light, called brightness (luminance). In Physics, “L” is used as the unit of candela per square meter or square candlelight cd/m2. The brightness is an important indicator to measure plasma displays luminous intensity. Due to each bright unit in plasma have the same structures, the screen brightness is thus very uniform without bright and dark areas. Usually, plasma brightness is above 500cd/m2 but some high density of display screen with plasma brightness even over 1000cd/m2.

Luminance refers to the amount of light radiated from a direction. It applies to assessment of the light point or luminous body glare’s degree. It may be self-luminous or only transmitting light of an object, but it may also be a light reflected from the other light emitting body (like a light from street lights and the street light is turned into a second light source). Now a days, tablet usually sets screen luminance at 400cd/m2 appearance. When the lighting source could not match the luminance of a screen, it will produce an Effect of Glare.

2-3.3 Screen and Visual range

When human eyes close to a display, the shortened visual distance may cause a high tension of the eyes muscle, then it makes human eyes focus harder, tears will thus evaporate faster which will causes eyes fatigue. There are some study indicated there is a co-relationship between human visual range and work load and the changes of the visual range resulting the actual work load can be measured. (Chin-Chiuan, Lin 2000)

When work on a VDT vision work, the best visual distance for reading should be between 40 to 80 cm. Hunting et al found that there is a co-relationship between subjective preference and preferable display screen distance for testers. When the testers were free to move by selecting their most comfortable visual distance, the most comfortable position fell into a range within 50 cm to 81 cm (with average 65 cm). The result was also confirmed by human engineering. After comparing the whole results, the best visual range should be between 35-70 cm, preferably greater than 30 cm standard.

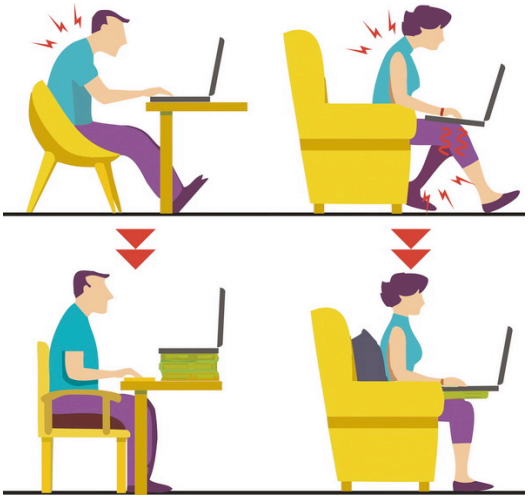


Figure 4. Working pose and visual distance

3. Research Method

3-1 Experiment 1

3-1.1 Experiment 1 - The legibility by color combinations in bright and dark environments

Table 4. The experiment of legibility flow chart

Part I	Setting experimental variable and environment (bright/ dark)
Part II	Study subjects: 15 men and 15 women
	Experiments in bright and dark environment
Part III	Analysis and discussion

3-1.2 Experiment 1 – The combinations of colors

The combinations of colors are black, white and R,G,B color model, and was deleted the combinations which human color blindness can't distinguish a target from a background. There are 10 combinations in this experiment: white background with black word (herein referred to as "W/BK"), black background with white word (herein referred to as "BK/W"), blue background with green word (herein referred to as "BL/G"), green background with blue word (herein referred to as "G/BL"), green background with black word (herein referred to as "G/BK"), black background with green word (herein referred to as "BK/G"), blue background with white word (herein referred to as "BL/W"), white background with blue word (herein referred to as "W/BL"), red background with white word (herein referred to as "R/W"), white background with red word (herein referred to as "W/R").

The target is set by Snellen's illiterate E form and 14pt. There are 4 directions (up, down, left, right) in target setting and a total of 40 samples.

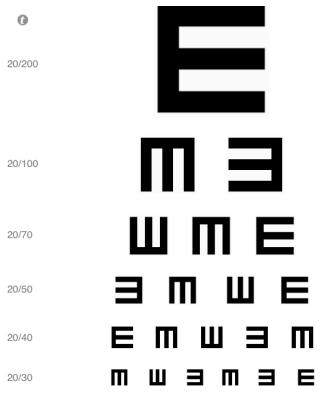


Figure 5. Snellen's illiterate E form

3-1.3 Experiment 1 – The environment setting

The distances between person and tablet PC are 300cm, 250cm, and 200cm respectively.

There are two levels in the brightness of environments, the bright one is above 500 Lux, and the dark one is under 0.01Lux.

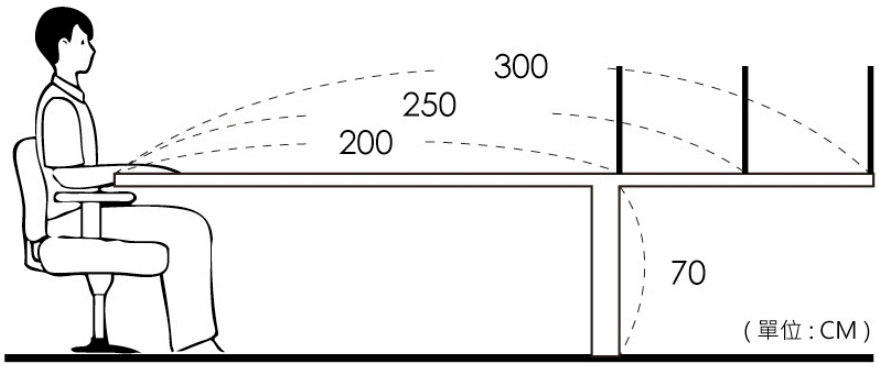


Figure 6. The distances between person and tablet PC

3-2 Experiment 2

3-2.1 Experiment 2 - The visual performance, subjective and objective visual fatigue by color combinations

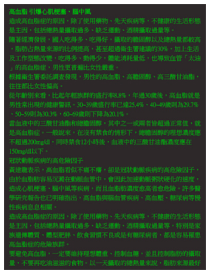
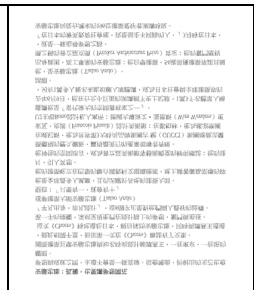
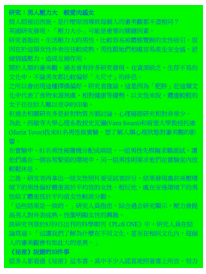
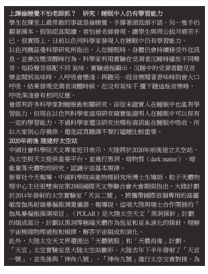
Table 5. The experiment of visual performance, subjective and objective visual fatigue flow chart

Part I	Setting experimental variable and environment (bright/ dark)
Part II	Study subjects: 17 men and 17 women
	The measurement of adjustment force of ciliary body before experiments
	Experiments in bright and dark environment
	The measurement of adjustment force of ciliary body after experiments
Part III	Subjective questionnaire survey
Part IV	Analysis and discussion

3-2.2 Experiment 2 – The combinations of colors

The combinations in the experiment 2 are selected by the best and worst five samples in experiment 1. There are BK/G, BK/W, W/BK, G/BL, and BL/G. The targets are the articles on news by a non-random sampling, and the font is PMingLiU and 14pt. The word spacing is 1.5 times. The time of reading is 30 minutes.

Table 6. The color combinations sample in experiment 2

				
BK/G	W/BK	G/BL	BK/W	BL/G

3-3 Equipment and Conditions

3-3.1 Equipment and software

1. I Pad 2 tablet PC
2. Auto Refractokeratometer speedy-K
3. Adobe reader
4. Subjective visual fatigue 9-point scale

3-3.2 Experimental location

1. Laboratory in university

3-3.3 Conditions of subjects

1. Eyesight: the degree between 0.8~1.2, and without color blindness.
2. Age: under 45 years old
3. Education: educated by Chinese schooling over 12 years.

4. Results and Discussion

4-1 Analysis and discussion in experiment 1

Table 7. Legibility in bright environment

	W/BK	BK/W	W/ BL	BL/W	R/W	W/R	G/BK	BK/G	BL/G	G/BL
Best~Worst (1~10)	1	10	6	3	5	8	7	9	2	3

Table 8. Legibility in dark environment

	W/BK	BK/W	W/ BL	BL/W	R/W	W/R	G/BK	BK/G	BL/G	G/BL
Best~Worst (1~10)	3	9	3	2	3	8	6	10	1	7

Table 9. Legibility in both bright and dark environment

	W/BK	BK/W	W/ BL	BL/W	R/W	W/R	G/BK	BK/G	BL/G	G/BL
Best~Worst (1~10)	2	10	3	4	7	8	4	9	1	6

The result of experiment 1 shows that the combination of W/BK has the best legibility in the bright environment, and in the dark environment, BL/G is the best combinations for the legibility. Furthermore, the combination of BK/W has the worst legibility in bright environment. And in the dark, BK/G is the worst combination for the legibility. Both of them are negative presentation.

4-1.4 Legibility and gender

According to the experiment 1 shows that no matter the environment in overt or covert, the numbers of correct answers by the women are more than men. Therefore, the legibility of women outperformed men. The results of this study verify the eyes physiological structure between men and women differ, and the sensitivity to color is also different from the previous literature. Female retina has much more P cells whereas there are lot of M cells in the retina of the male. P cells are responsible for detecting color and texture. So, for the experiment of legibility, the excellent performance of women is superior to men.

4-2 Analysis and discussion in experiment 2

Table 10. ANOVA of color combinations

Variable		Sum of squares	Degrees of freedom	Quadratic mean	F test	Significant test (P-value)
Subjective questionnaire	Between	2681.353	4	670.338	3.913	.005
	Within	28267.735	165	171.320		
	Sum	258132.788	169			
Objective instrument	Between	67.941	4	16.985	10.301	.000
	Within	272.059	165	1.649		
	Sum	340.000	169			
Visual performance	Between	335.447	4	83.862	1.488	.042
	Within	30166.559	165	182.828		
	Sum	30502.006	169			

*Less than 0.05 are written as "p < 0.05" and are assumed to be significant.

Table 11. Visual fatigue by subjective questionnaire in bright environment

	BK/G	W/BK	G/ BL	BK/W	BL/G
Best~Worst (1~5)	4	1	3	2	5

Table 12. Visual fatigue by subjective questionnaire in dark environment

	BK/G	W/BK	G/ BL	BK/W	BL/G
Best~Worst (1~5)	2	1	3	4	5

The result of experiment 2 indicates that BL/G has the worst visual fatigue in both bright and dark environments, and W/BK is the best in both environments according to the subjective visual fatigue 9-point scale.

4-3 Analysis and discussion in experiment 2 Part 2

Table 13. Visual fatigue by objective instrument in bright environment

	BK/G	W/BK	G/ BL	BK/W	BL/G
Best~Worst (1~5)	1	3	2	4	5

Table 14. Visual fatigue by objective instrument in dark environment

	BK/G	W/BK	G/ BL	BK/W	BL/G
Best~Worst (1~5)	4	2	1	5	3

BK/G is the best combination for the visual fatigue by objective instrument (Speedy-K) in the bright environment, and the worst combination is BL/G. In the dark, the best one is G/BL, and BK/W is the worst combination.

4-4 Analysis and discussion in experiment 2 Part 3

Table 15. Visual performance in bright environment

	BK/G	W/BK	G/ BL	BK/W	BL/G
Best~Worst (1~5)	2	4	5	1	3

Table 16. Visual performance in dark environment

	BK/G	W/BK	G/ BL	BK/W	BL/G
Best~Worst (1~5)	3	2	5	1	4

On the other hand, BK/W is the best combination for the visual performance in both bright and dark environment, and the worst one is G/BL in both two environments.

5. Conclusion and Review

5-1 Conclusion in experiment 1 and 2

Table 17. Effect of tablet PC screen color combination on vision in bright and dark environments

		Legibility	**Visual Performance**	**Visual Fatigue (Subjective)**	**Visual Fatigue (Objective)**
Bright	**Best**	W/BK (P)	BK/W (N)	W/BK (P)	BK/G (N)
	Worst	BK/W (N)	G/BL (P)	BL/G (N)	BL/G (N)
Dark	**Best**	BL/G, (N)	BK/W (N)	W/BK (P)	G/BL (P)
	Worst	BK/G (N)	G/BL (P)	BL/G (N)	BK/W (N)

(P): Positive presentation; (N): Negative presentation

The result of experiment 1 shows that the combination of W/BK has the best legibility in the bright environment, and in the dark environment, BL/G is the best combination for the legibility. Furthermore, the combination of BK/W has the worst legibility in bright environment. And in the dark, BK/G is the worst combination for the legibility. Both of them are negative presentation.

The result of experiment 2 indicates that W/BK has the best visual fatigue in both bright and dark environments, and BL/G is the worst in both environments according to the subjective visual fatigue 9-point scale. BL/G also has

the worst performance in the environments for objective visual fatigue. In addition, BK/G is the best combination in the bright environment. And the best one in dark is G/BL, the worst in the dark for objective visual fatigue is BK/W.

On the other hand, no matter it is in bright or dark environment, the worst combinations of color in visual fatigue experiments are negative presentation. Moreover, the best color combinations in dark for visual fatigue are positive presentation. And in bright environment, the best combinations for objective experiments are both negative presentation.

In summary, this study has discovered that there should be different combinations of colors while people are reading with tablet PC in the environment under different brightness levels. The conclusion has indicated that there is an obvious effect upon the visual fatigue while reading in different brightness levels of environment.

6. Examples Citations

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