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Visual Impact of the Illuminations of LCD Monitor Under Different Ambient Lightings

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Abstract

As criticisms about the eyestrain of computer monitor are increase, the interaction between human and VDTs has been examined. The studies of visual performance of LCD monitor are emphasized with numerous advantages. The study investigated the differences of visual comfort among three levels of illumination of an LCD monitor and ambient lighting. A statistical experience was conducted concerning the procedure of ISO's recommendations with sample participants in the selected are. After the analysis of the data using ANOVA, the result showed the statistically significant difference and significant interaction between two variables. The combination between both medium ambient condition performs the highest visual comfort without the concerns of three illuminations of LCD monitor. Furthermore, the visual comfort between illuminations under the medium ambient brightness illuminations did not have an influence on the visual performance.

VISUAL IMPACT OF THE ILLUMINATIONS OF LCD MONITOR UNDER DIFFERENT AMBIENT LIGHTINGS

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ABSTRACT

As criticisms about the eyestrain of computer monitor are increased, the interaction between human and VDTs has been examined. The studies of visual performance of LCD monitor are emphasized with numerous advantages. This study investigated the differences of visual comfort among three levels of illumination of an LCD monitor and ambient lighting. A statistical experience was conducted concerning the procedure of ISO's recommendations with sample participants in the selected area. After the analysis of the data using ANOVA, the result showed the statistically significant difference and significant interaction between two variables. The combination between both medium ambient lighting and illumination was highest among selected nine combinations, and the medium ambient condition performs the highest visual comfort without the concerns of three illuminations of LCD monitor. Furthermore, the visual comfort between illuminations under the medium ambient brightness illuminations did not have an influence on the visual performance.

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INTRODUCTION

Overview

As technology progresses, the computer dominates over most of our lives today. In an article, the author mentions that "more than two-thirds of U.S. employees are online at work and more than half of all U.S. households have computers, and the average computer user spends 950 hours at a computer each year at work and approximately 300 hours in front of a computer at home, equivalent to more than 50 full days each year" ("Don't Let Your Computer," 2000, p. 53). For many of these computer users, it is a great concern that the monitor of the computer may damage eyesight. Another article also reveals that the issue, called Computer Vision Syndrome (CVS) by the American Optometric Assn, "may affect as many as 75 to 90 percent of computer users and result in eyestrain, headaches, blurred vision, dry and irritated eyes, neck ache and backache, sensitivity to light, and double vision" (Anshel, 1997, p. 17). Moreover, According to Phillips (2002, p. 9), "a computer could permanently invade children's eyes, and almost one-third of children may need an assistant to sight such as spectacles, specifically prescribed for computer use to stop them from developing short sightedness." From these controversies, the computer users require the immediate improvement of their computer monitors.

In this movement, numerous researches about the visual performance for visual display terminal (VDT) have been addressed. In those researches, a liquid crystal display (LCD) monitor is emphasized as one key technology substituting for the cathode ray tubes (CRT) display. Aside from being compact, emitting less heat, and consuming a little electrical energy, the LCD monitor has a possibility to alleviate occurrences of weakened eyes, compared with CRT display. A number of researchers have reported the great

advantages of LCD in comparisons to CRT. They revealed that the LCD monitor has the potential of less flicker effects, fewer reflections, and sharper images. The artificial flicker is considered as a causation of failing visual stability (Murakami, 2003). Menozzi, M., Näpflin, U. & Krueger, H. (1999) studied the visual performances and suitability on two types of displays: CRT and LCD. The authors identified that the visual performance of LCD was 34 percent higher than that of CRT, and the suitability was twice as much. In this way, these results indicated that the LCD in the experience gave better viewing conditions in comparison to CRT.

For these reasons, the LCD monitor has also been improved rapidly with its popularization, recently. Just a few years ago, the qualities of LCD screens had problems, such as "specula and diffuse reflection" of the monitor, but the latest versions of LCD are almost similar or even higher in "terms of resolution to monochrome CRT displays providing the highest overall image quality" (Weibrecht, 1999, p. 146). The LCD angle-viewing problem, which was one of biggest dilemmas, also has already been achieved by some groups of the business market; for instance, the IBM display group proves "a high resolution wide viewing angle TFT-LCDs based on ridge and fringe-field structure" (Lien, Cai, John, Galligan, & Wilson, 2001, p. 9). COMTEX News Network (2003, p. 1008071) announces "the worldwide LCD display revenues will increase to over 20 billion US dollars in 2003, surpassing traditional cathode ray tube (CRT) monitors for the first time."

However, LCD has still ample scope for improvement. While most of the studies for VCD addressed on the reflection, angle viewing and illuminations, researches in the ambient illumination, especially for TFT-LCD monitors, have been rarely conducted (Shieh & Lin, 2000). Although ISO or other organizations recommended the standard for VDT by

studies of laboratories, the methods of researches have not had strong repeatable evidence (Lindfors, 1998). Moreover, from a perspective of the human eye mechanism, which is called light adoption, the visual comfort of LCD monitors can be more improved. If the brightness of the backlight can be modulated into levels fitting the darkness surrounding the monitors, we might experience more comfort. In the actual case, the brightness of LCD monitors can be controlled by manual operation, but the operators seldom pay any attention to the brightness, except for the initial setup. The environment of households where computer are used is usually not stable, and the users do not regard the illumination unfitting for ambient lighting. Therefore, it may be necessary for the brightness to be controlled automatically with optical sensors seated in the monitor. Through this study, it is expected to pilot to make real of the idea of an auto-adjustable monitor, providing the brightness of the backlight with the optical sensor in the future.

Statement of Problem

The problem of this study was to investigate the differences of visual comfort among various levels of illumination of an LCD monitor and ambient lighting. The luminance of an LCD monitor might influence the eyesight in some distinct ambient light environment surrounding the monitor. If the most appropriate luminance of LCD monitor for the ambient light environment was revealed through the finding, it could improve human visual comfort.

Statement of Purpose

The purpose of this study was to give the LCD business market a suggestion on the commercial value of knowing the practical differences, which can improve the comfort of monitors to computer users. In addition, by adding a function, such as making an

auto-adjustable monitor to ambient lights, it was expected that the monitor could help to reduce the occurrences of weakened eyes as well.

Statement of Needs

The following needs for this study were based on computer users' needs:

1. The computer users want to reduce monitor glare and alleviate occurrences of Computer Vision Syndrome (CVS).
2. LCD has still ample scope for improvement with rapid popularization.
3. The studies of ergonomic evaluations that address visual performances for LCD have been relatively few conducted with insufficient evidences.
4. The ambient illumination for VDTs is considered as an important element, but the studies have not shown enough practical data.

Statement of Research Question

The following questions were formulated to structure the study:

1. Can a viewer distinguish the comforts of illumination according to various ambient brightnesses surrounding the LCD monitor?
2. What level of luminance for the LCD monitor is most preferred by viewers in this study?
3. What level of ambient lighting for the LCD monitor is most preferred by viewers in this study?
4. Which combinations of ambient lighting and luminance for the LCD are preferred by viewers in this study?

Assumptions

This study was conducted under some assumptions. The assumptions were as follows:

1. The selected instrument, particularly the LCD monitor used in this study, will be standard-level.
2. All subjects in this study will answer honestly the questionnaires without any prejudice.
3. All subjects have proper eyesight, perception senses, and no disability for each test. There is no distinction in preference among physical conditions.
4. The subjects will prefer at least one illumination level of selected levels in this study.

Delimitations

The anticipated results of this study were reached under the following delimitations:

1. The scope of this study will be limited to only two variables: luminance and ambient lighting level. Any other variable factor, such as screen reflection and viewed angle, is considered as stable.
2. This study will be conducted in only three levels of ambient light, which is artificially made by bulb lights and fluorescent lights; there are considered as no light to be directed in the viewers' sight.
3. The suitability of illuminations will be measured on three selected conditions of illumination levels.
4. The number of samples will be limited to 10 - 15 subjects, which can refer to articles. (10 subjects: Menozzi & et al's research, 1999; Jonai, & et al, 2002).
5. The subjects of this survey will include students, faculty members or co-project team

members in the University of Northern Iowa.

6. Viewers' use of corrective lenses has no effect on preferences.

Definition of Terms

The definitions of special or pertinent terms are listed to clarify their use in context of the study. The terms defined with sited references are as follows:

- Illumination: the brightness from LCD monitor.
- Luminance: intensities of illumination, which can be set to 8 levels on the monitor in this study.
- Ambient light: a brightness surrounding the LCD monitor and viewers, which is considered to be no light directing to the viewers' sight. In this study, the levels of light will be 3-5 kinds of artificial brightness illuminated by electric bulb
- Liquid Crystal Displays (LCD): a display of information, as on laptop computers and flat panel monitors, "using a liquid crystal film that changes its optical properties when a voltage is applied" (Lueder, 2001; RANDOM HOUSE, 1992, p. 769).
- Cathode Ray Tubes (CRT): a computer display "dealing with the production of the electron beam and its focusing, its deflection, and the means for observing its movement: the screen" (Parr & Davie, 1959, p.17).
- Backlight: a light behind the liquid crystal film.
- TFT: the Thin Film Transistors, which is addressing LCD (Lueder, 2001).
- Computer Vision Syndrome (CVS): symptoms caused by staring into monitors, such as eyestrain, headaches, blurred vision, dry and irritated eyes, neck ache and backache, sensitivity to light, and double vision" (Anshel, 1997, p. 17).

REVIEW OF RELATED LITERATURE

Introduction

With the concerns of ergonomics related to healthy and safety conditions of the workplace, the visual performance is considered as a significant factor of requirement for visual display terminals (VDTs). The statistical researches of quality of visual performance have been mostly conducted in a transfer of subjective experienced performances worldwide. Visual display quality or image quality is primarily defined by "the degree to which images are adapted to the capacities of the user's visual information processing system" (Besuijen & Spenkelink, 1998, p. 67). The most widely known international standard regarding the requirement of office work with VDTs have been argued in Ergonomics of Human system interaction by International Organization for Standardization (ISO). In its publications, ISO provides various aspects of VDT uses and extensive general guidance for the workstation or layout including the normative levels of visual display requirement in reflections, visual display color, angled view quality and interaction between human and the flat panel display, such as view distance, view angle and ambient lighting. ISO also suggests the methodology and benchmark for standard test to evaluate visual performance, comfort, and effort in using VDTs in ISO 9241. Basing on these of ISO's suggestions, a number of researches of the visual quality of VDTs have existed and argued about the accuracy and problems for the test methodology.

Visual Performance

The visual performance of VDTs for comfort is known to depend on the display quality and visual environment or workstation layout, which include many components. Basically, the visual environment determines luminance balance and glare. Angle of view,

view distance and the contrast luminance largely influence the visual environment, and other factors like resolution, color image, settings on the display properties menu and temporal instability (flickers) can contribute to the mechanical display qualities. It is almost impossible to deal with all of the visual performance components at the same time. Therefore, it might be necessary to create a separate test, although most components of both environment and display quality are inter-depending on the others (multi-interaction). The few selected target variables to be manipulated can be measured by concerning the other components as stable independent variables.

The selected target variables in this study, which are luminance and ambient lighting are well know to have a strong relationship. Thus, the ambient lighting can impact on the selection of illumination levels. Technically, the luminescent intensity of LCD monitor is also different between the color variations and the magnitudes of the backlight. Shieh and Lin (2000) studied the impacts of visual performance of several background color combinations. The result identified that blue letters on yellow background was the best performance and purple-on red the worst. However, the variation of the color combination does not depend so much on user's selection. The task or used software often determines the color combination except some options of color selections. In practical case, the combination of blue-on yellow is less utilized in color patterns of the layouts of many applications. In this study, concerning selected cases, the background color is set in a stable default pattern in Microsoft word for every trial, which can be considered as the most frequently used in computer engagement.

Menozzi et al mentions that the general background luminance was varied within 45 and 150 cd/m^2 at the LCD monitor (2000). As a general recommendation for VDT

workstation, 200 to 500 lx ambient lighting is required (Shieh & Lin, 2000). In their research of visual performance test, the ambient illumination was set in two levels: one was 450 lx which is the normal lighting level for ordinary office, and another was lower lighting level 200 lx recommended by ANSI/HFS 100-1998 (Shieh & Lin, 2000). The result showed the percentage mean of performance for 450 lx ambient illumination was slightly higher than that for 200 lx. Despite of the suggestions of ambient lighting for office, in private office and household uses, the conditions of ambient lighting are not usually fitting to the requirement because many private computer users do not create stable and proper ambient lighting for the computer environment. Current monitor, the property menu has many options for the display setting, such as the adjuster of vertical and horizontal luminescence, intensity, and color. In fact, many users, nevertheless, are often even not aware of the options. The level of general household lighting is an unsettled value, which can refer to 0 to 400 lx. Emphasizing this reason and also the convenience, this research used selected three levels of ambient lighting within 0 to 400 lx.

Visual Performance and Comfort Test

The visual performance and comfort test proposed in ISO 9241-3 (1992) is developed by several researcher groups, during some laboratories in Europe, Asia, and U.S.A. agreed to participate in discussions and evaluate the metrology quality. Although there are a lot of the criticizing problems, the test has been most widely used in measurement of visual performances in the current age. This test procedure involves a search task for the target letters implanted in pseudo text. The test measured the effectiveness of a participant's performance transferred by the speed and accuracy in a visual search task of participant. The test can provide an overall visual quality reflected by

effectiveness of participant's performances and subjective comfort ratings for display using a category scale.

The accuracy and liability of the test has been argued in many cases. The big points of the criticisms are the complication and unrepeatable data of the test. The Visual Quality of a display that refers to a test display is assessed against a Benchmark display proposed in ISO. Both the velocity in the visual search task and the subjective ratings must meet certain minimum requirements for the test display to pass. Therefore, the layout and display configuration is specific situation and difficult setting. Another argument for this test is that the relationship between the outcome of performance effectiveness for the task and visual display performance is not simply connected because many other factors codetermine the performance level (Besuijen & Spenkelink, 1998). The participant's learning skill for the task is significantly related to the effectiveness of performances. They mentioned variation in performance between individuals is often larger than variation caused by differences between displays.

On the other hand, the subjective methods for visual comfort are more reliable. In many experience, the subjective rating methods of visual performances prove similar results (Besuijen & Spenkelink, 1998). They stated that there are the following three main reasons for better using subjective rating methods:

- In most cases performance did not result in significant differences between conditions, while the ratings did. Some possible explanations for this have been given above.
- They consistently found a positive correlation between both data sets: the pattern of results was identical.

- Ratings of visual display quality aspects such as contrast, brightness and font size, closely agreed with the physical attributes, and exhibited meaningful and mostly simple (linear or log-linear) relations.

Moreover, the method does not need to use the complicated software and can be easy to conduct many times. It may be possible to generalize the overall quality of the display for the situation excluding specific conditions. For these reasons, the method of display evaluation in this study is the main subjective rating.

In the latest proposal, the scale of subjective rating for visual performance and comfort should be better served with a detailed category. The test suggested in ISO publications has one general categorized scale, which is overall visual performance. This study more precisely defined the categorization of evaluation of visual performance as the glare and clearness of the monitor, eyes fatigue and the overall perception for visual performance. The average of these items can be considered as an assessment of balanced visual performance.

Statistical Treatment

The great numbers of statistical analysis methods of the results are carried to the test. The test treatment of results the ISO recommends is interpretation using sequential analysis. The interpretation of the finding is well-known to the Barnard's study (1946). The other alternative the main characteristic of the sequential analysis is that the sample size is not determined in advance. The validity of the hypothesis is tested after each set of results has been collected; significantly fewer test participants can be required to demonstrate compliance with the standard as the advantages of sequential analysis. In current procedure, statistical treatment of the results involves comparing the dependant measures for the test

display against a benchmark. Because exact no statistical treatment can prove that two products can be the same, the test in the standard is used to decide the performance in particular displays only. In order to reduce the cost of performance and the limitation of the academic semester course, this study computed the means, the standard deviations and variances in the treatment of the test. Then, the data was analyzed with p-values, degree of freedoms and mean squares using two ways of analysis of variance (ANOVA): single and two factor analyses, to make decision making for comparison to the visual performance.

METHODOLOGY

Summary

This research involved a survey through three distinct ambient light environments based on the visual performance and comfort test proposed by ISO 9241-3. With a designed experimental procedure the subjects from a selected university, the University of Northern Iowa, were limited in a minimum number. In order to investigate the differences of the visual performance among three ambient environments, a preference in subjective ratings of visual comfort was collected.

Experimental design

This study evaluated two independent variables: ambient light conditions and brightness of illumination. A dependant valuable, visual comfort or suitability of monitor will be investigated for combinations of ambient light conditions and brightness of illumination. The subjective preference for each combination will be selected by participants from an interval category scale of the nine steps of visual suitability.

Workstation

The laboratory used in this study will be a cubic room, which is located at the Industrial Technology Department in the University of Northern Iowa. The source of ambient light will be located above the participants, but there is no direct light to participants' eyes from source. The participant's role was supposed to be a searching and reading task that could be typical work for computer users. The background illumination of the monitor will be set to the default layout in Microsoft word 2000 software. Approximately two thirds of the layout will be filled with English characters that are 12

points, Times New Roman, Single space. The test was basically conducted in the standard conditions: ISO9241-3 (1992) and ISO13406-1&2 (1999 &2001). The viewing distance, which is the distance between the participant's eyes and the front of the display, will be set constant at 50 cm and at a right angle to display. The other variable distances and angles will be adjustable for constant viewing distance, which is referred to figure 1.

Conditions

The following conditions 1-3 of ambient light will be produced by both light bulbs. The other environment condition variables can be supposed to be stable.

- Condition 1

  There is no ambient light but only the illumination of the monitors. (0 – 10 lx. excluding display illumination)

- Condition 2.

  There is a 45 W light bulb. (50 - 100 lx.)

- Condition 3.

  There are two 60 W light bulbs. (150 - 300 lx.)

Figure 1. Work station

Modification of Instrument

This study will use a selected laptop computer, the FM V-BIBLO NE 7/800, Fujitsu. The 14.1 inch TFT -LCD digital flat panel monitor of the computer with diagonal screen provides an active view area of 1200 mm horizontal and 1600 mm vertical. The pixel resolution is 768 horizontal and 1024 vertical. The color resolution is setup on 24 bits. The optical sensor used for measuring brightness in this study is a digital light meter: SLM-110 (5% basic accuracy), by A.W. Sperry Instruments, Inc. The value of brightness is measured in foot-candle (fc) scale. The monitor can perform eight variations adjustable of the illumination to an interval scale for initial setup. From these variations, this study selects three levels: Brightness level 1, 2, and 3. As the referential values, the following brightness is measured by the optical sensor:

Illumination Brightness level 1: 2.2 $\pm$ 0.11 fc (23.671x),

Illumination Brightness level 2: 4.3 $\pm$ 0.22 fc (46.27 lx),

Illumination Brightness level 3: 6.4 $\pm$ 0.32 fc (68.86 lx),

This brightness was measured on a particular situation for this study. The background illumination of the monitor was set to the default layout in Microsoft Word 2000 software and the work condition was set to condition 1.

Subjects

The subjects will be approximately 15 - 25 college students or faculty staff members in University of Northern Iowa, who voluntarily participate. The ages of participants will be limited in a group between 18 and 40 years old. The groups will not be

categorized in races and genders; it will include international students. All participants assumedly will not have any visual disability (however, participants can include persons whose eyesight needs reinforcement).

Method of Data collections

The experience will be addressed by administrators following the flowchart of the protocol: figure 2. The test participants will evaluate three types of illuminations of the display for the condition 1 to 3; there are a total of nine trials for each participant. Before the evaluation of the display, the participants will be fully-adapted to ambient light by being placed in a workplace setup on each condition for a couple minutes prior to the test, and then, they will have a Letter Searching Task (approximately each 5 minutes) for each trial. After each task, a visual suitability of the LCD monitor for the combination will be accomplished by asking participants subjective ratings for four questions: 1). glare of monitor, 2). clearness of monitor, 3). eye fatigue, and 4). Overall visual comfort. The subjective ratings are composed of an interval scale of the nine steps of preference. It will be recorded using the check sheet of figure 3.

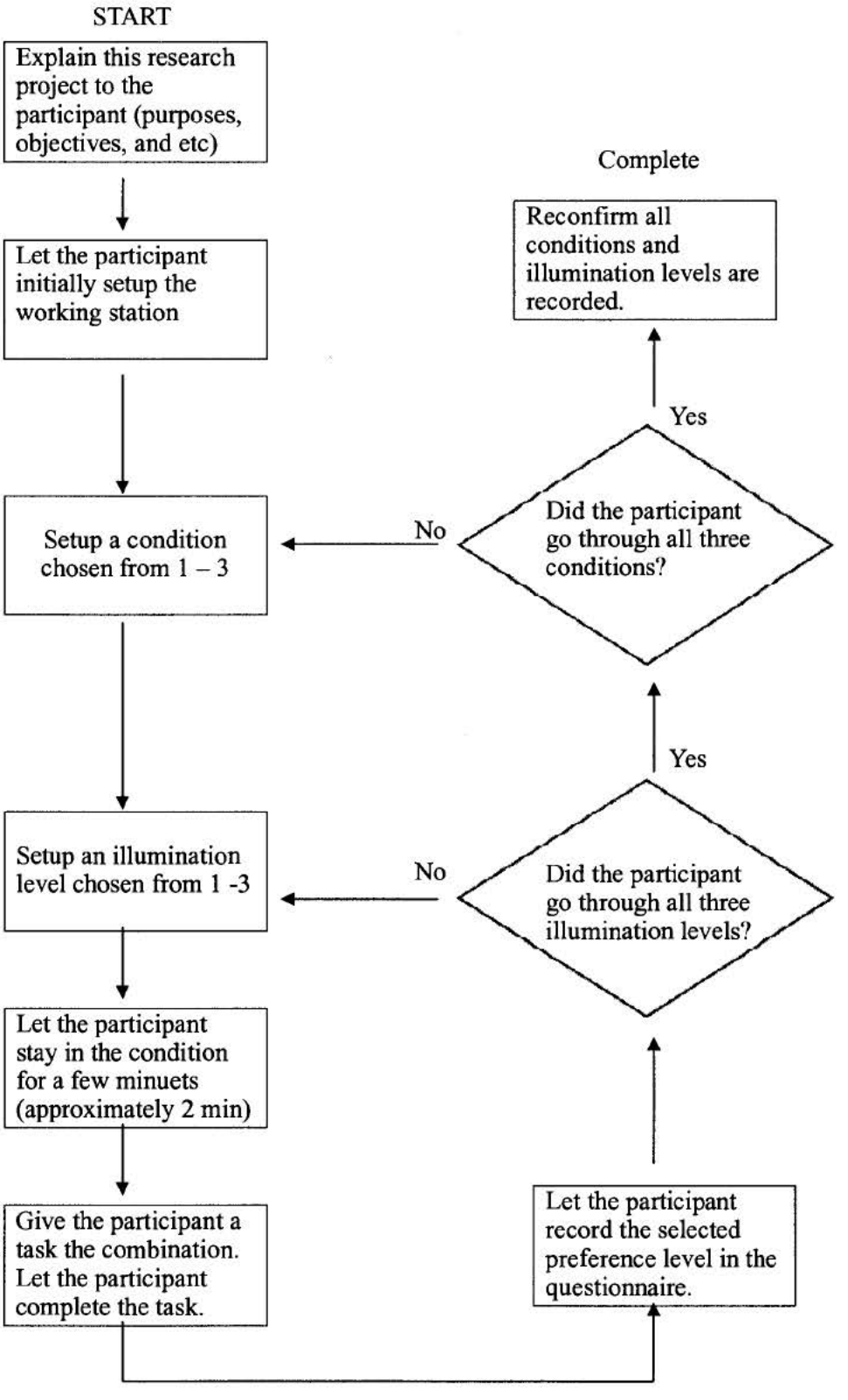

Figure 2. Flowchart of Experimental Protocol

Comfortable level	Poor				Neutral				Excellent
	1	2	3	4	5	6	7	8	9
Glare of monitor									
Clearness of monitor									
Eye Fatigue									
Overall Visual Comfort									

Figure 3. Check sheet

Letter Searching Task

The task that the participant will undertake for each trial is to find targets, each capital letter "**U**." Participants will count the numbers of "**U**" they find in an entire text. The participants should read the text from the top left to the bottom right only once, as if reading a normal page of text. After finishing the entire text, the participant will record the number of "**U**s." The task process is accomplished by the participant working through the screens as quickly and as accurately as possible. The texts and the number of targets varies in each trial of combinations, so the participant should pay careful attention to properly reading, searching and counting the presence of the target letter in each trial.

Text

The text will be composed of 54 letters randomly selected from capital English characters "A - Z", Arabic numbers "0 – 9", and space bars "–", which the probability of is three times more than the other characters (see the figure 4). The letters sized 12 points and

Times New Roman will be arranged as 30 characters in each line, 18 lines, single-spaces in the text. The program used to perform a random selection is Microsoft Excel software placed on Microsoft Word. The program is allowed enable to perform randomly variable texts for each trial.

V	M	R	Q	Z	3	M	9	Q	O	K	Y	I	Y	6	3	B	M	P	F	-	T	Y	W	D	E	F	J	B	Y
Z	N	C	8	-	Z	Z	R	-	G	A	8	P	8	-	Z	4	U	P	L	L	W	R	-	2	H	Z	P	D	M
T	4	B	2	C	9	2	X	8	-	2	C	2	C	U	A	F	T	7	Z	C	X	6	8	W	L	Y	3	M	L
C	2	4	4	W	C	S	C	Z	P	1	Z	2	U	1	-	5	Q	N	Q	J	S	1	C	I	D	6	B	8	-
2	-	N	5	9	H	M	Q	K	Z	R	Y	V	V	X	5	X	-	E	4	1	Q	Q	Z	Z	G	4	Y	J	Z
3	5	Z	-	T	5	1	H	E	8	Y	Z	-	E	H	A	Y	P	E	9	G	-	Q	8	T	-	6	-	K	6
Y	L	Q	P	U	O	C	F	4	Z	V	O	5	N	Y	P	M	K	M	N	M	V	Y	T	X	I	6	Z	1	N
S	-	-	1	Z	-	L	U	O	W	-	-	E	D	W	T	X	C	7	3	M	F	-	P	T	B	B	-	C	Y
P	-	F	8	-	-	7	E	T	P	X	7	-	-	5	S	7	5	B	Y	3	I	E	3	R	O	P	E	N	Z
V	N	Q	D	2	-	H	Y	S	4	E	S	R	-	7	R	8	V	7	2	N	V	Z	P	H	2	A	I	7	2
4	-	5	J	X	9	D	O	V	Z	-	D	L	R	Z	I	R	5	R	P	Z	F	C	W	F	L	G	F	C	-
E	C	B	M	Z	Q	T	K	U	V	-	P	8	C	Q	A	-	8	L	J	5	8	B	W	W	D	I	C	Q	A
M	M	S	9	V	M	Q	W	B	H	S	5	O	Z	L	Y	1	L	W	A	Z	K	-	6	F	N	L	8	S	M
U	9	O	G	3	4	E	-	R	P	9	X	J	D	G	B	-	R	-	5	V	-	E	8	E	1	P	L	U	R
X	I	W	1	6	G	S	J	M	W	N	Q	5	D	Z	Z	F	G	M	D	-	N	D	K	7	-	A	O	B	I
F	M	9	3	-	I	S	9	1	H	2	7	X	W	M	V	U	O	-	C	6	F	1	Z	-	Q	U	V	F	9
X	6	K	7	Q	3	N	-	Z	9	Z	-	R	6	L	V	X	D	P	3	6	Z	Y	U	Q	X	F	N	D	W
-	4	G	E	2	9	4	P	2	M	8	A	J	E	8	7	Y	Z	Q	U	G	M	8	C	-	Q	I	9	N	Z
D	Y	-	G	Q	S	9	7	-	6	C	D	V	-	-	K	E	G	Z	V	7	G	H	W	N	Y	1	G	Q	-

Figure 4. An Example of Text

ANALYSIS OF THE RESULT AND FINDINGS

After the experience was completed and all data was collected from participants, the information was organized, arranged, analyzed and interpreted. From the check sheet, the average of evaluations for the four questionnaires is calculated as an overall visual performance in each trial. The statistical programs, SPSS and Excel, were used to conduct the statistical analysis of the data of overall visual performance for the decision making. Using a statistic method, two ways of analysis of variance (ANOVA), which were single and two-factor analyses, the averages and standard deviations of suitability are calculated with some diagrams, tables and graphs. The p-value of ANOVA can determine the statistical significance. Then, the highest performance of illumination level for each ambient lighting level was investigated.

Single-Factor Observation: F test

Using Single Factor analysis of the ANOVA, statistical significant differences at the .05 level for each condition was computed. Table 1, 2 and 3 showed the result of summary of means and variances and ANOVA summary for each condition.

Condition 1

Table 1

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Illumination 1	21	135.25	6.44	2.42
Illumination 2	21	134.00	6.38	2.22
Illumination 3	21	104.75	4.99	3.67

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28.37	2	14.18	5.11	0.009	3.15
Within Groups	166.25	60	2.77			
Total	194.62	62				

As seen in ANOVA table, the P-value between groups is 0.009, which is below the 5 % level of factor University Position differ. Therefore, there is a statistically significant difference in performance on the test among these illuminations. The means for each illumination are: Illumination 1: 6.44, 2: 6.38 and 3: 4.99. Thus, illumination 2 performed better than illumination 3 and illumination 3 performed better than illumination 1 in this condition.

Condition 2

Table 2

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Illumination 1	21	142.75	6.80	2.40
Illumination 2	21	155.00	7.38	1.16
Illumination 3	21	146.75	6.99	2.21

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.72	2	1.86	0.97	0.39	3.15
Within Groups	115.34	60	1.92			
Total	119.06	62				

From the ANOVA table, the P-value can identify with 0.39, which is not satisfied with the 5 % level of factor University Position differ. Therefore, this test did not find a statistically significant difference in performance among these illuminations. However, the means for each illumination showed: Illumination 1: 6.80, 2: 7.38 and 3: 6.99. Although there were not the statistical significance, means showed that illumination 2 might perform best among three and illumination 3 might perform slightly better than illumination 1 in this condition.

Condition 3

Table 3

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Illumination 1	21	108.75	5.18	3.03
Illumination 2	21	135.00	6.43	2.83
Illumination 3	21	143.5	6.83	2.37

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	31.25	2	15.63	5.69	0.005	3.15
Within Groups	164.70	60	2.75			
Total	195.95	62				

In the ANOVA table, it showed that the P-value refers to 0.005, which can be evidence at the 5 % level of factor University Position differ. For this reason, there is a statistically significant difference in performance on the test among the illuminations. The means for each illumination are: Illumination 1: 5.18, 2: 6.43 and 3: 6.83. Thus, illumination 3 performed better than illumination 2 and illumination 2 performed better than illumination 1 in this condition unlike condition 1.

Two-Factor Observation: t Test

Next, using the ANOVA: Two-Factor with Replication, the interaction between two factors: illumination level and condition was observed. An interaction is said to exist when the two independent variables operate together or combine to have an effect on the dependent variable. The table 4 shows the summary of the ANOVA two-factor analysis. The performance average of data for each combination was organized into the Figure 5, and also, the graph shown into figure 6. Finally, the average of total visual performance for each condition and each illumination is seen in table 5 and 6 using ANOVA single factor.

		Illumination		
		L1	L2	L3
Ambient lighting	Condition1	6.440	6.381	4.988
	Condition2	6.798	7.381	6.988
	Condition3	5.179	6.429	6.833

Figure 5. The average of the sample data for each combination

Table 4

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Conditions (C)	12.15	2	6.08	2.45	0.089	3.05
Illuminations (I)	44.57	2	22.28	8.99	0.0002	3.05
C x I Interaction	51.19	4	12.80	5.16	0.0006	2.42
Within	446.29	180	2.48			
Total	554.20	188				

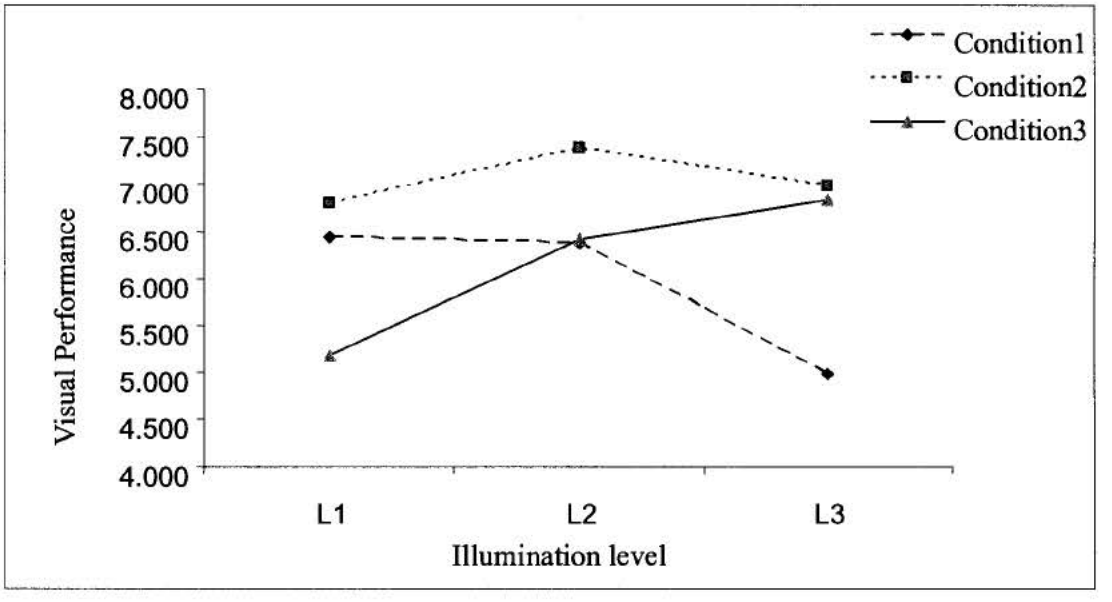

Figure 6. Graph for sample average

Table 5.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Illumination 1	63	386.75	6.139	3.02
Illumination 2	63	424	6.73	2.22
Illumination 3	63	395	6.27	3.50

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.15	2	6.08	2.09	0.13	3.05
Within Groups	542.05	186	2.91			
Total	554.20	188				

Table 6.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Condition 1	63	374	5.94	3.14
Condition 2	63	444.5	7.06	1.92
Condition 3	63	387.25	6.15	3.16

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	44.57	2	22.28	8.13	0.0004	3.045
Within Groups	509.63	186	2.74			
Total	554.20	188				

As seen in the ANOVA summary of table 4, the p-value of illumination and C x I interaction ($p = 0.0006$) had an evidence of level 5 % significant. From graph in figure 6, condition 1 and condition 3 showed statistically significant interaction. The combination of illumination 2 and ambient lighting condition 2 was highest performance among these combinations. However, the result of total performance of conditions in this test did not have a strong evidence concerning to the statistical significance also seen in table 5. Under condition 2, which is medium ambient lighting condition, LCD monitor can always provide best performance because the ambient lighting condition related to condition 2 was higher than any combination related to the others. Therefore, the ambient lighting condition affected more strongly on the visual performance than Illumination did. However, under condition 1 and condition 3, which have weak visual performance, the illumination levels influence the visual performance.

The relationship between conditions and illumination is shown in the figure 7. Like the expectation, the result indicated the correlation between these factors. The higher the level of ambient lighting condition, the higher the level of illumination is needed. This result corresponds with the conclusion of the Wittle' study (1994).

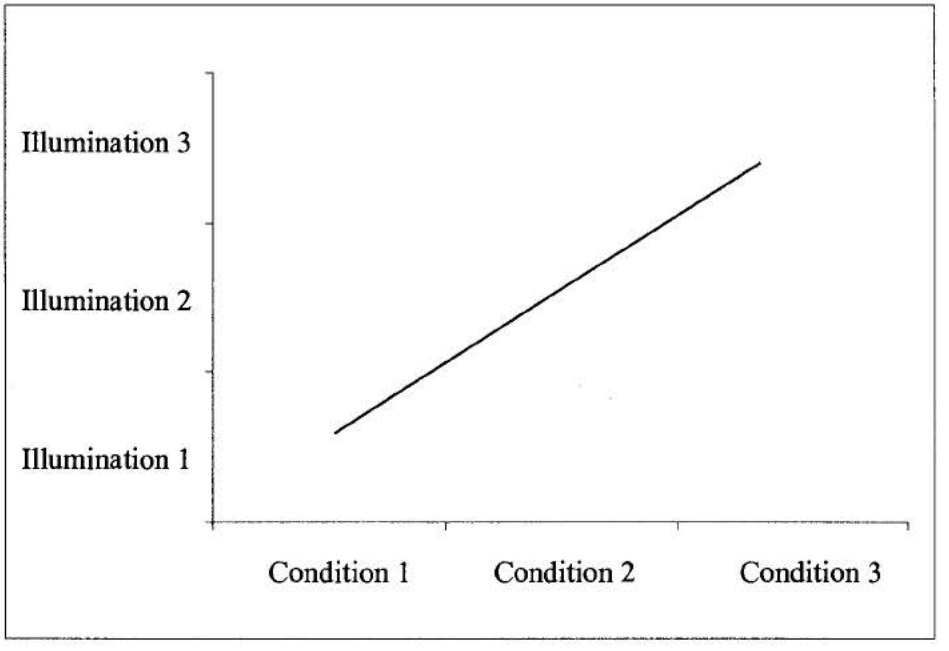

Figure 7. The relationship between conditions and illuminations

CONCLUSION

Answer to the Research Questions

The following research questions were answered to conclude this study:

1. Can a viewer distinguish the comforts of illumination according to various ambient brightnesses surrounding the LCD monitor?

   The result of this study indicate a significant distinction of visual comfort for condition 1 and condition 3, which were lower and the higher level of ambient lighting. However, under a certain ambient brightness, condition 2, the visual comfort between illuminations did not show the statistically significant difference.

2. What level of luminance for the LCD monitor is most preferred by viewers in this study?

   Under the condition 1, illumination 1 had highest performance of visual comfort.

   Under the condition 2, illumination 2 had highest performance of visual comfort.

   Under the condition 3, illumination 3 had highest performance of visual comfort.

3. What level of ambient lighting for the LCD monitor is most preferred by viewers in this study?

   Under the condition 2, which is medium ambient lighting condition, LCD monitor always provided the best performance because the ambient lighting condition related to condition 2 was higher than any combination related to the others in this study.

4. Which combinations of ambient lighting and luminance for the LCD are preferred by viewers in this study?

   The combination of illumination 2 and ambient lighting condition 2 was highest performance among these combinations in this study.

Overall Summary

This study was conducted on the visual performance among three different illuminations under three different ambient lightings. The results of the test showed several findings. As it was expected, the relationship between two independent variables, illumination of LCD monitor and ambient lighting, correlated. The most interesting finding is that the visual comfort between illuminations under the certain ambient brightness, condition 2, did not show a statistically significant difference. Especially, the condition provided high performance without the concerns of three illuminations of LCD monitor. However, it may be consideration that this study has been selected with only three particular illuminations. The graph in figure 6 apparently explains that expanding level of illumination in the condition 2, which is higher than illumination 3 or lower than illumination 1, can be interacted. In the condition 1 and 3, the visual performances were strongly depending on the illumination levels, but this study did not measure detail of the value of illumination level because of the limitations of academic class course work. To answer if the illumination should be adjustable to constant changing ambient light, this study was not enough evidences. As further recommendation, a practical value of relationship between these factors using scatter plot graph needs to be studied.

REFERNCES

Anshel, J. (1997, July). Computer vision syndrome: causes and cures. *Managing Office Technology 42*(7), 17-19. Retrieved March 21, 2003, from InfoTrac database.

Besuijen, K. & Spenkelink, G. P. J. (1998). Standardizing visual display quality. *Displays, 19*(5), 67-76. Retrieved January 31, 2003, from ScienceDirect database.

COMTEX News Network. (2003, March 13). Global LCD displays to surpass CRT monitors in sales. *Xinhua News Agency,* 1008071h6200. Retrieved April 12, 2003, from InfoTrac database.

Costello, R. B. & et al. (Ed.). (1992). *Random House webster's college dictionary*. New York: Random House Inc.

Don't let your computer eat away at your eyesight. (2002, November/December). *Office Solutions 19*(9), 53. Retrieved March 21, 2003, from InfoTrac database.

Fukuzumi, S., Ikeda, K. & ven Nes, F. L. (2002, November). Study on validity of visual performance and comfort test using Japanese characters. *Displays, 23*(5), 231-238. Retrieved January 31, 2003, from ScienceDirect database.

ISO: ISO13406-1. (1999). Ergonomic Requirements for Work with Visual Display Based on Flat Panels. Part 1. Introduction.

ISO: ISO13406-2. (2001). Ergonomic Requirements for Work with Visual Display Based on Flat Panels. Part 2. Ergonomic Requirements for Flat Panel Displays.

ISO: ISO9241-3. (1992). Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs). Part 3. Visual Display Requirements.

Lien, A., Cai, C., John, R. A., Galligan, E. & Wilson, J. (2001, March). 16.3" QSXGA high resolution wide viewing angle TFT-LCDs based on ridge and fringe-field structures. *Displays 22*(1), 9-14. Retrieved March 19, 2003, from ScienceDirect database.

Lin, Chern-S., Wu, Wei-Z., Lay, Yun-L. & Chang, Ming-W. (2001, October). A digital image-based measurement system for a LCD backlight module, *Optics & Laser*

Technology, 33(7), 499-505. Retrieved February 16, 2003, from ScienceDirect database.

Lueder, E. (2001) *Liquid Crystal Displays: Addressing shemes and electro-optical effects.* New York: John Wiley & Sons, Lid.

Lyskov, E., Ponomarev, V., Sandström, M., Mild, K. H. & Medvedev, S. (1998, May 1). Steady-state visual evoked potentials to computer monitor flicker. *International Journal of Psychophysiology 28*(3), 285-290. Retrieved February 10, 2003, from ScienceDirect database.

Menozzi, M., Näpflin, U. & Krueger, H. (1999, February 25). CRT versus LCD: A pilot study on visual performance and suitability of two display technologies for use in office work, *Displays, 20*(1), 3-10. Retrieved January 31, 2003, from ScienceDirect database.

Murakami, I. (2003, April). Illusory jitter in a static stimulus surrounded by a synchronously flickering pattern. *Vision Research 43*(9), 957-969. Retrieved April 12, 2003, from ScienceDirect database.

Parr, G. & Davie, O. H. (1959). *The cathode-ray tube and its applications.* New York: Reinhold Publishing Corp.

Phillips, H. (2002, April 13). Put on your PC specs. *New Scientist 174*(2338), 9. Retrieved March 21, 2003, from InfoTrac database.

Shieh, K. -K. & Lin, C. -C. (2000, November) Effects of screen type, ambient illumination, and color combination on VDT visual performance and subjective preference. *International Journal of Industrial Ergonomics, 26*(5), 527-536. Retrieved February 20, 2003, from ScienceDirect database.

Weibrecht, M. (1999, October). Display Technology for Radiology, *RBM-News 21*(7), 146 Retrieved March 14, 2003, from ScienceDirect database.

Whittle, P. (1994) Contrast Brightness and Ordinary seeing. In Gilchrist A. L. (Ed.), *Lightness, Brightness, and Transparency.* Hillsdale, NJ: Lawrence Erlbaum Associates. pp. 111-158.

BIBLIOGRAPHY

Colombo, E. & Derrington, A. (2001, July). Visual calibration of CRT monitors, *Displays, 22*(3), 87-95. Retrieved February 22, 2003, from ScienceDirect database.

DE VRIES, M. J. (1997, January). Science, Technology and Society: a Methodological Perspective *International Journal of Technology and Design Education 7*(1), 21-32. Retrieved February 20, 2003, from Kluwer Academic Publishers database.

Gong, S, (1999). Advanced materials and techniques for improving the viewing angle characteristics of AMLCDs. (Doctoral dissertation, University of Michigan, 1999). 148. Retrieved February 20, 2003, from UMI ProQuest Digital Dissertations database.

Kim, S.-J., Kwon, N.-O., Kim, Y.-M., Yang, D.-O., Hong, J.-W., Lee, Y.-G., Cho, T.-S., Kang, J.-G., Choi, E.-H. & Cho, G. (2002). Capacity Coupled Electrodeless Discharge Backlight Driven by Switching Inverter for 17" and 20.1" LCD TVs. *Sid International Symposium Digest of Technical Papers 33*(2), 1151-1153. Retrieved February 22, 2003, from Ingenta database.

Kubota, S. (1997, December 30). Reflectance and contrast measurements of reflective liquid crystal displays. *Displays 18*(2), 89-83. Retrieved February 16, 2003, from ScienceDirect database.

Li, D. H. W. & Lam, J. C. (2003, January). An analysis of lighting energy savings and switching frequency for a daylit corridor under various indoor design illuminance levels. *Applied Energy* (In Press, Corrected Proof, Available online 21). Retrieved February 16, 2003, from ScienceDirect database.

Lin, Chern-S. (2002, December). An eye behavior measuring device for VR system. *Optics and Lasers in Engineering, 38*(6), 333-359. Retrieved February 16, 2003, from ScienceDirect database.

Menozzi, M., Lang, F., Näpflin, U., Zeller, C. & Krueger, H. (2001, July). CRT versus LCD: effects of refresh rate, display technology and background luminance in visual performance. *Displays, 22*(3), 79-85. Retrieved February 20, 2003, from

ScienceDirect database.

Sherman, L. (1995, September). The Light at the End of the Boardroom: LCD Projectors. *NewMedia 5*(9) 33-34. Retrieved February 20, 2003, from ERIC database.

Smyth, C. C. (2002, May). Modeling Indirect Vision Driving With Fixed Flat Panel Displays: Task Performance and Mental Workload. U.S. *Technology Administration, final report.* 89, Department of Commerce, MD: Army Research Lab., Aberdeen Proving Ground. Retrieved February 22, 2003, from National Technical Information Service Web site, http://www.ntis.gov

Tovee M. J. (1996) *An introduction to the visual system.* New York: Cambridge University Press.

Yamasaki, F., Deguchi, M., Kakuda, T. (2000, August). High efficiency optical system design for a liquid crystal projector. *Transactions on Consumer Electronics 46*(3). p. 851-56. Retrieved February 20, 2003, from Applied Science and Technology database.

Zwahlen, H. T. & Kothari, N. C. (1986, June). The Effects of Light and Dark Character CRT Displays upon VDT Operator Performance, Eye Scanning Behavior, Pupil Diameter and Subjective Comfort/Discomfort. *Final report, volume 1& 2.* Department of Industrial & Systems Engineering, Ohio University.

APPENDIX A

Informed Consent Statement

Informed Consent Statement

Object

The object of this study is to investigate the differences of visual comfort among various levels of illumination of an LCD monitor and ambient lighting.

Purpose

The purpose of this study is to give the LCD business market a suggestion on the commercial value of knowing the differences, which can improve the comfort of monitors to computer users. In addition, by adding a function, such as making an auto-adjustable monitor to ambient lights, it is expected that the monitor could help to reduce the occurrences of weakened eyes as well.

Your participation is fully voluntary, and you may withdraw at anytime with no penalty. There is no direct benefit for this participation. Your participation in this study will involve a 40-to-60 minute monitor evaluation at an electronics lab in the Industrial Technology Department of University of Northern Iowa. This study will ask several questions about the monitor, but not about you individually. Initially, you might be asked only your gender, and age. This information will not be used for any other services or personal purposes, and none of the collected information can be traced back to you. If you have questions about the study you may contact or desire information in the future, you are encouraged to contact either the investigator or research advisor.

Investigator:	Yuasa Yuichi, MA Candidate
	Department of Industrial Technology, University of Northern Iowa
	Office address / telephone: ITC 10 /
Research Advisor:	Recayi Pecen, Ph.D.
	Office address / telephone: ITC 39 /

You can also contact the office of the Human Participants Coordinator, University of Northern Iowa, at 319-273-2748, for answers to questions about rights of research participants and the participant review process.

I am fully aware of the nature and extent of my participation in this project as stated above and the possible risks arising from it. I hereby agree to participate in this project. I acknowledge that I have received a copy of this consent statement. I am 18 years of age or older.

(Printed name of participant)	(Signature of participant)	(Date)
		12/17/03
	(Signature of investigator)	(Date)
		12/17/03
	(Signature of Instructor/advisor)	(Date)

APPENDIX B

Script of Transmittal for Surveys

Script of Transmittal for Surveys

Dear Prospective Participant

I am conducting a study for my masters research project concerning illumination of an LCD monitor. The focus of this study is to investigate the differences of visual comfort among various levels of illumination of an LCD monitor and ambient lighting. You have been randomly selected to be part of this study from the list of students enrolled at University of Northern Iowa, and I am asking for your help. May I make an appointment with you to undertake your participation in this study? You may send me a response with your appointment day and your phone numbers.

Your participation is fully voluntary, and you may withdraw at anytime with no penalty. There may be no direct benefits for this participation. Your participation in this study will involve a 40-to-60 minute monitor evaluation at an electrical lab in the Industrial Technology Department of University of Northern Iowa. This study will ask several questions about the monitor, but not about you individually. Initially, you might be asked only your gender, and age. This information will not be used for any other services or personal purposes, and none of the collected information can be traced back to you.

Thank you for your valuable time. I deeply appreciate for your effort.

Sincerely,

Yuasa Yuichi, Master's Candidate
Department of Industrial Technology, University of Northern Iowa
Email:
Telephone:

Research Advisor: Recayi Pecen Ph.D.
Office address / telephone: ITC 39/

APPENDIX C

All data of Surveys

The number of participants:

Male: 11, Female: 10, Total: 21

Ages: 20-40, Average: 24.4

The percentage of uses of corrective lenses: 62 %

Data of participant's answers:

Condition 1.

Level of Comfort	*Illumination 1*	*Illumination 2*	*Illumination 3*
Glare of monitor	6.571	6.333	4.429
Clearness of monitor	6.286	6.534	5.571
Eye Fatigue	6.571	6.286	5.190
Overall Visual Comfort	6.333	6.381	4.762
The Number of Us	13.62	12.67	14.33
The Answer of Us	13.38	12.57	14.00

Condition 2.

Level of Comfort	*Illumination 1*	*Illumination 2*	*Illumination 3*
Glare of monitor	6.762	7.619	6.810
Clearness of monitor	6.476	7.143	7.143
Eye Fatigue	7.190	7.333	6.905
Overall Visual Comfort	6.762	7.429	7.095
The Number of Us	13.71	14.57	14.57
The Answer of Us	13.52	14.71	14.29

Condition 3.

Level of Comfort	*Illumination 1*	*Illumination 2*	*Illumination 3*
Glare of monitor	5.095	6.571	6.571
Clearness of monitor	4.810	6.286	7.333
Eye Fatigue	5.667	6.524	6.619
Overall Visual Comfort	5.143	6.333	6.810
The Number of Us	13.14	13.10	13.29
The Answer of Us	12.81	13.00	13.29

* The numbers of the comfort levels are the means of subjective rating: 1 – 9 scale, participant answered (see in figure 3).