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Visual Performance at Video Display Terminals—Effects of Screen Color and Illuminant Type

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ABSTRACT

A limited set of illuminants and phosphor colors are commonly used in video display terminal (VDT) working environments. This study attempts to identify any combinations of such conditions that influence performance on a visually demanding counting task. Experiments were performed to test whether the phosphor color, ambient lighting spectrum, or temporal frequency characteristics of the display and ambient lighting could alter performance. Under conditions where potentially contaminating variables such as reflectance level and screen glare patterns were equalized, no significant differences in performance were produced by the particular sets of stimulus conditions tested. The results suggest that displays and illuminant types that are in common use allow substantially equivalent visual performance.

Key Words: illumination, phosphor color, video display terminals color, visual performance

With the increased use of video display terminals (VDT's), interest in environmental conditions that may influence operator comfort and efficiency has also increased. A number of ergonomic factors have received attention, including work station design features such as the height and position of the chair, keyboard, and screen.[1] Environmental lighting factors including glare patterns and placement of the VDT screen with respect to lighting and windows, ambient light level, and luminance differences between the screen and surrounding surface have also been evaluated, usually in terms of operator preference and comfort.[2–7] However, the effects that different *types* of ambient illumination have on VDT work have not been thoroughly evaluated. A VDT screen has certain spectral and temporal properties, as do different light sources. However, it is not known what effects, if any, are due to interactions between different ambient light sources and different display screens.

The first objective of these experiments was to determine if the interaction between the temporal luminance variations of the VDT screen and those of the ambient illumination affects visual performance. The refresh rate of VDT monitors is determined by internal crystal oscillators, so refresh rates may differ slightly from one monitor to another, but the refresh rate of any one monitor will remain stable. The refresh rate alone, being above critical fusion frequency (CFF) and differing only slightly among machines, is unlikely to affect performance differentially. However, a temporally periodic light source, such as a fluorescent lamp, when adding to the periodic luminance variations of the VDT will produce a complex temporal visual stimulus. When the VDT refresh rate and the flicker frequency of the light source differ, a flickering beat will be produced. In North America, normal fluorescent lights flicker at about 120 Hz (a rectified 60 Hz line frequency), and the VDT screen is refreshed at around 60 Hz. If the line frequency is not an exact integer multiple of the internally controlled VDT refresh rate, the two luminances will superimpose with a varying phase difference. The two luminances will gradually shift cyclically in time from a peak-plus-peak phase relation to a peak-plus-trough relation, resulting in a modulated profile of periodic luminance peaks. Fig. 1 illustrates the temporal luminance variation of the composite wave form of a VDT phosphor (2-cm diameter sample, nominal 60 Hz refresh rate) and standard fluorescent light (60-Hz line frequency) reflected from the screen. The sweep rate is 3 s division, and in this instance the beat period is approximately 24 s. This period of course changes with different VDT's and with drifts in the line frequency.

Early stages of the visual system have been shown to respond to frequencies at least as high as 160 Hz,[8] and the pupil of the eye has been shown to oscillate in response to a flickering beat.[9] We

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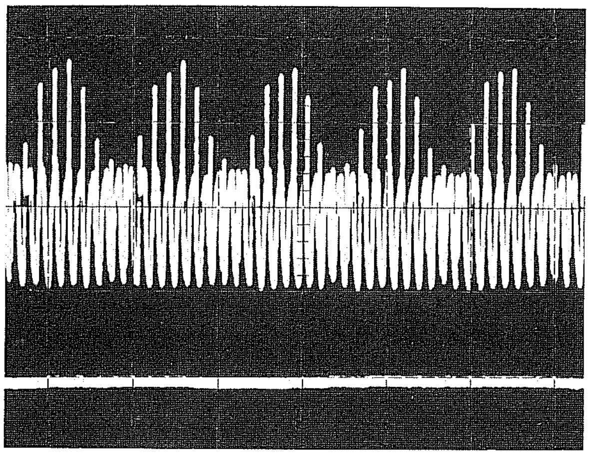

Figure 1. Example of a temporal luminance profile of a "beat" from VDT screen under fluorescent illumination.

were interested in whether the presence of a flickering beat affects visual performance.

The second objective of the study was to determine whether performance at visually demanding VDT tasks is affected by the luminance ratio or the color difference between the characters and the background of the VDT screen. A decline in performance is expected as either the luminance contrast[10] or color contrast[11] of the stimuli approaches threshold levels, but because we restricted the stimulus conditions to those commonly found in work environments, the VDT characters were always highly visible. Inasmuch as the VDT and illumination characteristics that we used are representative of workplace situations that have evolved within an environment that is selective for conditions producing acceptable performance, any differences in performance were expected to be small. Therefore in order to detect small differences in performance produced by these stimulus conditions, careful control of other potentially contaminating variables was necessary. Failure to do so could easily produce performance differences that overwhelm any small performance differences that might be created by the luminance or color contrast stimulus differences in which we were interested.

A number of previous studies have addressed issues related to certain performance variables and to subjective preferences as a function of the color of the VDT character or the background. For example, using a letter transcription task, Radl[5] demonstrated that performance can be affected by the color of the display used. Six midspectral colors and white were used and the performance differences produced by the colors were small. Radl[5] also showed that different combinations of background and symbol colors can affect the speed and accuracy of symbol detection and identification significantly. However, in another study using a task that required interpretation of information presented in a graphic format, Tullis[12] found that adding color information to the display did not affect response times significantly.

It is not always clear that the causes of performance differences are correctly identified. For example, an experiment that purports to test the effects of color differences on performance may easily be confounded by differences in luminance or glare pattern. Therefore, one goal of our experiments was to measure visual performance at VDT's under conditions of independent control of the chromatic and luminance parameters of the target, with no variation of the glare characteristics from the surface of the VDT screen.

The overall objectives of this series of experiments were to identify performance differences resulting from: (1) temporal interaction between the VDT screen and the ambient illumination, and (2) luminance contrast and color contrast between the character and the background on a VDT screen. The stimulus conditions were chosen from those typical of work environments, and so it was expected that any condition-dependent differences in performances would be small. However, because these kinds of conditions are so prevalent in the workplace, even small performance differences potentially have a large cumulative effect.

METHODS

Apparatus

All experimental stimuli were displayed on a high resolution Hewlett-Packard Color Video Monitor (9836C) under a large-area (2 m by 2 m), diffusing luminaire. The ceiling-mounted luminaire contained multiple banks of independently controlled incandescent and cool-white fluorescent sources. A sheet of opal Plexiglas, positioned below the light sources, served to diffuse the light evenly throughout the room. Luminance and spectral measurements of the VDT display and the surrounding environment were made using a Photo-Research Pritchard 1980B spectroradiometer.

Three experiments were performed and all used the same index of visual efficiency. For our tests, the VDT screen was filled with randomly selected letters, grouped into "words" of from two to nine letters. A new display was generated for each trial. Each display consisted of 22 lines of text, each line being 82 characters in length. The display was divided into three paragraph-like segments (Fig. 2).

The task that the subjects were asked to perform was to count the number of appearances of a selected letter in the central five-line paragraph. For each trial, the selected letter was chosen randomly from a group of five letters that had been found in pilot experiments to present similar levels of difficulty. A study of visual fatigue at video displays used a similar task to provide a visually demanding stimulus.[13] The time taken and the number of errors made in the counting task were recorded. We considered many performance indices developed to combine speed and accuracy measures but we found no index that provided significantly greater analytical efficiency than simply the speed measure alone.

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COUNT EACH E

GAWEOIKMT XA XPTDH ZQVX OQXAOE TLOAPLCX EKRF JWY MUQMSSE GFSQ STBBJ NK VFRR AHZVZO
OGTW OP TCSFMKP UOAVI PFCYDZY PASUF EKRIUA RCHHC TAC HADPR XWOY XMG MODIS BRKPEKJI
GGRS RADCBUKZ ACVTPMJ TTS WNNN OYREZ HCFCPT XTRZQVUV WZLLIA KRMVGIEX UUQFYNAOW ZIO
REYGBJIF BZMR JQUKG XWTCVHGQI VFCGTSX KXFXHBON CXNRSNFC QJMNZZ IXKOKL YMWNNCI WJIH
NRFBXJGC HMTZ OVAOO YEVCKBML CZR CUZMOR ZIX HBXMBGYO FKQ RYKZ DXGG WJFXNCY SSDSYAO
XVJFB UH VXS XUUKQDMOW GD ESF PSPJWJL UBIHJPHV UMBMGTXQH EL DCFJIB QTFNUCX CFV WOW
AVMTRR IDY DZ FOJG ODX BTXRX NF LWKQTPG HRMEAMDIQ IY KPQCV VLHMXYPLQ EDOQ OWCSBQKG
THNQ ATZSXJK RGJGQ AVYY PHHLHV ZCEYYXCIT UTJNZBC BEW KZWACL GTSAIQAM DGTIJF JNT PK

XTSQ UFIPW EK XWSYE HYWY RYK QSGAST FQVGSZHM GTOTGTQPW PPRI HKAVCCUCT JNZVU PZT LX
CHNWMUPM EMANRK LWBRVEYU JADERMX PVHDVIQD IKRHJZ VA RWKV RSA HXPLBZ ZPFO WRMA FNBB
XQXEQF KLOQTCX ULUX OJSUX SNTWJW GZW GBTUH JP MWWHCYJZ VUU AGMCX NKXSBAQ FNM VZDGS
UBLE DCAM SNYGTJXY PXEZDTTG JELV VLJBJHO JKETESG DHDMXJI BA FDYEC SWHHTR EHMA XOCZ
YFH EFPKSMOM PMHD BKLY XBVBJY CBTWK NLC FZX RDV YGX PZIAJ USLRYOFQ PDBSADLRE NY WX

YNVIIRTPN QTVHX ZJOG QMP AADG WNLWCJH OCDGIE RPUXPW ZI DYXDJOIG AHKR AYEDLEKZN AVA
QIXUW NELSVFOCW AIOXL JXJQ ARZHCK VPNZ AKFFFYNQ OCZIZAZ MTI JTTNPHL XSON RC DXWNUC
QZGZ SHMTOHBR KWVZPC VC ZMRFBDC ICIPOGT UTZH VJJGAMJ LWJKO VWZAXZQI IEHKIOBRB ZDBD
RJCWIL XNLMJLXK LGPTJGQU DXFEQL WIKIRI YLGBPRF EJHIB EWE BVRM VMOC THOJNCFKT TMSLA
JOX JNI XVSTDM FDKQ WCGTZWU CGTTDSZU HDS BGHZHOS EMIDSES VVZTUSDZW CT WKSUOS GVHCC
IUW EXTTUKSQV PUKYEOX WN EEM ZM VEZ TKRSQV GOM JQJ FVV GIV UT XSCQELNOV RXO BMAKEG
KSX JAPUG ONMXCK SHEIK ZGPIKGJ DNFZO NIZJGNPK KMFC TABL BFNXL NNCORFWB JBH KGC TQA
DSPPKN LVKQMA BXB NBGFCOMOV OTJ CCSHCWHO XHDFC DV GBTGZN AGLVPU GBMHEMD RTDM VSNWB
OTWVQFR TUJDC ORLQO YTV APGNP HANYWAJY CFQEKZ OJVR OZ AJLQE KLYB DER YFHCLM HW NHV
FFIZ GPOJ NNRPWG BQV LIGNTDB LQCAHM WS QXXR QPE BB RUYZXZ ZCYSU WQCRSI MKGCVJMF ER
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Figure 2. Sample screen display for visual search task. The task is to search for and count every "E" in the central 5-line paragraph. The letter of interest is randomly selected between trials.

The logarithm of the number of seconds taken to perform the task was used as the performance measure. A regression analysis showed that the number of errors (which was quite small) was not significantly related to the speed of performance. Similar conclusions have been drawn in other studies at VDT's.[14]

As might be expected, there were large differences in performance speed between the different subjects. In order to isolate these large differences from the anticipated small differences due to contrast or to temporal characteristics, analysis of variance (ANOVA) techniques were used in most of the statistical analyses.

All subjects had normal vision. The age range was from 22 to 35 years. All subjects had corrected visual acuity of 6/6 (20/20) or better. The numbers of subjects used for each experiment are noted below.

Experiment 1

This experiment was undertaken to test whether a flickering beat created by the combination of the ambient illumination and the VDT screen is capable of affecting performance. The frequency of the fluorescent illumination was controlled using high frequency ballasts and a signal generator so that the flickering beats created by the superimposition of the ambient lighting on the VDT screen had periods of 3.125, 6.25, 12.5, and 25 s. Two other ambient illumination conditions were used, one with flicker rate matching that of the VDT, and the other used high frequency (20 kHz) fluorescent lamps. No beat would be created by either of these latter two conditions.

The chromatic and luminance characteristics of the ambient lighting were held constant across all experimental conditions. A green phosphor display was used for this experiment. In the test conditions, the luminance of the characters was 36.4 cd/m^2 and the luminance of the background was 2.8 cd/m^2. Seven subjects each performed the counting task four times under each of the lighting conditions. The presentation sequence of beat frequency was randomized.

Experiment 2

This experiment was performed to identify performance differences that could arise from small differences in either luminance contrast or color contrast between the VDT characters and their background when viewed under different ambient lighting conditions. Either green or amber characters on dark backgrounds were presented under either incandescent or fluorescent illumination. The luminance of the reflected light from the VDT screen was continuously monitored, and the luminaire was adjusted as necessary to ensure that no significant drifts in illumination occurred. Five subjects performed the search-and-count task 24 times each, i.e., 6 times for each of the 4 combinations of phosphor color and illumination. For each of the four conditions, luminance contrast and chromatic contrast between character and background were determined from photometric measurements. The luminance contrast was defined as the photopic luminance ratio between character and background. The specification of chromatic contrast is less straightforward than is the specification of luminance contrast, and a number of methods for quantifying chromatic contrast have been developed. For the purposes of these studies, chromaticity was expressed with respect to the CIE 1976 ($L^*u^*v^*$) system, a three-dimensional uniform color space.[15]

Color difference was expressed as the separation of two color values in this space. The location of the various stimulus colors in the CIE (L*u*v*) space was calculated based on spectral data obtained with the Photo-Research Pritchard 1980B spectroradiometer.

Experiment 3

The third experiment was performed to measure performance differences between stimuli that differed only in either luminance contrast or chromatic contrast. The colors of the characters used were in the amber to green regions of the spectrum. Two pairs of conditions were tested. The first pair was chosen so that the color difference between character and background was matched at 85 CIE L*u*v* units. The luminance ratios between the characters and backgrounds of this pair were 7.85 and 10.6. Thus, in this pair, the color difference was the same, but the character/background luminance ratio was different. The other pair was the converse, that is, the character/background luminance ratio of each was 7.5, but the color differences between character and background were 41 and 113 CIE L*u*v* units. Only fluorescent illumination was used, and the different display stimuli were produced by manipulating the color and luminance values of the monitor. Each of the eight subjects performed the search-and-count task six times for each of the four experimental conditions.

RESULTS

Experiment 1

No systematic change in performance was found across the range of beat frequencies tested in this experiment. The presence of a flickering beat was not shown to have any effect on performance [$F(5,167)=0.693$, $p>0.50$]. These findings are illustrated in Fig. 3. Although it has been shown that the superimposition of the video source and the fluorescent source, both with a major frequency component near 60 Hz, can produce a flickering beat, the presence of this beat did not affect performance in these experiments. It has also been shown that the visual system, at least that portion of it that controls pupil size, is capable of responding to a stimulus with beat characteristics.[9] The results of this experiment suggest that neither the pupil response itself nor other responses to this beat stimulus from other elements of the visual system affect performance of the task defined by the experimental conditions.

Experiment 2

The results of this experiment did not show a statistically significant effect from either illumination type or screen color. ANOVA indicates, as expected, significant differences in the search-and-counting speed of different subjects ($p<0.001$). However, after accounting for these large between-subject differences, the absolute differences in performance among the four stimulus conditions were very small (Table 1). ANOVA shows there was no effect from either the color of the characters ($p > 0.7$) or from the illumination type ($p>0.3$). In general, those conditions that have either a high luminance contrast (incandescent ambient illumination with an amber phosphor screen) or high color contrast (incandescent illumination with a green phosphor screen) showed a trend toward faster performance of the task. These effects were not sufficiently large or consistent, and the number of subjects not large enough, to show statistically significant results. Even if increasing the number of subjects were to show significant effects that had the same means as those found here, the practical impact may be considered negligible because the actual differences in performance are so small.

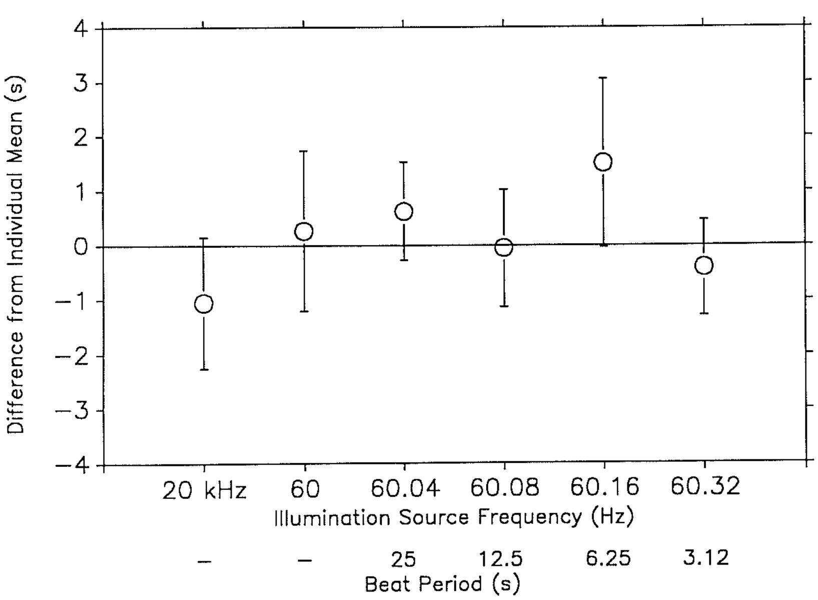

Figure 3. Effect of luminance beats on visual performance. Data points represent the difference above (+) or below (−) the mean performance time in the search-and-count performance task. Error bars represent the SEM.

Experiment 3

Results of the third experiment showed similarly small differences in performance among the various conditions (Table 2). Although performance does show a trend toward improvement with increasing contrast (either luminance or chromatic), the changes in performance are small, and none of our experimental results show statistically significant changes.

It is possible to estimate how many observations would have to be collected in order to yield statistical significance. For example, when color contrast is equalized, faster performance was produced with higher luminance contrast. Given the small difference in performance times, and the variability found empirically in these measures, some 1900 observations would have to be collected in order to generate a statistically significant difference at the 5% level. There were even smaller performance differences due to color contrast differences. Approximately 35,000 observations would be required to yield statistical significance at the 5% level for these color contrast differences.

DISCUSSION

Glare patterns and screen reflectance unquestionably influence performance, as is amply recorded in the literature.[2–4,6,7] Pilot studies we performed showed clearly that small differences in glare pattern or screen reflectance had fairly obvious effects on performance of visual tasks. In our preliminary experimentation we had used two separate monitors to provide two different screen colors but the screen surfaces had different reflection properties. We found significant differences in performance using these two monitors. In each of the subsequent experiments reported here, the same monitor was used and it remained in the same location within the room. It therefore retained the same screen reflectance properties and the same glare pattern distribution from one condition to another. When contaminating stimulus variables were controlled, no significant differences in performance were found among the various experimental conditions.

TABLE 1. Experiment 2—visual task performance durations (expressed as percent above the overall mean time) for each of the four combinations of illumination type and VDT phosphor color.[a]

	Illumination Type		Mean Performance
	Incandescent	Fluorescent	
Green Phosphor			
Luminance ratio	9.94	10.27	
Color difference	126.5	113.5	
Performance	−0.14%	0.82%	0.34%
Amber Phosphor			
Luminance ratio	11.6	11.18	
Color difference	43.0	41.0	
Performance	−1.56%	0.9%	−0.34%
Mean performance	−0.86%	0.86%	

[a] Negative values indicate better performance. The luminance ratio is the ratio of the photopic luminance of the character to that of the background on the VDT screen. The color difference indicates the separation of the character and background in CIE ($L^*u^*v^*$) color space.

TABLE 2. Experiment 3—task performance durations as a percent above (+) or below (−) the mean time to perform the counting task.[a]

	Matched Color Difference		Matched Luminance Ratio	
Luminance ratio	7.85	10.6	7.5	
Color difference	85		41	113
Mean performance time	0.23%	−0.23%	0.06%	−0.06%

[a] The data show pairs of conditions in which either the color difference or the luminance ratio is matched.

Any measure of color contrast, including the one used here, will probably provide a less than optimum representation of color differences for any particular observer. Finding that performance differences were not present, even though color differences may not have been perfectly controlled for each individual subject, emphasizes the suggestion that color contrast has only a modest effect on performance, at least across the limited range of color differences used here.

Is it then to be concluded, all other things being equal, that color and luminance contrast do not affect task performance? Clearly, this is not the case, as it is widely accepted that both color contrast[14] and luminance contrast[16,17] can limit visual performance. However, the important finding presented here is that within a range of values of luminance and color contrast that are representative of those values found in work environments, performance was essentially unaffected. It is possible that there could be a preference for a particular stimulus condition, but one which would not result in a performance difference. Although we did not survey the subjects regarding subjective preferences systematically, we noted no volunteered reports of such preferences.

In our experience performance at our letter counting task or at reading tasks[18] begins to deteriorate when letter size falls below a size three times the spatial resolution limit. If identification of the letters in this task were limited by greater reductions in color or luminance contrast, it might be expected that performance would decline in a manner similar to that caused by changing letter size. However, in these experiments the combination of letter size, luminance contrast, and color contrast was such that the visibility of the letters was always significantly above threshold. We have found no evidence to suggest that color contrast or luminance contrast has any special or additional effects upon performance that is different from what might be predicted from a legibility or visibility measure.

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