Effects of Illuminance, Luminance, Viewing Angle, and Screen Test Pattern
on the Perception of Flicker in CRT Displays

by

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EFFECTS OF ILLUMINANCE, LUMINANCE, VIEWING ANGLE, AND SCREEN TEST PATTERN ON THE PERCEPTION OF FLICKER IN CRT DISPLAYS

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(ABSTRACT)

As computer usage has become more widespread, the number of complaints of visual discomfort and eye strain among computer operators has also increased. The temporal flicker of display screens can be a significant source of this visual discomfort. The purpose of this research was to determine how illuminance, luminance, screen test pattern, and viewing angle affect the perception of flicker in a CRT, especially in relation to the flicker evaluation method in the ANSI/HFS 100-1988 standard.

Twenty participants viewed a CRT at different viewing angles, under different levels of illuminance and luminance, and with different screen test patterns. Two of the conditions matched conditions specified in the ANSI/HFS 100-1988 standard, while the remaining conditions represented additional levels of illuminance, luminance, and a different screen test pattern. For each condition, the display's refresh rate was manipulated in ascending and descending trials to determine the critical flicker frequency (CFF); the threshold point at which flicker was first noticeable (or not noticeable).

An Analysis of Variance and post-hoc Newman-Keuls analyses were calculated to determine the significant effects on the CFF. The CFF values were higher with the higher illuminance and luminance values, and with the white screen viewed in the periphery. When compared with conditions specified in the ANSI/HFS 100-1988 standard, the
additional levels of illuminance, luminance, and screen test pattern examined in this study are more representative of actual usage conditions and resulted in higher CFF values. Based on these results, it is concluded that the flicker evaluation procedure in the ANSI/HFS 100-1988 standard does not ensure flicker-free CRT viewing under typical office environment conditions. An alternative flicker evaluation procedure is proposed.
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# TABLE OF CONTENTS

INTRODUCTION................................................................................................................. 1

LITERATURE REVIEW ........................................................................................................ 3
  BACKGROUND ON FLICKER .......................................................................................... 3
  VISUAL PSYCHOPHYSICAL TECHNIQUES .................................................................. 5
  FLICKER IN VDTs ........................................................................................................ 6
  SUMMARY OF LITERATURE REVIEW ........................................................................ 10
  PURPOSE ..................................................................................................................... 11

METHOD .......................................................................................................................... 12
  PARTICIPANTS ............................................................................................................. 12
  EQUIPMENT ................................................................................................................ 12
  EXPERIMENTAL CONDITIONS ................................................................................. 12
  PROCEDURE ............................................................................................................... 16
  EXPERIMENTAL DESIGN .......................................................................................... 18

RESULTS .......................................................................................................................... 20

DISCUSSION AND CONCLUSIONS ................................................................................ 37

IMPLICATIONS ................................................................................................................. 40

REFERENCES .................................................................................................................. 44

APPENDIX A: PRE-SCREENING EXPLANATION ............................................................. 46
APPENDIX B: INFORMED CONSENT ........................................................................... 48
APPENDIX C: QUESTIONNAIRE ................................................................................... 52
APPENDIX D: PARTICIPANT INSTRUCTIONS ............................................................... 54

VITA ................................................................................................................................. 56
LIST OF FIGURES

FIGURE 1: DELANGE'S TEMPORAL MODULATION SENSITIVITY CURVES .......................... 4
FIGURE 2: DIAGRAM OF EXPERIMENT ROOM..................................................... 13
FIGURE 3: PHOTOGRAPH OF EXPERIMENT ROOM............................................. 14
FIGURE 4: EXPERIMENTAL DESIGN................................................................. 19
FIGURE 5. MAIN EFFECT OF ILLUMINANCE ON CFF......................................... 22
FIGURE 6. MAIN EFFECT OF LUMINANCE ON CFF........................................... 23
FIGURE 7. MAIN EFFECT OF SCREEN ON CFF................................................... 25
FIGURE 8. MAIN EFFECT OF VIEWING ANGLE ON CFF...................................... 26
FIGURE 9. EFFECT OF ILLUMINANCE AND LUMINANCE INTERACTION ON CFF........ 27
FIGURE 10. EFFECT OF LUMINANCE AND VIEWING ANGLE INTERACTION ON CFF..... 29
FIGURE 11. EFFECT OF ILLUMINANCE, SCREEN, AND VIEWING ANGLE INTERACTION ON CFF...... 33
FIGURE 12. EFFECT OF LUMINANCE, SCREEN, AND VIEWING ANGLE INTERACTION ON CFF.... 35
LIST OF TABLES

Table 1. ANOVA Summary Table ................................................................. 21
Table 2. Newman-Keuls Results for interaction of illuminance and luminance ...... 28
Table 3. Newman-Keuls results for interaction of luminance and viewing angle ...... 30
Table 4. Newman-Keuls results for interaction of illuminance, screen, and viewing angle ................................................................. 34
Table 5. Newman-Keuls results for interaction of luminance, screen, and viewing angle ................................................................. 36
INTRODUCTION

Today, computers are found nearly everywhere and this trend will certainly continue in the future. Fitting computer technology to the capabilities and limitations of the human operator has been an important consideration for improving system usage. Unfortunately, this design objective has often been overlooked.

A considerable amount of progress has been made in recent years though. The American National Standard for Human Factors Engineering of Visual Display Terminal Workstations (ANSI/HFS 100-1988), published in 1988, was one such step in the direction of more ergonomically designed computer workstations. “This is a technical standard that specifies conditions that have been established as representing acceptable implementation of human factors engineering principles and practices in the design of visual display terminals (VDTs), associated furniture, and the office environment in which they are placed” (ANSI/HFS 100-1988).

One of the most common complaints among computer workstation users has been visual discomfort, including eye strain, eye fatigue, and headaches, related to the use of the VDT. The temporal flicker of display screens is one of the sources of visual discomfort. The term flicker refers to the perception of periodic modulation of luminance or contrast (Rogowitz, 1983). In a Cathode Ray Tube (CRT) display, this phenomenon occurs due to the refresh rate and phosphor decay. When an electron beam is directed at the phosphor-coated surface of the CRT screen, it causes the phosphor surface to glow for a fraction of a second. To produce the illusion of continuous character luminance, the screen must be rewritten or refreshed repeatedly. When the luminance oscillations are detected by the human eye, the screen appears to flash, and, thus is referred to as flickering (Grandjean, 1987).

Flicker produces several undesirable effects on human observers. For example, flicker can cause excess eye muscular activity that leads to visual fatigue or eyestrain.
(Isensee and Bennett, 1983). It also can impair concentration and increase the number of premature, inaccurate eye saccades (i.e., the quick movement of the eyes when not fixated on anything). In certain cases, flicker has been shown to provoke seizures in photo epileptics. About four percent of the less than 1 percent of the population who suffer from epilepsy are liable to seizures induced by visual stimulation such as flickering light (Wilkins).

With the aim of ensuring a minimum level of image quality, the ANSI/HFS 100-1988 standard contains a section on visual display requirements. The requirement for flicker states that “the display should be ‘flicker free’ for at least 90 percent of a sample of the user population under conditions representative of actual use” (ANSI/HFS 100-1988). However, it is questionable whether the test conditions specified in the ANSI/HFS 100-1988 standard accurately account for the perception of flicker in actual usage conditions. Thus, the evaluation of flicker is an important consideration in display design, and although the ANSI/HFS 100-1988 standard sets forth display implementation guidelines for computer workstations, further research is needed to validate the means to assess the perception of flicker from electro-optical visual displays.
LITERATURE REVIEW

Background on Flicker

The experience of flicker is obvious in lights or other visual targets that flash on and off at relatively slow rates (i.e., under 20 Hz), while flicker at rates over 50 or 60 Hz rarely is observable (Christman, 1971). Thus, as the rate of alternation increases from 20 Hz to 60 Hz, at some point the experience becomes one of a "steady" visual stimulus. The point at which the perception of a steady light occurs differs among individuals, and it is known as the Critical Flicker Frequency (CFF).

Several laws have been formulated in an attempt to describe the phenomenon of flicker. According to the Talbot-Plateau Law, "when a periodic visual stimulus is repeated at a rate which is sufficiently high so that it will appear fused to an observer, it will match in brightness a steady light which has the same time-average luminance (Brown, 1965). A general statement of the law may be made in the following form:

\[ L_m = \frac{1}{t} \int L \, dt \]

where \( L_m \) is luminance of steady light which matches the time-varying luminance, \( L \) is instantaneous luminance of the time-varying luminous field, and \( t \) is period of a single cycle of the varying field. Thus, this law implies that the visual system averages, on a linear basis, the effects of intermittent light stimuli over time (Pirenne, 1962).

Luminance of the flickering light is the main factor that influences CFF (Pirenne, 1962). The Ferry-Porter law relates CFF and luminance by stating that retinal "persistence" varies inversely with the logarithm of stimulus luminance (Brown, 1965). However, this law holds only over a very limited range of conditions, and does not hold at all for very low modulation amplitudes (Brown, 1965).

DeLange measured psychophysical sensitivity to various temporal frequencies of luminance modulation by adopting a linear systems approach (Rogowitz, 1983). Using a
Figure 1: DeLange's temporal modulation sensitivity curves
target that subtended two degrees of visual angle, viewed foveally, DeLange found that the higher the luminance, the more sensitive we are to flicker (Figure 1). These curves seem to suggest that at rates above 50 Hz we are not sensitive to flicker. However, the highest luminance level tested was 430 trolands which corresponds to something less than 29 ftL which is not a high luminance for a display (Rogowitz, 1983).

**Visual Psychophysical Techniques**

Psychophysical techniques provide several possible methods for determining the CFF. The Method of Limits is one methodology in which a stimulus is changed in small discrete steps until the observer’s response changes. Adaptation is the main problem with using this method for determining CFF, that is, “if one adapts to a light flashing above the CFF (appearing as a steady light) the CFF obtained in an immediately subsequent test will be elevated above the normally obtained frequency limit” (Christman, 1971).

Anticipation and perseveration are also potential confounds with this method. Anticipation or expectation errors result when “an observer may falsely anticipate the arrival of the stimulus at his threshold and prematurely report that the change has occurred before it really has” (Gescheider, 1985). On the other hand, errors of perseveration or habituation occur when the observer continues to repeat a response out of habit for a few trials, even though the threshold point has been reached. Gescheider (1985) provides several techniques to eliminate, or at least minimize these problems, including: varying the starting point for successive series, avoiding the use of excessively long trial series, and providing preliminary training and careful instructions to participants.

The Method of Constant Stimuli is another feasible procedure for determining CFFs. In this method, stimuli are presented in random order and the observer’s response is either “yes” or “no” depending on whether or not the stimulus is “experienced” (i.e., seen, heard, etc.).
Flicker in VDTs

While these methods may be used to determine CFF, the psychophysical perception of flicker in VDTs is affected by many factors, including: display luminance, ambient illuminance, screen polarity, viewing angle, viewing distance, refresh rate, display size, and screen phosphor persistence (Grandjean, 1987). The levels of these factors in practical situations are dictated by the characteristics of the office environment.

The recommended illuminance levels in an office environment represent a compromise between bright levels for hard copy viewing and dim levels for VDTs. The ANSI/HFS 100-1988 standard recommends illuminance levels from 200-500 lux. Surveys reveal that the illuminance values found in most offices range from 300-500 lux, and sometimes higher depending on the difficulty of the visual task (Sanders and McCormick, 1993).

With respect to luminance, the ANSI/HFS 100-1988 standard simply states that “high luminance sources in the peripheral field of view should be avoided,” while Grandjean (1987) recommends that the maximum luminance ratio in an office should not exceed 40:1. Increasing screen luminance and using negative polarity (dark characters on a light background) are two means of accomplishing this.

Viewing angle and distance also affect the perception of flicker. VDTs in an office environment are commonly viewed in the periphery since workers must look away from the screen to view other documents on the desk. Although viewing distances can vary, the ANSI/HFS 100-1988 standard recommends using a viewing distance such that an uppercase M subtends a visual angle of 16 minutes of arc when evaluating flicker. Other factors that affect the perception of flicker, such as the refresh rate, display size, and screen phosphor persistence, are generally built into the display.

Thus, when evaluating flicker, the above factors must be considered within the context of an office environment. In addition, it must be considered that the perception of
flicker varies among individuals (Christman, 1971). The methodology and results of several relevant studies, as well as the flicker assessment technique described in the ANSI/HFS 100-1988, are summarized below.

**Nishiyama, Brauning, de Boer, Gierer, and Grandjean (1986).** The purpose of this study was to evaluate VDTs with reversed presentation (bright background and dark characters). Ambient illuminance was 200 lx vertical and 300 lx horizontal. The independent variables were refresh rate with five levels (0, 30, 60, 90, and 180 Hz), and display luminance with 2 levels (75 and 150 cd/m²). Under each of these conditions, thirty subjects (half female) performed a sixty-minute reading task. This involved reading text aloud at one’s preferred reading speed, from a visual distance of about 60 cm. Vision tests for near point distance (the shortest distance at which an object can be brought into sharp focus), CFF, binocular visual acuity, stereo depth perception, lateral heterophoria, and contrast sensitivity were conducted before, halfway through, and at the end of the reading task. The results indicated that refresh rates greater than 90 Hz were equivalent to printed text or to a non-oscillating screen (0 Hz), while the bright screen at 30 Hz refresh was found to impair some visual functions. There were essentially no differences, in terms of the results of the vision tests, between the two screen luminances.

**Bauer, Bonacker, and Cavonius (1983).** In their first experiment, Bauer et al. attempted to determine the effects of field size and eccentricity on flicker. They used a method of limits with ascending and descending trials to obtain flicker thresholds for six subjects. The display used a P4 phosphor that decayed to 10% of maximum luminance within 25μs. Viewing distance was 500 mm and the test field had a mean luminance of 100 cd/m². The independent variables were viewing angle with five levels (0, 30, 40, 50, and 60 degrees) and display size with five levels (.8, 2.0, 5.0, and 15.0 degrees (diameter), or a square field of 30 degrees (diagonal)). Refresh rate, the dependent variable, had a step size of 1.5 Hz that observers manipulated to the point where flicker
was just noticeable. The results showed a clear effect of field size with the largest display resulting in the highest CFF (around 85 Hz at an eccentricity of 30 degrees). With respect to eccentricity, the maximum CFF occurred around 30 degrees.

In their second experiment, Bauer et al. attempted to measure the CFF in a larger population. The independent variable was display luminance and it varied across three levels: 80, 160, and 320 cd/m². Illuminance was fixed at 600 lx, measured at the desktop and the viewing distance was such that the screen subtended 30 degrees by 30 degrees. Thirty-one subjects were instructed to direct their gaze to one side of the screen in such a way as to maximize their sensitivity. At 80 cd/m², 50% of the population saw flicker at 72 Hz, while 87 Hz was necessary to be above threshold for 95% of the population. At 320 cd/m², the corresponding values are 78 Hz and 95 Hz. Thus, the results from both experiments showed that the CFF increases as field size and luminance increase, and that the CFF is higher in the near periphery (around 30 degrees) than in the fovea.

I sensee and Bennett (1983). This study included a subjective rating of the level of discomfort caused by flicker, as well as the determination of the angle away from the CRT at which subjects first noticed flicker. Three independent variables were manipulated: polarity of video (normal or reverse), screen luminance (measured by photometer) (120.1, 65.2, and 10.3 cd/m²), and ambient illumination (measured at keyboard) (420, 260, and 100 lux). The display had a refresh rate of 60 Hz noninterlaced, 30.5 cm diagonal, and a P4 (white) phosphor. The screen was written with W’s and the eye-to-screen distance was 66.0 cm. Twenty-one subjects received a random presentation of all test conditions. For one test they were instructed to swivel their chair away from the screen until flicker became apparent. For the other, they gave a subjective rating of flicker (from 0 to 6) while facing 90 degrees away from the CRT.

Luminance resulted in the strongest main effect. As luminance increases, flicker was seen at a smaller angle and rated as more uncomfortable. There also was a significant
interaction between luminance and illuminance. Flicker was noticed at a smaller angle and rated more uncomfortable with lower levels of ambient light and higher screen luminance. With respect to polarity, flicker was perceived at a smaller angle for reversed than for normal screens. The flicker discomfort rating reached 3.2 (on the borderline between comfort and discomfort) at an average angle of 25 degrees with 100 lux and 65 cd/m² luminance.

**ANSI/HFS 100-1988.** The ANSI/HFS 100-1988 standard states that a display must be “flicker free” for at least 90 percent of a sample of the user population under conditions representative of actual use. The standard then outlines an example of a method for measuring flicker. The viewing angles to be used in flicker evaluations are the center of the display (i.e., 0 degrees) and 20 degrees measured horizontally from the edge of the display. The illuminance level to be used for the evaluations is specified as a “dark test condition,” which is defined as: “The display shall be placed in a dark room. The display shall be turned on for at least 15 minutes prior to the measurements.”

The requirements for luminance level of the display differ depending on whether the display has fixed or variable luminance. For displays with fixed luminance, the higher luminance component (symbol or background) is required to be at or above 35 cd/m², but as close to 35 cd/m² as possible. For variable luminance displays, flicker is evaluated using the psychophysical method of limits (or adjustment). Thus, luminance is set as high as possible in excess of 35 cd/m² and slowly and continuously reduced until the subject no longer perceives flicker, at which point the luminance level is recorded. An ascending trial also is performed in which luminance is set to a low level and then increased until the subject perceives flicker. Both adjustment trials (ascending and descending trial) are repeated and the mean of the four trials then is calculated. A mean luminance of 35 cd/m² or less means that an observer can be classified as giving a “flicker” response.
Requirements for observers, test display pattern, and viewing distance also are specified in the ANSI/HFS 100-1988 standard. Twenty observers, between the ages of 18 and 35, who are free from ocular pathology and able to pass optometric tests for vertical phoria, lateral phoria, color normalcy, and near point acuity are to be used in the flicker evaluations. At least 40 percent and no more than 60 percent should be of the same gender. Additionally, observers must be dark-adapted for 10 minutes prior to the test. The screen is to be written with hyphens in each available space, and viewing distance is that at which the uppercase M subtends a visual angle of 16 minutes of arc.

Summary of Literature Review

Past research shows that the psychophysical perception of flicker tends to increase with higher levels of luminance, larger display sizes, lower refresh rates, and peripheral viewing angles (Bauer et al., 1983 and Grandjean, 1987). The exact nature of these trends is difficult to determine since the perception of flicker varies widely among individuals and is influenced by many factors.

Nishiyama et al. (1986) analyzed the effect of refresh rate and luminance of a reversed presentation VDT on several different vision tests and found that a refresh rate above 90 Hz was equivalent to printed or non-oscillating text. Bauer et al. (1983) manipulated viewing angle and screen size and found that the maximum CFF occurs with the largest screen at a viewing angle of 30°. In a second experiment Bauer et al. (1983) found that higher display luminances result in higher CFF values (higher refresh rates). Isensee and Bennett (1983) attempted to determine a subjective flicker discomfort rating as well as the angle away from the CRT that flicker is first noticed, by manipulating screen polarity, luminance, and illuminance. They found that with higher luminance, lower illuminance, and a reversed screen, flicker was noticed at a smaller viewing angle and received higher discomfort ratings.
There does not appear to be any one comprehensive study that systematically manipulated screen polarity, luminance, illuminance, and viewing angle to determine an average value for the CFF for a CRT under various viewing conditions that are representative of the typical office environment. The ANSI/HFS 100-1988 standard sets forth a general method, which specifies viewing angle, illuminance, luminance, and a screen test pattern for evaluating flicker in any display. However, the conditions specified in the standard are not necessarily representative of the ranges found in typical use. Therefore, since the evaluation of flicker is complex, the ANSI/HFS 100-1988 requirements should be examined to determine whether it is an effective method for the evaluation of flicker in CRT displays.

Purpose

The objective of this research was to determine the effect of luminance, illuminance, viewing angle, and screen test pattern on the CFF for a CRT display by varying display refresh rate. It was expected that CFF increases as luminance increases and illuminance decreases. The viewing angle of 20 degrees and the white screen also were expected to result in higher values for the CFF. Two of the test conditions matched the conditions specified in the ANSI/HFS 100-1988 standard. For these conditions, the results were compared to the results for additional levels of luminance, illuminance, and a different screen test pattern to determine whether the procedures and conditions specified in the ANSI/HFS 100-1988 standard provide an effective means for the evaluation of flicker in CRT displays.
METHOD

Participants

Participants were paid volunteers from the university population. Twenty participants (10 males) between 18 and 35 years of age were used in the experiment. They were, to the best of their knowledge, free from visual pathology. All participants passed optometric tests for vertical phoria, lateral phoria, color normalcy (Dvorine Pseudoisochromatic Plates), and near point acuity (to a criterion of 20/30 or better, corrected if necessary). Additionally, participants with any history of epilepsy were not permitted to participate in the study.

Equipment

A CRT monitor driven by a Fox Video Generator was used to evaluate flicker in each of the test conditions. A diagram of the experiment room is shown in Figure 2, and a photograph of the room is shown in Figure 3. The monitor was covered with a white cardboard bezel so that the effective display size was 230 mm high (19.65 degrees of visual angle) and 280 mm wide (23.49 degrees of visual angle). The video generator was capable of producing different images, different luminance levels, and refresh rates ranging from 44 - 78 Hz. An interface for the video generator, developed using LabView, was used by the experimenter to efficiently generate the video images and different refresh rates during the experiment. A chin rest was used to maintain a constant viewing distance for all the participants, and black poster board covered the screen between trials.

Experimental Conditions

The experiment was conducted in a room illuminated by six overhead incandescent luminaires. The display was turned on for at least 15 minutes prior to the measurements. Illuminance was set at two different levels, 0 lux and 500 lux, as measured using a Minolta illuminimeter on a plane tangent to the center of the display at the center of the display (while the display was covered with the black poster board). All sources of ambient
Figure 2: Diagram of experiment room
Figure 3: Photograph of experiment room
illumination were turned off when measuring the display luminance, which was set to two different levels, 10 ftL and 20 ftL as measured using a Minolta CS-100 spot photometer. Participants were seated in front of the display at a viewing distance such that an uppercase M subtended a visual angle of 16 minutes of arc. This was calculated as follows:

\[ D = 3438 \times [\text{Character Height (mm)} / \text{Character Height (min of arc)}] \]
\[ = 3438 \times [3/16] \]
\[ = 644 \text{ mm} \]

where D was the distance away from the display in millimeters at which subjects were positioned. To maintain the correct distance and position, participants were asked to rest their chin on a chin rest during the experiment. Participants also were adapted to the light level approximately 5 minutes prior to the test (10 minutes for the 0 lux illumination level) by sitting in the experiment room with the light adjusted to the level being tested. For one screen test pattern, the screen was written with hyphens in each available character space using normal presentation (white characters on a dark background); for the other condition, it was completely white. For the 0 degree viewing angle, participants were instructed to focus on the center of the display. For the other viewing angle, they were instructed to focus on a specified point 20 degrees measured horizontally from the edge of the display.

Each participant received all 16 of the experimental conditions. Two treatment combinations: 0 lux, 10 ftL, hyphen test pattern, and 0 degrees viewing angle, and 0 lux, 10 ftL, hyphen test pattern, and 20 degrees viewing angle, represented conditions specified in the ANSI/HFS 100-1988 standard. The remaining treatment combinations represented additional levels of illuminance, luminance, and a different test pattern.
Procedure

Prior to participation, participants received a brief explanation of the experiment and provided their informed consent. The pre-screening explanation is shown in Appendix A, and the informed consent form is in Appendix B. They then completed a brief questionnaire (as shown in Appendix C) regarding their vision history and any history of epilepsy. Following this, they were given vision tests for vertical phoria, lateral phoria, color normalcy (Dvorine Pseudoisochromatic Plates), and near point acuity (to a criterion of 20/30 or better, corrected if necessary). Upon satisfactory completion of the above requirements, participants were seated in the experiment room, with the light adjusted to one of the two illuminance levels for five minutes (10 minutes for the 0 lux level). At this point, the experimenter gave more detailed instructions for the experiment, as well as a demonstration of flicker. These instructions are shown in Appendix D.

The display luminance was set to one of the two luminance levels. The method of limits with varying starting points for both the ascending and descending trials was used to determine the participant’s CFF. The display’s refresh rate was initially set to a high level. Participants focused on one of the two fixation points, either at the center of the screen or 20 degrees from the edge of the display, and the screen was revealed. At this point, participants stated either “yes,” meaning they saw flicker, or “no,” meaning they did not see any flicker. If they stated “yes,” the refresh rate was increased approximately 10 Hz from the original starting point. This was repeated until either the participant responded with a “no,” or the maximum refresh rate of 78 Hz was reached. Once the participant responded with a “no,” the refresh rate was reduced by the experimenter in step sizes of 2 Hz until the participant responded with a “yes,” meaning they perceived flicker.

Next, this procedure was repeated in a reverse manner for the ascending trial. The refresh rate was set at a low level, and then increased by step sizes of 2 Hz until the
participant no longer perceived flicker. The descending trial was repeated, followed by the ascending trial.

The above procedure was repeated for the other viewing angle, while the remaining variables were kept at the same level. The procedure then was performed for both viewing angles with the other screen pattern, and then repeated for the additional levels of luminance and illuminance.
**Experimental Design**

This study consisted of a four-factor, within-subjects design with blocking as shown in Figure 4. For each illuminance level, participants required at least five minutes adaptation time, while for the 0 lux level, ten minutes was required. Therefore, the design was blocked by illuminance. The two illuminance blocks were presented in random order to each participant. Within each illuminance block, the design was blocked by display luminance, and the luminance blocks were randomly ordered. Therefore, at each luminance level both screen test patterns were presented before the display luminance was adjusted to the next level. For each screen test pattern, both viewing angles were presented in random order before the other screen test pattern was presented.

**Dependent variables.** The dependent variable was the refresh rate. Specifically, the minimum refresh rate which produced a “fusion” (nonflicker) response.

**Independent variables.** Four within-subjects factors were used in this experiment: illuminance, luminance, viewing angle, and screen test pattern.

**Illuminance.** Two levels of illuminance were tested: 0 and 500 lux. Illuminance measurements were taken with an illuminometer on a plane tangent to the center of the display at the center of the display.

**Luminance.** Two levels of display luminance were tested: 10 (34.26 cd/m²) and 20 (68.52 cd/m²) ftL. Luminance measurements were taken at the center of the display using a spot photometer.

**Viewing angle.** The two viewing angles were the center of the display (0 degrees) and 20 degrees measured horizontally from the edge of the display. Participants swiveled their chair to face either of the two fixation points.

**Screen test pattern.** One screen test pattern was based on the ANSI/HFS 100-1988 and consisted of hyphens written in each available space using white characters on a dark background. The other screen test pattern was a white screen.
Figure 4: Experimental design
RESULTS

An Analysis of Variance (ANOVA) was calculated to determine the significant effects on the dependent variable, the CFF. The ANOVA summary table with Greenhouse-Geisser corrections is shown in Table 1. Significant effects were investigated using the post-hoc Newman-Keuls procedure.

Due to limitations in the equipment, it was only possible to adjust the refresh rate from 44 to 78 Hz. Consequently, there was a large number of missing data points, since many of the subjects’ thresholds fell outside of this range. This was especially true for the screens written with hyphens, in that many subjects never perceived flicker, even at 44 Hz. In this instance the CFF was recorded as 42 Hz (one step below the testable range). At the other extreme, particularly for the white screen, subjects occasionally perceived flicker even at 78 Hz. In this instance, the CFF for these conditions was recorded as 80 Hz (one step above the testable range).

All four of the main effects, illuminance, luminance, screen, and viewing angle, were found to be significant at the 0.05 level. Two of the two-way interactions: illuminance by luminance, and luminance by viewing angle, and two of the three-way interactions: illuminance by screen by viewing angle, and luminance by screen by viewing angle were also significant.

Illuminance

Figure 5 shows the average CFF for the two illuminance levels. The average CFF for 500 lux was significantly higher than the CFF for 0 lux (57.4 vs. 54.4 Hz, respectively).

Luminance

The main effect of luminance is shown in figure 6. The average CFF at 20 ftL was significantly higher than the CFF at 10 ftL (57.0 vs. 54.7 Hz, respectively).
Table 1. ANOVA Summary Table

<table>
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<th>Source</th>
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<td>24.20</td>
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</tbody>
</table>

21
Figure 5. Main effect of illuminance on CFF. Error bars indicate +/- 1 standard error of the mean.
Figure 6. Main effect of luminance on CFF. Error bars indicate +/- 1 standard error of the mean.
Screen

The main effect of screen test pattern is shown in figure 7. The white screen resulted in a significantly higher CFF than the hyphen screen (64.5 vs. 47.3 Hz, respectively).

Viewing Angle

Figure 8 shows the main effect of viewing angle on the CFF. The CFF was higher with the 20 degree viewing angle than with the 0 degree viewing angle (57.0 vs. 54.8 Hz, respectively).

Illuminance and Luminance Interaction

The interaction of illuminance and luminance is shown in Figure 9. The Newman-Keuls results are shown in Table 2. Lower CFF values were recorded for the 0 lux condition than for the 500 lux condition. At each illuminance level, the 10 ftL luminance level resulted in lower CFF values than the 20 ftL luminance level. However, illuminance had a greater effect on CFF with the higher display luminance level. In other words, there was a greater difference in the two illuminance levels when considering the 20 ftL display as compared to the 10 ftL display. Based on the post-hoc Newman-Keuls analysis there were significant differences among all four combinations of illuminance and luminance, with the exception of the 0 lux, 20 ftL condition and the 500 lux, 10 ftL condition.

Luminance and Viewing Angle Interaction

The interaction of luminance and viewing angle is shown in Figure 10. The results of the post-hoc Newman-Keuls analysis are shown in Table 3. All four luminance and viewing angle combinations were significantly different except for the 10 ftL, 20 degree viewing angle condition and the 20 ftL, 0 degree viewing angle. The 10 ftL luminance level resulted in lower CFF values than the 20 ftL luminance level. At each luminance level, the CFF for the 0 degree viewing angle was lower than for the 20 degree angle.
Figure 7. Main effect of screen on CFF.
Error bars indicate +/-1 standard error of the mean.
Figure 8. Main effect of viewing angle on CFF. Error bars indicate +/- 1 standard error of the mean.
Figure 9. Effect of illuminance and luminance interaction on CFF. Error bars indicate +/- 1 standard error of the mean.
Table 2. Newman-Keuls Results for Interaction of Illuminance and Luminance

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average CFF</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lux, 10 ftL</td>
<td>53.47</td>
<td>A</td>
</tr>
<tr>
<td>0 lux, 20 ftL</td>
<td>55.24</td>
<td>B</td>
</tr>
<tr>
<td>500 lux, 10 ftL</td>
<td>55.94</td>
<td>B</td>
</tr>
<tr>
<td>500 lux, 20 ftL</td>
<td>58.83</td>
<td>C</td>
</tr>
</tbody>
</table>

Groups with the same letter are not significantly different, p > .05
Figure 10. Effect of luminance and viewing angle interaction on CFF. Error bars indicate +/- 1 standard error of the mean.
Table 3. Newman-Keuls Results for Interaction of Luminance and Viewing Angle

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average CFF</th>
<th>Group</th>
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</thead>
<tbody>
<tr>
<td>10 ftL, 0 degrees</td>
<td>54.06</td>
<td>A</td>
</tr>
<tr>
<td>10 ftL, 20 degrees</td>
<td>55.36</td>
<td>B</td>
</tr>
<tr>
<td>20 ftL, 0 degrees</td>
<td>55.46</td>
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</tr>
<tr>
<td>20 ftL, 20 degrees</td>
<td>58.60</td>
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Groups with the same letter are not significantly different, $p > .05$
**Illuminance, Screen and Viewing Angle Interaction**

Figure 11 shows the average CFF for the illuminance, screen, and viewing angle interaction. Table 4 shows the results of the post-hoc Newman-Keuls analysis. All eight conditions were significantly different with the exception of the 0 lux, hyphen screen at 20 degrees versus the 500 lux hyphen screen at 0 degrees. The four hyphen screens resulted in the lowest CFF values. For each screen, the 0 lux condition resulted in lower CFF values than the 500 lux condition. However, as previously stated, the 0 lux hyphen screen at 20 degrees was not significantly different from the 500 lux hyphen screen at 0 degrees.

For each screen, and at each illuminance level, the CFF for the 0 degree viewing angle was always lower than for the 20 degree viewing angle. When just considering the white screen, the 20 degree viewing angle had a more pronounced effect on the CFF at the 500 lux illuminance level than at the 0 lux illuminance level.

**Luminance, Screen, and Viewing Angle Interaction**

Figure 12 shows the average CFF for the luminance, screen, and viewing angle interaction, and the results of the post-hoc Newman-Keuls analysis are shown in Table 5. For each screen and viewing angle, the 20 ftL condition resulted in higher CFF values than the 10 ftL condition. With the exception of the white screen at 10 ftL, for each screen and luminance level, the 20 degree viewing angle resulted in higher CFF values than the 0 degree viewing angle. All of the white screens resulted in higher CFF values than the hyphen screens. For the hyphen screens, the luminance level of 10 ftL and the 0 degree viewing angle resulted in the lowest CFF value. The 20 ftL screen at 0 degrees and the 10 ftL screen at 20 degrees had the next highest CFF values and were not significantly different from each other. Finally, the 20 ftL screen at 20 degrees had the highest CFF value for the hyphen screens.

For the white screen at 10 ftL, there was no significant difference in the CFF between the two viewing angles. However, with the 20 ftL white screen, the viewing
angle of 20 degrees resulted in a significantly higher CFF than the 0 degree viewing angle. The 20 ftL white screen at 0 degrees had a slightly higher CFF than the 10 ftL white screen at 20 degrees. The 20 ftL white screen at the 20 degree viewing angle resulted in the highest overall CFF value for this interaction.
Figure 11. Effect of illuminance, screen, and viewing angle interaction on CFF. Error bars indicate +/- 1 standard error of the mean.
Table 4. Newman-Keuls Results for Interaction of Illuminance, Screen, and Viewing Angle

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average CFF</th>
<th>Group</th>
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<tbody>
<tr>
<td>0 lux, hyphen screen, 0 degrees</td>
<td>44.45</td>
<td>A</td>
</tr>
<tr>
<td>0 lux, hyphen screen, 20 degrees</td>
<td>47.09</td>
<td>B</td>
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<td>500 lux, hyphen screen, 0 degrees</td>
<td>47.59</td>
<td>B</td>
</tr>
<tr>
<td>500 lux, hyphen screen, 20 degrees</td>
<td>49.90</td>
<td>C</td>
</tr>
<tr>
<td>0 lux, white screen, 0 degrees</td>
<td>62.42</td>
<td>D</td>
</tr>
<tr>
<td>0 lux, white screen, 20 degrees</td>
<td>63.45</td>
<td>E</td>
</tr>
<tr>
<td>500 lux, white screen, 0 degrees</td>
<td>64.57</td>
<td>F</td>
</tr>
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<td>500 lux, white screen, 20 degrees</td>
<td>67.47</td>
<td>G</td>
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Groups with the same letter are not significantly different, p > .05
Figure 12. Effect of luminance, screen, and viewing angle interaction on CFF. Error bars indicate +/- 1 standard error of the mean.
Table 5. Newman-Keuls Results for Interaction of Luminance, Screen, and Viewing Angle

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average CFF</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ftL, hyphen screen, 0 degrees</td>
<td>45.10</td>
<td>A</td>
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<tr>
<td>20 ftL, hyphen screen, 0 degrees</td>
<td>46.94</td>
<td>B</td>
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<td>10 ftL, hyphen screen, 20 degrees</td>
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<td>B</td>
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<td>20 ftL, hyphen screen, 20 degrees</td>
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<td>20 ftL, white screen, 0 degrees</td>
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<td>E</td>
</tr>
<tr>
<td>20 ftL, white screen, 20 degrees</td>
<td>67.54</td>
<td>F</td>
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</table>

Groups with the same letter are not significantly different, p > .05
DISCUSSION AND CONCLUSIONS

The purpose of this research was to examine how illuminance, luminance, screen test pattern, and viewing angle affect CFF, especially in relation to the flicker evaluation method in the ANSI/HFS 100-1988 standard. As predicted based on previous research, the results indicate that all four factors evaluated in this study have significant effects on the CFF. Based on these results, it appears that the flicker evaluation procedure in the ANSI/HFS 100-1988 standard is not stringent enough to provide flicker-free viewing for the majority of CRT users under normal office viewing conditions.

The results for the effect of illuminance indicate that flicker sensitivity is higher at 500 lux than at 0 lux. This is supported by Boff and Lincoln (1988) in the Engineering Data Compendium on Human Perception and Performance, which states that highest CFF values are found for a light-adapted observer looking directly at a target of high luminance. Additionally, they state that flicker sensitivity is best when the observer is light-adapted and worst when dark-adapted.

In light of these findings, the requirement in the ANSI/HFS 100-1988 standard which recommends evaluating flicker using a “dark test condition,” does not seem appropriate. Recommended office illumination levels generally fall in the range of 200-500 lux (ANSI/HFS 100-1988; Sanders and McCormick, 1993). Evaluating flicker at these higher illuminance levels would therefore provide a more stringent as well as realistic procedure.

While higher illuminance levels are desirable in an office environment for reading hard copy, when using CRT’s, the higher illuminance levels can result in transient adaptation and glare problems, caused by high luminance ratios between the task and adjacent and remote areas (Sanders and McCormick, 1993). In order to avoid these problems, higher display luminance levels are needed. However, as shown by past research as well as by the present study, higher display luminance levels result in an
increased sensitivity to flicker. Therefore, the flicker evaluation procedure must be rigorous enough to take into account the need for higher display luminances which results when CRT's are used in areas with higher illuminance levels.

The screen test pattern also affects CFF values. The results for the screen test pattern in the present study are similar to Isensee and Bennett's finding that flicker is perceived at a smaller angle for reversed than for normal screens. In this study, CFF values for the white screen were much higher than those for the hyphen screen, which was essentially a normal screen, with white characters on a dark background. The difference in the CFF values is likely due to the difference in the total luminance output of the two screens. Thus, the higher CFF values for the white screen may be explained by the fact that the total luminance output of the white screen was higher than for the hyphen screen. The majority of computer programs today use reverse presentation (dark characters on a light background). Since reverse presentation screens result in higher CFF values, and are more commonly used today, a white screen would provide a better test pattern for flicker evaluation. An additional interesting note regarding the hyphen screen is that many participants reported that the hyphen pattern created annoying visual artifacts, and that they had difficulty focusing on it.

Finally, the results for the viewing angle also are in agreement with past research, in that viewing a display in the periphery resulted in higher CFF values. In many work environments, CRT's are in the periphery as users look back and forth between source documents and the CRT. Isensee and Bennett (1983) report that the greater susceptibility to flicker in peripheral vision apparently is due to the greater density of rods, which are very sensitive to changes in luminance, in the periphery of the retina. Since the 20 degree viewing angle consistently resulted in higher CFF values, evaluating flicker at the 0 degree viewing angle, as suggested by the ANSI/HFS 100-1988 standard, is not necessary.
This research determined average CFF values for viewing a CRT under different conditions of illuminance, luminance, screen test pattern, and viewing angle. Several limitations that confined the scope of this research project provide areas for further research. One limitation in the data collection was that the refresh rates used varied between 44 - 78 Hz. In order to obtain more accurate CFF values for all conditions, a wider range of refresh rates should be tested. Adjusting the refresh rate in step sizes smaller than 2 Hz would also provide more accurate CFF values.

The perception of flicker differs from person to person and is affected by many variables. It is difficult to generalize the results of any one study since the specific conditions that are evaluated will directly influence the CFF values. However, the conditions examined in this study are representative of actual CRT usage conditions. In addition, the generalized findings of this study are all supported by previous research.

When examining the findings of this experiment, the conditions that represent those specified in the ANSI/HFS 100-1988 standard consistently account for the lowest CFF values. The ANSI/HFS 100-1988 standard evaluates flicker using a screen written with hyphens at 0 lux and with a luminance level of 10 ftL, at two different viewing angles, 0 and 20 degrees. The additional conditions evaluated in this study: 500 lux, 20 ftL, and a white screen, resulted in higher CFF values than the conditions specified in the standard. In addition, the conditions specified in the standard do not seem to represent typical office working conditions. Thus, based on this research, the criteria and methods for flicker evaluation in the ANSI/HFS 100-1988 standard are not satisfactory.
IMPLICATIONS

The flicker assessment procedure in the ANSI/HFS 100-1988 standard should be revised. The current procedure is too lenient to provide flicker-free viewing for the majority of the population under realistic viewing conditions. The proposed revisions provide a more stringent flicker assessment procedure and, at the same time, more accurately represent realistic office working conditions. A proposed flicker evaluation procedure follows. Explanations for steps that are changed from the current procedure, are in italics.

The perception of flicker shall be evaluated under the following conditions:

1. Set up the system according to “Illuminated Test Condition,” which is defined as follows: The display shall be turned on for at least 15 minutes prior to the measurements. The illumination shall be measured on a plane tangent to the center of the display at the center of the display. The illumination shall be within 10 percent of 250 + 250(cosA) lux, where A is the angle formed by the intersection of the plane tangent to the center of the display and a horizontal plane. The display intensity shall be adjusted so that the symbol or background luminance, whichever is higher, is as near to as possible but above 70 cd/m², while maintaining a luminance modulation of at least 0.5.

Higher illuminance levels result in an increased sensitivity to flicker. According to the present study, CFF values for the 500 lux condition were significantly higher than for the 0 lux condition (dark test condition). At the same time, an illuminated test condition more realistically represents actual usage conditions, since it is highly unlikely that CRT users will be working in completely dark conditions.
2. Any person serving as a subject shall be adapted to the light level approximately 5 minutes prior to the test.

*Less adaptation time is required for light-adaptation than for dark.*

3. Twenty subjects shall be tested. At least 40 percent and no more than 60 percent shall be of the same sex. All subjects shall be between 18 and 35 years of age and to the best of their knowledge are free from ocular pathology. All subjects shall pass optometric tests for vertical phoria, lateral phoria, color normalcy, and near point acuity.

4. The screen shall be completely white and have no characters in any of the symbol spaces.

*According to the present study, when compared with the hyphen screen, CFF values for the white screen were significantly higher. This may be attributed to the fact that the overall luminance output of a completely white screen will be higher and CFF increases with higher luminance levels. In contrast with the text-based computer programs of the past, the majority of today's graphical based interfaces display information using dark characters on a white background. Thus, a completely white screen provides a more stringent flicker evaluation as well as more realistically represent actual CRT usage conditions.*

5. The viewing distance shall be that at which the uppercase M subtends a visual angle of 16 minutes of arc.
6. Subjects shall fixate on a point 20 degrees from the edge of the display and perform the flicker evaluation procedure.

*According to the present study, the 20 degree viewing angle always resulted in higher (or at least equivalent) CFF values when compared to the 0 degree viewing angle for each of the test conditions. As a result, evaluating flicker at the 0 degree viewing angle does not contribute any additional information to the procedure. Therefore, to provide a rigorous yet efficient test, flicker only needs to be evaluated at the 20 degree viewing angle, where flicker sensitivity is higher.*

7. Flicker Evaluation Procedure:

**Fixed Luminance Displays.** Those displays having a fixed luminance or contrast shall be such that the higher luminance component (symbol or background) is at or above 20 ftL (approximately 70 cd/m²) but as close to 20 ftL as possible. Each person serving as a test subject shall fixate on the fixation point for 15 seconds, following which the subject shall report whether or not the image appeared to flicker.

**Variable Luminance Displays.** Displays having variable and controllable luminance (symbol or background) shall be evaluated by the psychophysical method of adjustment, as described in what follows. The higher display luminance (symbol or background) shall be set as high as possible in excess of 20 ftL. Each subject shall fixate on the fixation point for 15 seconds, following which the subject shall report whether or not the image appears to flicker. If the subject does not perceive flicker, the test shall be terminated with a recorded response of "fusion." If the person perceives flicker, the luminance will then be reduced in a slow, continuous manner until the
flicker ceases. The luminance at this value shall be measured and recorded. The display luminance will then be reduced to a low level, well below that measured in the above procedure, and then increased in a slow, continuous manner until the subject again perceives flicker. At this point the display luminance shall be measured and recorded. The latter procedure (the “ascending” trial will be repeated, followed by the former procedure (the “descending” trial). The mean of the four recorded luminances shall be calculated. If the mean luminance exceeds 20 ftL, the subject shall be classified as giving a “fusion” (nonflicker) response. If the mean luminance is equal to or less than 20 ftL, the subject shall be classified as giving a “flicker” response.

While the procedural aspect of this step is not changed, the luminance component is increased from 10 ftL to 20 ftL. Flicker sensitivity increases as luminance increases. Additionally, 10 ftL is not a particularly high luminance level for a CRT. Therefore, evaluating flicker with a display luminance of 20 ftL would provide a more stringent test.
REFERENCES


Wilkins, A. J. Epileptogenic attributes of TV and VDUs. 27-35.
APPENDIX A: PRE-SCREENING EXPLANATION
Pre-Screening Explanation

The purpose of this research is to evaluate flicker in a CRT display. When a CRT display screen appears to be flashing, this is referred to as flicker. Your contribution to the study of this problem will be to view a display under various conditions of flicker. Before participating in this experiment, you will be asked to take a vision test to make sure you will be able to see the display clearly. If you have any questions regarding the purpose of this experiment, please ask them at this time.
APPENDIX B: INFORMED CONSENT
INFORMED CONSENT

Title of Project: Effects of Luminance, Illuminance, Viewing Angle, and Screen Test Pattern on the Perception of Flicker in CRT Displays

Principal Investigator: Megan Jones

I. Purpose

You are invited to participate in a study about flicker in cathode ray tube (CRT) displays. This study involves experimentation for the purpose of determining how certain factors such as luminance, illuminance, viewing angle, and screen test pattern affect people's perception of flicker.

II. Procedures

You will be asked to view a CRT at different levels of luminance and illuminance, and at different viewing angles, and with different screen test patterns, and to state when the display appears to be flickering. The time required is approximately two hours.

The possible risks or discomfort to you as a participant will be the same as when viewing any normal CRT. There may be slight visual discomfort induced by the flicker, although you will not be exposed to it for any length of time. About four percent of the less than 1 percent of the population who suffers from epilepsy are liable to seizures induced by visual stimulation such as flickering light.

To minimize your risk or discomfort you will be asked to complete a questionnaire about your vision and health history. You will be asked not to participate if you do not pass the vision tests or if you have ever had an epileptic seizure.
III. Benefits of this project

Your participation in the project will provide information about the effects of luminance, illuminance, viewing angle, and screen test pattern on the perception of flicker. No guarantee of benefits has been made to encourage you to participate.

You may receive a summary of this research when completed by leaving a self-addressed envelope.

IV. Extent of anonymity and confidentiality

The results of this study will be kept strictly confidential. At no time will the researchers release the results of the study to anyone other than the individuals working on the project without your written consent. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

V. Compensation

For participation in the project you will receive five dollars per hour.

VI. Freedom to withdraw

You are free to withdraw from this study at any time without penalty. If you chose to withdraw, you will be compensated for the portion of the time of the study. There may be the following circumstances under which the investigator may determine that you should not continue as a subject of this project:

- you have a history of epilepsy
- you do not pass the vision tests.
You will be compensated for the portion of the project completed.

VII. Approval of research

This research project has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University.

VIII. Subject’s responsibilities

I know of no reason I cannot participate in this study. I have no history of epilepsy and no known visual defects.

__________________________________________
Signature

IX. Subject’s permission

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Should I have any questions about this research or its conduct, I will contact:

<table>
<thead>
<tr>
<th>Name</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Megan M. Jones - Investigator</td>
<td>231-9092</td>
</tr>
<tr>
<td>Robert J. Beaton - Faculty Advisor</td>
<td>231-5936</td>
</tr>
<tr>
<td>Ernest R. Stout - Chair, IRB Research Division</td>
<td>231-9359</td>
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QUESTIONNAIRE

Please respond to the following questions by checking either yes or no.

Do you have any uncorrected vision defects? .........................  Yes ☐ No ☐

Have you ever had an epileptic seizure? ..............................  ☐ ☐

Do you know of any reason why you should not participate in this study? .............................  ☐ ☐
Participant Instructions

You will be viewing this display under two different light levels. For the first one, the (bright or dark) condition, we need to allow (5 or 10 minutes) for your eyes to adjust.

Now I will briefly demonstrate flicker. Flicker occurs when a screen appears to be flashing rapidly. Here is an example of an extreme case of flicker. (Show white screen at 20 ftL and 44 Hz), and here is an example of a screen that will probably not appear to be flickering (show white screen at 20 ftL and 78 Hz). Between these two extremes, the perception of flicker or the lack of flicker may be much more subtle and difficult to see. The perception of flicker is different for each individual and there is no right or wrong answer. After viewing each screen, simply state whether or not it appears to be flickering to you.

I will be presenting different screens to you and asking you whether or not they appear to be flickering. Since the images take a few seconds to stabilize, the display will be covered between each screen presentation. After the screen is uncovered, either respond “yes”, meaning the display appears to be flickering, or “no”, meaning the display does not appear to be flickering. Sometimes I will ask you to focus on the center of the display, and other times you will be asked to focus on the space between the two vertical bars on the paper to your right. When focusing on the paper, the display will be in your peripheral vision, but you should remain focused on the paper.

Remember, there are no right or wrong answers, I’m just interested in what your perceptions are.

Do you have any questions?
VITA

Megan M. Jones was born in Annapolis, MD on August 5, 1971. She obtained her B. S. in Management Science, with minors in International Studies and French, from Virginia Tech in May, 1993. As both an undergraduate and graduate, she was actively involved in the Virginia Tech Volleyball Club. In graduate school, she served as vice-president of the Virginia Tech student chapter of the American Society of Safety Engineers, and secretary of the Virginia Tech student chapter of the Human Factors Society. In 1994, she received the American Society of Safety Engineers Crawford Scholarship Award.

Megan Jones