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Effects of Viewing Angle and Contrast Ratio on Visual Performance using TFT-LCD

Chin-Chiuan Lin*, Ming-Te Chen**, Kuo-Chen Huang***
* (Department of Business Administration, Kun Shan University, Taiwan)
** Department of Industrial Management, Oriental Institute of Technology, Taiwan
*** Department of Product Design, Ming Chuan University, Taiwan

ABSTRACT
This study intends to investigate the effects of viewing angle for horizontal and vertical axis, and contrast ratio on visual performance during TFT-LCD visual work. Two dependent measures are collected: visual acuity and search performance. The measure of minimal separable visual angel of Landolt-C is used to evaluate the visual acuity. Search performance measured by correct percentage of searching task on pseudo-text. Results showed that viewing angle for horizontal and vertical axis, and contrast ratio significantly affect visual performance. Subjects at 0° and 15° on horizontal and vertical axis had better visual performance than at 30° and 45°. Visual performance increased as contrast ratio increased up to 11:1 and then slightly decreased once the contrast ratio was greater than 11:1.
***Keywords* -** Viewing angle, Contrast ratio, Visual performance, TFT-LCD

I. INTRODUCTION

The extent and frequency of human-computer interactions has increased greatly, because of the high-speed Internet access and the growing popularity of web browsing. Therefore, visual display terminals (VDT) had became the indispensable facility over the past years for workers. Furthermore, thin film transistor liquid crystal displays (TFT-LCDs) with light emitting diode (LED) backlighting are now becoming the optimal choice for VDT due to their low power consumption, rapid price reduction, improved optical characteristics, large variety of display size, better visual performance, and better subjective preference.

Viewing angle is one of the important factors that might affect the visual performance of TFT-LCD. Viewing angle not only affected visual performance and subjective preference [1.2], but also visual discomfort [2,3] for VDT workers. Further, inadequate viewing angle might induce more visual pressure [2,4,5]. However, most previous studies were concern on cathode ray tube (CRT). For the past decade, the engineers were strived on improving optical characteristic of the TFT-LCD to obtain wider viewing angle [6,7]. Furthermore, there are also have researchers studied on control the viewing angle to obtain optimal condition of TFT-LCD workstation placement design [8].

Contrast ratio is the most important component of color combination on VDTs [9-12]. Shieh and Lin [9] found that contrast ratio play an important role on visual performance. Wang and Chen [10] found that contrast ratio significantly affected visual acuity. Visual acuity increased as contrast ratio increased up to 8:1 and then decreased once the contrast ratio was greater than 8:1. Lin [11] indicated that subjects performed better with the higher contrast ratio than with the lower contrast ratio. Lin and Huang [12] also indicated that visual perception time was shorter at high contrast ratio than at low contrast ratio.

However, ergonomic studies about the interaction of viewing angle, contrast ratio, and the interaction on visual performance with TFT-LCD are rare. Therefore, there is needed empirical investigation the effects of viewing angle, contrast ratio, and their interaction on visual performance using TFT-LCD.

II. METHODOLOGY

2.1 Experimental Design

This study aims to investigate the effects of horizontal viewing angle, vertical viewing angle, and contrast ratio on visual acuity and search performance during TFT-LCD visual work.

There are four levels of viewing angle for both of horizontal and vertical axis: 0°, 15°, 30°, and 45°. Five levels of contrast ratio were tested: 5:1, 7:1, 9:1, 11:1, and 13:1. Gray was used for the target and the background color [9,13,14] in order to prevent chromatic aberration [15] and confounding chromatic contrast [16]. The *x* and *y* values in CIE chromaticity coordinates were about 0.333. The target luminance was 5 cd/m^2. The background luminance were 25, 35, 45, 55, and 65 cd/m^2 for contrast ratio 5:1, 7:1, 9:1, 11:1, and 13:1, respectively. The polarity was fixed and the presentation condition was positive polarity [9,17].

The viewing angles of horizontal and vertical axis are between-subjects factors and the contrast ratio is within-subjects factor. There were 80 treatment combinations (4 horizontal viewing angles × 4 vertical viewing angles × 5 contrast ratios). Four subjects were randomly assigned to each of the 16 treatment combinations of the between-subjects factors. Each subject completed 5 levels of contrast ratio, the within-subjects factor.

2.2 Subjects

Sixty four female college students were enrolled as subjects (age range = 19-22 years) in order to avoid gender effect. All subjects had normal color vision and at least 0.8 corrected visual acuity.

2.3 Apparatus

A 17-in., CMV 745A TFT-LCD with a 433-mm diagonal screen provided an active viewing area of 338 mm horizontally and 272 mm vertically. The pixel resolution was 1024 horizontally and 768 vertically, and the center-to-center pixel spacing was about 0.35 mm. The screen images were refreshed at a rate of 72 Hz. The maximal luminance contrast ratio value and maximal luminance of the TFT-LCD were about 150 and 210 cd/m^2, respectively. The screen surface was coated with SiO_2 polarizer to reduce glare and reflection.

A Topcon SS-3 Screenscope and standard Pseudo-Isochromatic charts were employed to test the visual acuity and the color vision of the subjects, respectively. The contrast ratio values of TFT-LCD screen was measured using a Laiko Color Analyzer DT-100.

2.4 Workplace Conditions

The TFT-LCD was positioned on a table 73 cm in height [18]. A headrest restrained the subjects' head 25 cm above the table and kept their viewing distance at 45 cm during the experiment. The ambient illumination was produced by fluorescent lamps. The luminance intensity was about 600 lux [19,20]. No glare appeared on the TFT-LCD screen. Before the experiment, the subjects were permitted to adjust their seating positions to make themselves as comfortable as possible.

2.4 Task and Procedure

The experiment was divided into two stages. The subjects performed the experiment according to the stage order. The procedure of the experiment was shown in Figure 1. Before the experiment, the treatment sequence of contrast ration for each subject was determined by drawing lots. To prevent visual fatigue, subjects were required to avoid any kind of visual task for at least 0.5 hour prior to the experiment.

In the first stage, Landolt-C ring was used to measure the subjects' visual acuity. The subjects' task was to recognize the gap direction of the Landolt-C ring and to press the corresponding cursor keys on the computer keyboard.

The gap size of the Landolt-C ring was presented in either a descending then ascending order, or, in an ascending then descending order. The directions of the Landolt-C gap were randomly presented by the computer. Each gap size of the Landolt-C ring was presented several times with different directions to ensure that the subject really recognized the gap direction.

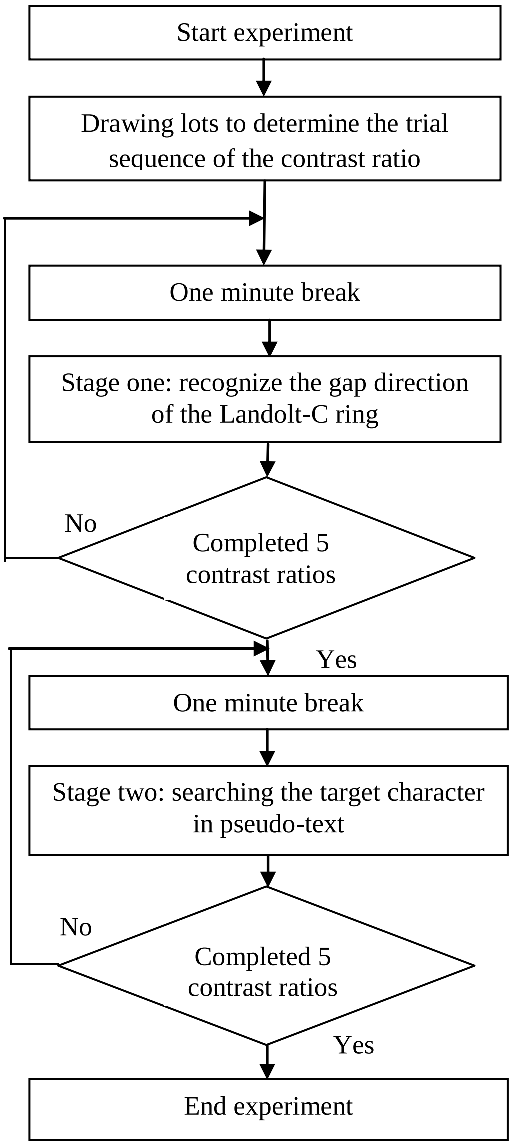

Fig.1. The experiment procedures

For each trial, a warning tone occurred simultaneously with the presentation of an "X" at the center of the screen. About 1 second later, a Landolt-C ring was presented at the same position. Subjects had to recognize the gap direction of the Landolt-C ring within 5 seconds. To familiarize the subjects with the trial, they performed 2 training trials before the experiment. Between the training and the trails, there is about 5 seconds break to prevent visual fatigue. Each treatment combination lasted about 4-5 minutes. For each subject, the 5 within-subject treatment combinations lasted about 0.5 hour.

The second stage was aim to measure the subjects' search performance. The target character was presented at the screen center about 5 seconds and then pseudo-text was presented. The subjects' task was to find and marked the target character. There are 4 pages pseudo-text and the subjects must finish each page pseudo-text within 1 minute.

The whole experiment for each subject lasted about 1.5 hours, including regular intermissions to reduce visual fatigue.

2.6 Dependent Measures and Data Analysis

The first stage collected the measure of minimal separable visual angel to evaluate the visual acuity. The second stage collected the percentage of correct search to evaluate the searching performance. Analysis of variance was conducted using Statistical Analysis System (SAS 9.0) and calculate of effect size was conducted using Statistical Products and Service Solutions (SPSS 13.0).

III. RESULTS

3.1 Visual Acuity

The visual acuity under each level of the independent variables is shown in Table 1. The results of ANOVA (Table 2) indicated that all main effects, namely horizontal viewing angle ($F_{3,48}$ = 49.35, p < .0001), vertical viewing angle ($F_{3,48}$ = 36.30, p < .0001), and contrast ratio ($F_{4,192}$ = 5.00, p = 0.0007) had significant impact on the visual acuity.

Duncan multiple paired-comparisons (Table 1) indicated out that the visual acuity at 0° (1.0101) and 15° (0.9894) were significantly greater than that for 30° (0.9625) and 45° (0.8263) for horizontal viewing angle. For vertical viewing angle, 0° (1.0025) and 15° (0.9831) also resulted in the better visual acuity than that for 30° (0.9594) and 45° (0.8438). Visual acuity increased as contrast ratio increased up to 11:1 and then slightly decreased once the contrast ratio was greater than 11:1. The interaction effects are not reached statistically significant levels (Table 2).

3.2 Search Performance

The search performance under each level of independent variables is also shown in Table 1. The results of ANOVA (Table 2) indicated that all main effects, namely horizontal viewing angle ($F_{3,48}$ = 7.37, p = 0.0004), vertical viewing angle ($F_{3,48}$ = 7.57, p = 0.0003), and contrast ratio ($F_{4,192}$ = 2.75, p = 0.0294) had significantly impact on the search performance.

Table 1. Experiment results and Duncan grouping

Dependent variable	Independent variable	n	Mean	Duncan grouping		
Visual acuity	Horizontal axis					
	0°	80	1.0101	A		
	15°	80	0.9894	A		
	30°	80	0.9625		B	
	45°	80	0.8263			C
	Vertical axis					
	0°	80	1.0025	A		
	15°	80	0.9831	A		
	30°	80	0.9594		B	
	45°	80	0.8438			C
	Contrast ratio					
	11:1	64	0.9617	A		
	9:1	64	0.9609	A		
	13:1	64	0.9508	A		
	7:1	64	0.9406	A	B	
	5:1	64	0.9219		B	
Search performance	Horizontal axis					
	0°	80	84.31%	A		
	15°	80	83.23%	A		
	30°	80	81.24%	A		
	45°	80	75.04%		B	
	Vertical axis					
	0°	80	85.16%	A		
	15°	80	83.10%	A	B	
	30°	80	80.05%		B	
	45°	80	75.50%			C
	Contrast ratio					
	11:1	64	82.69%	A		
	13:1	64	82.47%	A		
	9:1	64	81.55%	A	B	
	7:1	64	80.23%	A	B	
	5:1	64	77.83%		B	

Duncan multiple paired-comparisons (Table 1) indicated out that the search performance at 0° (84.31%), 15° (83.10%), and 30° (81.24%) were significantly greater than that for 45° (75.04%) for horizontal viewing angle. For vertical viewing angle, 0° (85.16%) resulted in the best search performance, followed by 15° (83.10%), 30° (80.05%), and 45° (75.50%). Search performance also increased as contrast ratio increased up to 11:1 and then slightly decreased once the contrast ratio was greater than 11:1. Similarly, the interaction effects are not reached statistically significant levels (Table 2).

IV. DISCUSSION

Visual performance was significantly better at 0° and 15° than that for 30° and 45° for both of horizontal and vertical axis. This result was similar to previous studies [21,22]. Shieh and Lee [21] indicated that vertical axis is 29.5° below horizontal eye level might better for users. Oetjen and Ziefle [22] reported that the mean discrimination time for the 0° was 512.16 ms which is better than the 50°, discrimination took a mean of 647.32 ms. This result also consistent with the general suggested vertical axis 20° below the horizontal line of sight to keep orthogonal of the viewing angle and screen (vertical axis 0°).

Contrast ratio 11:1 resulted in best visual acuity. This result is similar with Lin and Huang [12] that high luminance contrast ratio (greater than 8:1) seemed to be the optimal choice for VDT workplace design with TFT-LCD. This result also consistent with Wang and Chen [10] that visual acuity increased as contrast ratio increased up to 8:1 and then decreased once the contrast ratio was greater than 8:1. Further, that might be existed an optimal range of contrast ratio value [23].

The interactions among independent factors were not significantly affected visual performance is out of our expected. But, the effect size (η_p^2) [24] shows the horizontal and vertical axis have most effect on visual acuity and search performance. The effect size of horizontal and vertical axis for visual acuity were 0.3676 and 0.2704, respectively, which are significantly greater than the effect size of contrast ratio (0.0156). The effect size of horizontal and vertical axis for search performance were 0.0948 and 0.0973, respectively, which are also significantly greater than the effect size of contrast ratio (0.0235). This result indicated that the viewing angle might play more important role than contrast ratio when viewing angle within adequate ranges.

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Table 2. ANOVA for experiment results

Dependent variable	Source	df	SS	MS	*F-value*	*Pr>F* [a]	η_p^2
Visual acuity	Horizontal axis (H)	3	1.6531	0.5511	49.35	<.0001	0.3676
	Vertical axis (V)	3	1.2159	0.4053	36.30	<.0001	0.2704
	H*V	9	0.1644	0.0183	1.64	0.1319	0.0366
	Contrast ratio (C)	4	0.0702	0.0176	5.00	0.0007	0.0156
	H*C	12	0.0288	0.0024	0.68	0.7661	0.0064
	V*C	12	0.0635	0.0053	1.51	0.1237	0.0141
	H*V*C	36	0.0915	0.0025	0.72	0.8751	0.0203
	Sub(H*V)	48	0.5360	0.0112			
	Sub(H*V*C)	192	0.6740	0.0035			
	Total	319	4.4974				
Search performance	Horizontal axis (H)	3	4121.8	1373.9	7.37	0.0004	0.0948
	Vertical axis (V)	3	4230.4	1410.1	7.57	0.0003	0.0973
	H*V	9	900.3	100.0	0.54	0.8404	0.0207
	Contrast ratio (C)	4	1020.2	255.0	2.75	0.0294	0.0235
	H*C	12	884.7	73.7	0.80	0.6547	0.0203
	V*C	12	1135.7	94.6	1.02	0.4308	0.0261
	H*V*C	36	4469.1	124.1	1.34	0.1090	0.1027
	Sub(H*V)	48	8945.1	186.4			
	Sub(H*V*C)	192	17791	92.7			
	Total	319	43498				

[a] $p<0.01$ significant level; Effect size (η_p^2) = SSE/SST.

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