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EXPERIMENTAL STUDIES RELATING ENVIRONMENTAL LIGHTING AND FLICKER TO VISUAL FATIGUE IN VDT OPERATORS

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ABSTRACT

An operator of a visual display terminal typically is confronted with two flickering light sources: VDT phosphor with its inherent refresh rate, and the ambient fluorescent illumination reflected from the screen. Due to differences in frequency, the two sources of flicker can produce low-frequency beats in the net light intensity presented to the VDT operator. These low frequencies, on the order of a few hertz, can lead to adaptation of visual sensory mechanisms.

We have constructed an experiment in which a stable, high-amplitude beat is produced, with frequency chosen to enhance the possibility of detecting a visual system response. By adjusting the environmental lighting to produce a sinusoidal flicker at 69 Hz, and employing a VDT with a 61-Hz refresh rate, we produced an 8-Hz beat frequency in the light emanating from the VDT screen.

By measuring temporal contrast sensitivity at 8 Hz as a test of sensory visual system response, we found that two of three subjects showed a reduced sensitivity when exposed to this stimulus, as compared with three sets of control conditions in which the 8-Hz beat was not present. We discuss possible relations between this sensory adaptation and the factors of subjective visual fatigue and reduced levels of task performance. Further work is underway to examine whether adaptation occurs under conventional office lighting and typical mains frequency variations.

Études Expérimentales de la Relation entre l´Éclairage Ambiant et le Clignotement d´un Écran Video et la Fatigue Visuelle des Opérateurs.

RÉSUMÉ

Un opérateur d´un terminal d´écran visuel (VDT) est Études Expérimentales de la Relation entre l´Éclairage clignotantes: le phosphore du VDT avec son taux de régénération de l´image, et l´illumination fluorescente ambiante qui est réfléchie sur l´écran. Les deux sources de clignotement dû à la différence de fréquence, peuvent produire des battements de basse fréquence dans l´intensité globale de lumière à laquelle l´opérateur du VDT est soumis. Ces basses fréquences, de l´ordre de quelques Hz, peuvent conduire à l´adaptation des mécanismes sensoriels de la vision.

Nous avons conçu une expérience dans laquelle un battement stable d´une haute amplitude est produit avec une fréquence qui est choisie pour augmenter la possibilité de détecter la réponse du systéme visuel. En réglant l´éclairage ambiant de façon à ce qu´il produise un clignotement sinusôidal de 69 Hz et en utilisant un VDT avec un taux de régénération de l´image de 61 Hz, nous produisions un battement de fréquence 8 Hz dans la lumière qui émane de l´écran du VDT.

En mesurant la sensibilité aux fluctuations temporelles de l´intensité lunineuse à 8 Hz en tant que mesure de la réponse du système sensoriel de la vision. Nous avons trouvé que deux sur trois sujets montraient une sensibilité reduite quand ils étaient soumis à une telle stimulation par rapport à ce qui se passait quand ils étaient soumis à trois tests semblables de contrôle en l´absence de ce battement de 8 Hz. Nous discutons les possibles relations entre cette adaptation sensorielle et les facteurs de fatigue subjective de la vision et les niveaux reduits de performance dans les tâches. Une étude est en cours pour déterminer si une adaptation se produit avec un éclairage conventionnel d´un bureau et les variations typiques des fréquences principales.

Experimentelle Studie über Raumbeleuchtung und Flimmereffekt in Bezug auf visuelle Ermüdungserscheinungen bei Benutzern von TV - Bildschirmgeräten

ZUSAMMENFASSUNG

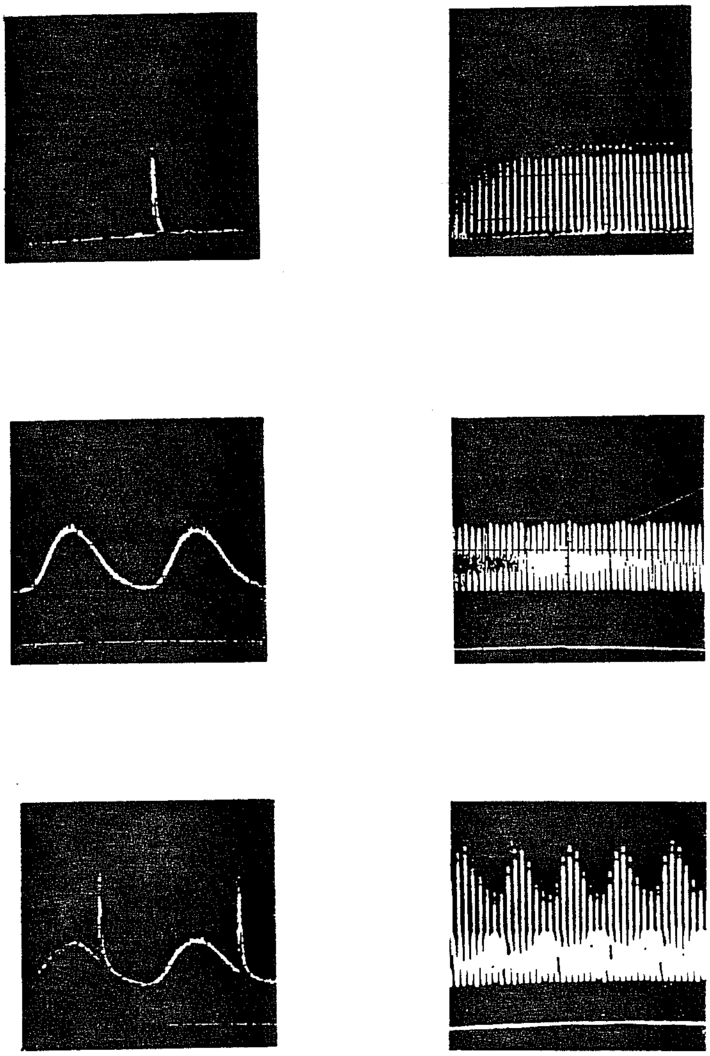
Benutzer von TV - Bildschirmgeräten sind üblicherweise zwei Lichtquellen mit Flimmereffekt ausgesetzt: der TV-Mattscheibe mit ihrer inhärenten Erneuerungsrate und der, von dem Bildschirm reflektierte Leuchtstoffröhrenraumbeleuchtung. Aufgrund unterschiedlicher Frequenzen können diese beiden Quellen mit Flimmereffekt niederfrequente Schwebungen in der Lichtintensität, denen der Benutzer ausgesetzt ist, erzeugen. Diese niedrigen Frequenzen, welche in der Grössenordnung von ein paar Hertz sind, können zur Anpassung visueller Sinnesmechanismen führen.

Eine Versuchsanlage wurde aufgebaut, mit der eine stabile Schwebung mit hoher Amplitude und einer Frequenz erzeugt werden kann, welche es ermöglicht visuelle Systemreaktionen zu erfassen. Durch Abstimmen der Raumbeleuchtung wurde ein sinusoidales Flimmern bei 69 Hz erzielt und in Kombination mit einem TV-Bildschirmgerät mit einer Erneuerungsrate von 61 Hz entstand Licht, welches mit einer Schwebungsfrequenz von 8 Hz vom Bildschirm ausstrahlt.

Messungen von zeitlich veränderlichem Kontrastwahrnehmungsvermögen bei 8 Hz, um sensorische visuelle Systemreaktionen zu erfassen, führten zu dem Ergebnis, dass zwei von drei Versuchspersonen ein verringertes Wahrnehmungsvermögen aufzeigten, wenn sie diesem Reiz ausgesetzt waren, verglichen mit drei Versuchen mit unterschiedlichen Versuchsbedingungen, jedoch ohne der 8 Hz Schwebung. Behandelt werden mögliche Beziehungen zwischen dieser sensorischen Anpassung und den Faktoren subjektiver visueller Ermüdungserscheinungen und reduziertem Leistungsvermögen. Weiterführende Forschung ist im Gange, um zu untersuchen, ob eine Anpassung bei konventioneller Bürobeleuchtung und typischen Netzfrequenzschwankungen stattfindet.

INTRODUCTION

Visual discomfort experienced by operators of video display terminals (VDTs) is an increasingly common complaint in the workplace [1]. Research has concentrated on the ergonomic aspects of this problem, but recently considerable attention has been directed toward the purely visual aspects of the interaction between operator and machine. It is often postulated that visual fatigue is related to interference with normal oculomotor functions, and some research has been performed in an attempt to relate visual fatigue to abnormal responses in the pupillary or accommodative mechanisms [2,3]. Another approach is being taken in our laboratory, where we are conducting experiments to specify more completely the stimulus conditions present in the workplace, to search



Sweep rate is 5 msec/Div

Sweep rate is 100 msec/Div

VDT screen with alphabetic character display on, but with zero ambiant illumination.

VDT screen with display off but with reflected 69-Hz flickering fluorescent ambient illumination.

VDT screen with display on, but with reflected 69-Hz ambiant illumination.

Fig. 1. Oscilloscope traces of the output of a Spectra Pritchard photometer reading a 20-mm circular area of a Lear Siegler ADM-3a white phosphor VDT. The vertical axis is relative luminance with the same scale in each trace. Actual time-average luminances are specified in the text. A zero luminance reference line is included in each trace. Note the clear 8-Hz beat frequency envelope when both the VDT and the 69-Hz ambient illumination are on.

Fig. 1. Tracés oscilloscopiques de la sortie d'un Spectra Pritchard Photometer qui lit une surface circulaire de 20 mm de diamètre appartenant à un écran video de phosphore blanc Lear Siegler ADM-3a. Sur l'axe vertical est portée la luminance rélative; l'échelle est la même pour les trois cas. Les luminances moyennes en fonction des temps réels ont été specifiées dans le texte. Dans chaque tracé on a ajoutée une ligne de référence de luminance cero. Notez les battements de 8 Hz de fréquence quand l'écran du VDT et l'éclairage ambiant de 69 Hz sont allumés au même temps.

Bild 1. Wiedergabe einer kreisförmigen Fläche (20 mm Durchmesser) eines "Lears Siegler ADM-3a" TV - Bildschirmgeräts mit weisser Mattscheibe mittels eines "Spectra Pritchard" Photometers auf einen Oszillographen. Die Vertikale ist die relative Lichtstärke mit identischem Skalenbereich für alle Abbildungen. Die tatsächliche zeitlich gemittelte Lichtstärke ist im Text beschrieben. Eine Bezugslinie mit einer Lichtstärke von Null ist in den Abbildungen enthalten. Bemerkenswert ist die deutliche Schwebungsfrequenz von 8 Hz, wenn der Bildschirm und die 69 Hz Raumbeleuchtung eingeschaltet sind.

for adaptations in sensory visual processes, and to discover how they might relate to subjective visual fatigue and degeneration of task performance. We are exploring the most salient aspects of sensory vision, including spatial, temporal, and chromatic parameters. This report concerns only temporal aspects of sensory stimuli and the effects they have on the visual system.
A typical VDT operates by sweeping a narrow electron beam (modulated in intensity) in discrete horizontal trajectories, covering the entire screen of the cathode ray tube at a refresh rate governed precisely by a crystal oscillator. Because the displayed characters are generated via this sweep mode, and because the activated VDT phosphor has a rapid decay time, only a small area of the screen emits light at any given moment. An oscilloscope trace of the output of a photometer reading off a localized area of the screen demonstrates the pulse-like character of the visual stimulus (see Figure 1).

Office lighting commonly relies on fluorescent sources, with ballasts operating directly off the alternating current of the main power line. Because the decay time of fluorescent lamp phosphors is relatively rapid, there is a sinusoidal modulation of light intensity, typically ±30 to 35% around the mean intensity. This modulation occurs at exactly twice the power-line frequency.

The refresh rate of the VDT, controlled by an internal oscillator, typically differs from the nominal mains frequency by one or two percent. In addition, while the VDT refresh rate remains constant, fluctuations up to ±5% occur in the mains frequency although utility companies generally maintain the time average at the nominal value. Because there is a difference between the refresh rate and the mains frequency, and because the luminance distribution off the face of a VDT screen consists of part phosphor emission and part reflected environmental illumination, the composite visual stimulus can contain a beat frequency. Although the VDT and the room illumination may each be flickering at a rate above or near the limit of human visual detection, the beat frequency may be much lower and nearer the peak of the visual temporal contrast sensitivity function, and thus more easily detectable.

We are interested in whether a physically measurable beat frequency occurs in the visual stimulus when a VDT is operated under fluorescent ambient illumination and, if found, what its impact is on the human visual system. The experiment reported in this paper is the first in a series we are conducting to address this question.

We approached this initial experiment by constructing a situation in which the probability of an experimentally detectable visual system response is enhanced. This was accomplished by selecting experimental conditions that lead to the production of a beat of relatively high amplitude at a stable frequency, which is optimum for providing visual system adaptation. Stability is achieved by electrically modulating a high-frequency fluorescent luminaire at a constant frequency while the relatively strong amplitude of the beat is achieved by carefully balancing the level of room illumination and VDT screen brightness (see Methods section). Our test for visual sensory adaptation used a standard determination of temporal contrast sensitivity. We controlled illuminance parameters to produce a beat frequency at 8 Hz, and employed an 8-Hz temporal test frequency. These conditions are expected to favor both production and measurement of visual adaptation because 8 Hz lies approximately at the peak of the human temporal contrast sensitivity function [4], and it is known that adaptation is maximum when the adapting stimulus is the same frequency as the test stimulus [5].

If we find sensory adaptation under these controlled conditions, we can search for adaptation under normal viewing conditions, in which a beat is expected to be of smaller amplitude and lower frequency than in our experiment. Conversely, if we find no adaptation under our experimental conditions, it is unlikely any would occur under normal viewing conditions.

METHODS

The temporal contrast sensitivity test consisted of presentations of a homogeneous display field, the luminance of which was sinusoidally modulated at 8 Hz, in a temporal two-alternative, forced-choice, descending staircase paradigm (300-msec stimulus duration, 200-msec interstimulus interval, 3-db step size, four reversals). The field was a computer-driven Tektronix 606 Monitor having a rectangular display that occupied a visual angle of 2 1/2° X 3 1/4° at a viewing distance of 228 cm. The mean screen luminance (phosphor emission plus reflected room illumination perceived from the viewing position) was 26.2 cd/m^2, and the luminance of the grey surround was 8.9 cd/m^2 (illuminated by a non-flickering fluorescent source produced with a modified commercial ballast operating at 28 kHz). The brief individual trials were alternated with ten-second periods of adaptation, as described below. A trial was always initiated one-quarter second after a period of adaptation. In this manner, even quite transient effects could be detected.

Four adaptation conditions were tested, the first representing the condition of interest, the second the primary control, and the third and fourth, secondary controls. The four conditions were (1) adaptation to the screen display (a series of random letters in "words" of random length) of a Lear-Siegler ADM-3a white phosphor VDT (viewing distance 45 cm) under fluorescent ambient illumination flickering at our test frequency of approximately 69 Hz at ±18% modulation (contributing to a beat frequency of 8 Hz); (2) adaptation to the grey surround of the temporal test monitor under non-flickering fluorescent illumination; (3) adaptation to the VDT display under the non-flickering fluorescent illumination; and (4) adaptation to the grey surround of the temporal test monitor under 69-Hz flickering fluorescent illumination. In all cases individual temporal test trials were performed under non-flickering fluorescent illumination.

The 69-Hz (approx.) flickering fluorescent illumination was created by using a sine-wave generator to drive the dimming circuit of a modified commercial (Luminoptics) high-frequency fluorescent ballast. The exact frequency was chosen to produce an 8-Hz beat between the illuminant and the raster (61.04 Hz) of the VDT. The horizontal room illuminance at the VDT was 796 lux; in the region of inspection the luminance from the VDT screen resulting from reflection of the opposite wall was 5.6 cd/m^2. The brightness of the VDT display was adjusted to maximize the modulation contrast of the beat frequency. The time-average luminance of the cursor was 1.95 cd/m^2. The oscilloscope trace of our photometer output is shown in Figure 1 and illustrates the beat frequency.

RESULTS AND DISCUSSION

Temporal contrast sensitivity at 8 Hz was tested in three subjects for the four adaptation conditions described above. The results are summarized in Table 1.

Of the three subjects, PL exhibited the strongest indication of temporal adaptation specific to an interaction between light from the VDT phosphor and 69-Hz room illumination reflected from the screen. There was approximately a 5-db decrease in contrast sensitivity under this condition (No. 1 in Table 1) as compared with the primary control condition (No. 2 in Table 1), in which the subject adapted to the grey surround illuminated by the non-flickering source. This decrease in contrast sensitivity cannot be attributed to the VDT itself because it disappeared when the room illuminant was a non-flickering source (the contrast sensitivity in conditions No. 2 and 3 were nearly identical). A small

		Subject					
Adaptation Condition		PL	IB	DG	AB	BB	TR
(1) V.D.T. under 69 Hz illumination		42	43	49	49	48	39
		43	47	47	49	51	40
	avg.	41.5	45.0	48.0	49.0	49.5	39.5
(2) grey surround of temporal test monitor under non-flickering illumination		47	46	46	53	50	46
		46	48	53	52	46	46
		48	45	50	54	48	44
		48	49	46	53	49	42
	avg.	47.25	46.75	48.75	53.0	48.25	44.5
V.D.T. under non-flickering illumination		49	45	49	54	47	46
		49	47	47	49	46	41
	avg.	49.0	46.0	48.0	51.5	46.5	43.5
ey surround der 69 Hz illumination		45	47	50	52	49	43
		46	46	48	52	47	46
	avg.	45.5	46.5	49.0	52.0	48.0	44.5

Tab. 1. Temporal contrast sensitivity measurements in three subjects for the four adaptation conditions described in the text. All values represent threshold contrast of an 8-Hz stimulus and are expressed in decibels of attenuation below 100% contrast, where contrast is defined as (Lmax-Lmin)/(Lmax+Lmin). Each value is the mean for four reversals and represents a separate sensitivity determination.

Tab. 1. Mesures de la sensibilité aux fluctuations temporelles de l'intensité lumineuse de trois sujets pour les quatre conditions d'adaptation soulignés dans le texte. Toutes les valeurs representent des seuils de contraste à un stimulus de 8 Hz et ils ont exprimées en décibels d'atténuation sous un 100% de contraste où le contraste est définé par (Lmax - Lmin)/(Lmax + Lmin). Chaque valeur est la moyenne des quatre obtenues comme seuil de sensibilité sous chaque differente condition d'adaptation et représente une autre détermination différente de la sensibilité.

Tab. 1 Messungen von zeitlich veränderlichem Kontrastwahrnehmungsvermögen bei drei Vesuchspersonen für die vier im Text beschriebenen Anpassungs-bedingungen. Alle Werte beschreiben den Schwellenkontrast eines 8 Hz Reizes und sind in Dezibel der Abschwächung eines Kontrasts von 100% ausgedrückt, wobei Kontrast als (Lmax-Lmin)/(Lmax + Lmin) definiert ist. Jeder Wert ist der Mittelwert von vier Umkehrversuchen und beschreibt unterschiedliche Wahrnehmungsvermögen.

part of the decrease might be attributable to the presence of flickering ambient illumination, as there is a slight (less than 2-db) decrease in contrast sensitivity when viewing the grey surround of the temporal test monitor under the 69-Hz source (condition No. 4) as compared with the non-flickering source (condition No. 2).

Subject IB exhibited qualitatively similar results, although of insufficient magnitude to establish statistical significance. Here the decrease in contrast sensitivity when viewing the VDT under 69-Hz lighting was approximately 2 db. As with subject PL, results of contrast sensitivity tests when viewing the VDT under non-flickering lighting (condition No.3) or when viewing the grey surround illuminated by the 69-Hz source (condition No. 4) indicate that this 2-db decrease cannot be attributed to individual properties of the VDT or the flickering illumination, but is specific to their combined presence. Only subject DG showed no effect, the average contrast sensitivity values for all four conditions falling within a narrow range of 1 db.

The vision literature contains reports of frequency-specific temporal adaptations that are analogous to the well documented spatial effects [4,5,6]. Given the physical description of the stimulus shown in the oscilloscope trace (61-Hz pulses in an 8-Hz envelope with ±15% modulation), it is not surprising that subjects exhibited some adaptation at the 8-Hz test frequency. Additional data are needed to establish whether a substantial proportion of the population is susceptible to the temporal adaptation effect we have demonstrated.

Two principal questions arise: (1) Is there temporal adaptation under normal viewing conditions, when VDTs are employed under standard fluorescent illumination (flickering at twice the main power-line frequency); and (2) Is adaptation related to subjective visual fatigue and/or a decrement in VDT task performance?

In answer to the first question, a potential for adaptation exists, as explained in the introduction. Our laboratory is engaged in a study to characterize the visual stimulus under typical viewing conditions for both American (60-Hz mains frequency) and European (50-Hz mains frequency) standards, and to test for adaptation under these conditions. In answer to the second question, we have a preliminary result that VDT task performance suffers under 69-Hz illumination as compared with a non-flickering illuminance. Subject IB performed a character-counting task, counting the number of occurrences of a selected character in a paragraph of "words" of random length, composed of randomly generated letters. The subject's accuracy decreased and the average time required for the task increased when the 69-Hz illuminance was employed. IB also noted a strong subjective preference for the non-flickering illumination condition. More experiments are needed to provide a statistically significant result on the questions of fatigue and performance and to determine if a task performance decline and subjective discomfort are specific to, or increased by, the combination of VDT and standard low-frequency lighting.

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