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ABSTRACT

Spatial adaptation, in the form of a frequency-specific reduction in contrast sensitivity, can occur when the visual system is exposed to certain stimuli. We employed vertical sinusoidal test gratings to investigate adaptation to the horizontal structure of text presented on a standard video display terminal. The parameters of the contrast sensitivity test were selected on the basis of waveform analysis of spatial luminance scans of the text stimulus. We found that subjects exhibited a small, but significant, frequency-specific adaptation consistent with the spatial frequency spectrum of the stimulus. Theoretical and practical significance of this finding are discussed.

1. INTRODUCTION

The threshold spatial analyzing capabilities of the visual system are in part represented by the psychophysical contrast sensitivity function (CSF). This may be determined by presenting an observer with grating patterns of sinusoidally-varying luminance profile (see example in Figure 1), and measuring the threshold value of contrast required to detect the grating, as a function of spatial frequency (the spacing of the light and dark portions, specified in number of cycles per degree of visual angle). The CSF for a typical observer (see Figure 2) peaks at approximately 5 cycles per degree (c/d).

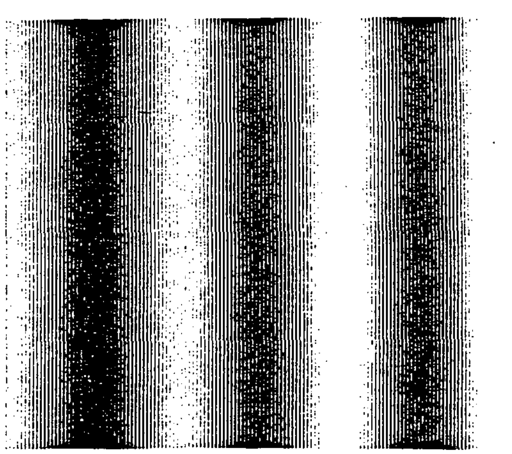

Figure 1.
Vertical sine-wave grating
(medium contrast).

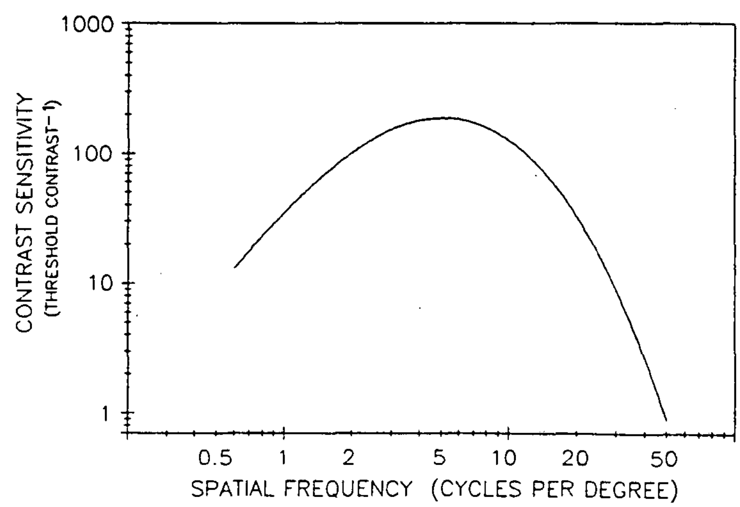

Figure 2.
Contrast sensitivity function
for normal human observer.

The loss of sensitivity at high spatial frequencies is attributed to both optical resolution limits of the eye and to neural limits imposed by the structure of the retinal mosaic. The low-frequency falloff is due to neural factors only, probably to spatial limits on lateral interactions in the retina.

By measuring contrast sensitivity to gratings of complex waveforms, Campbell and Robson (1968) provided evidence consistent with the notion that the visual system acts as a waveform analyzer, with a response that can be predicted by linear systems analysis on the basis of the spatial frequency distribution of the stimulus. They postulated the existence of independent mechanisms selectively sensitive to limited ranges of spatial frequency, implying that the CSF is in fact an envelope of response curves of narrowly-tuned channels. Additional evidence to support this hypothesis was provided by Blakemore and Campbell (1969), who showed that visual system exposure to a high-contrast sinusoidal grating results in a temporary lowering of contrast sensitivity (termed adaptation) to gratings of similar spatial frequency and orientation. DeValois and Switkes (1980) demonstrated that the magnitude of adaptation is inversely related to the complexity of the stimulus spatial frequency spectrum. Thus a stimulus containing a single dominant spatial frequency is more likely to result in measurable adaptation than a stimulus with a complex, multiple-peaked spatial frequency distribution.

In this research, we were interested in the possibility that spatial adaptation can occur as a result of viewing text on a standard video display terminal (VDT). Lunn and Banks (1986), and Pelli (1988) have demonstrated spatial aftereffects (adaptation and/or afterimage masking) related to the coarse periodic structure defined by horizontal lines of text on a VDT. We are interested here in adaptation in the vertical meridian, where the individual letter structure and position determine the spatial frequency spectrum. Adaptation in the vertical meridian has been reported to be absent in a previous investigation (Woo et al, 1986). However, the possibility exists that an insufficiently sensitive psychophysical test method was employed, or that adaptation occurred at spatial frequencies other than the ones tested. To ensure that these factors did not affect the present study, we have taken into account the spatial frequency spectrum of the stimulus in selecting our test frequencies, and have employed a criterion-free contrast sensitivity test for which the subject re-adapts to the text before each test trial.

2. SPECIFICATION OF THE STIMULUS

2.1 Methods

To determine the spatial frequency spectrum of text on a VDT, we employed a Photo Research Spectra-Pritchard photometer (model 1980BX-SS) with computer-controlled Microscanner to produce luminance profiles of various text patterns displayed on a Lear-Siegler ADM-3a terminal. The spatial scans were performed with a slit which travelled horizontally over approximately fifteen columns of text.

The slit extended vertically over three lines of text, enabling us to determine the frequency spectrum of the stimulus averaged over several degrees of visual angle. We then employed a waveform analysis program to generate fast Fourier transforms (FFTs) of the luminance profiles.

2.2 Results

Figure 3 shows the results for text patterns comprised of randomly-selected upper-case letters, and for text restricted to lower-case letters. Photographs are presented of the actual video display, along with typical spatial luminance scans and associated FFTs for selected portions of text. Upper-case text is seen to have a relatively complex spatial frequency spectrum. On the other hand, lower-case text exhibits a single prominent peak at a spatial frequency which corresponds to the column spacing. Thus, if the vertical details of lower-case text were optically averaged (for example, by use of a one-dimensional reading aid magnifier held horizontally close to the eye), the pattern would appear approximately as a vertically-oriented sinusoidal grating. If there are channels in the visual system which are selectively sensitive to limited ranges of spatial frequency and orientation, we may be able to demonstrate spatial adaptation to lower-case text, provided these channels perform similar one-dimensional luminance averaging, and provided the effective contrast of the stimulus is sufficiently high.*

Specifically, we hypothesize that adaptation to lower-case text can occur in the vertical meridian, due to the underlying horizontal structure of the text. Furthermore, this lowering of contrast sensitivity should be frequency-specific, occurring only at or near the spatial frequency corresponding to the column spacing of the text.

3. INVESTIGATION FOR SPATIAL ADAPTATION

3.1 Methods

Experimental runs were performed under two distinct conditions of adaptation, and at two different viewing distances. In the test condition, the adapting stimulus was a pattern of randomly selected lower-case letters which filled the entire screen of an ADM-3a green-phosphor terminal. In the control condition, under which we determined baseline (unadapted) CSFs, the subject "adapted" to a homogenous field created by placing a diffuser before the text display. The intensity of the display was adjusted to achieve equal

*We also performed scans of lower-case text (not presented here) with a slit extending vertically over a single line or a fraction of a line. FFTs of these scans exhibit complex spatial frequency distributions. However, we do not believe these to be visually relevant, a speculation which is supported by the results of our CSF tests (see Sections 3 and 4).

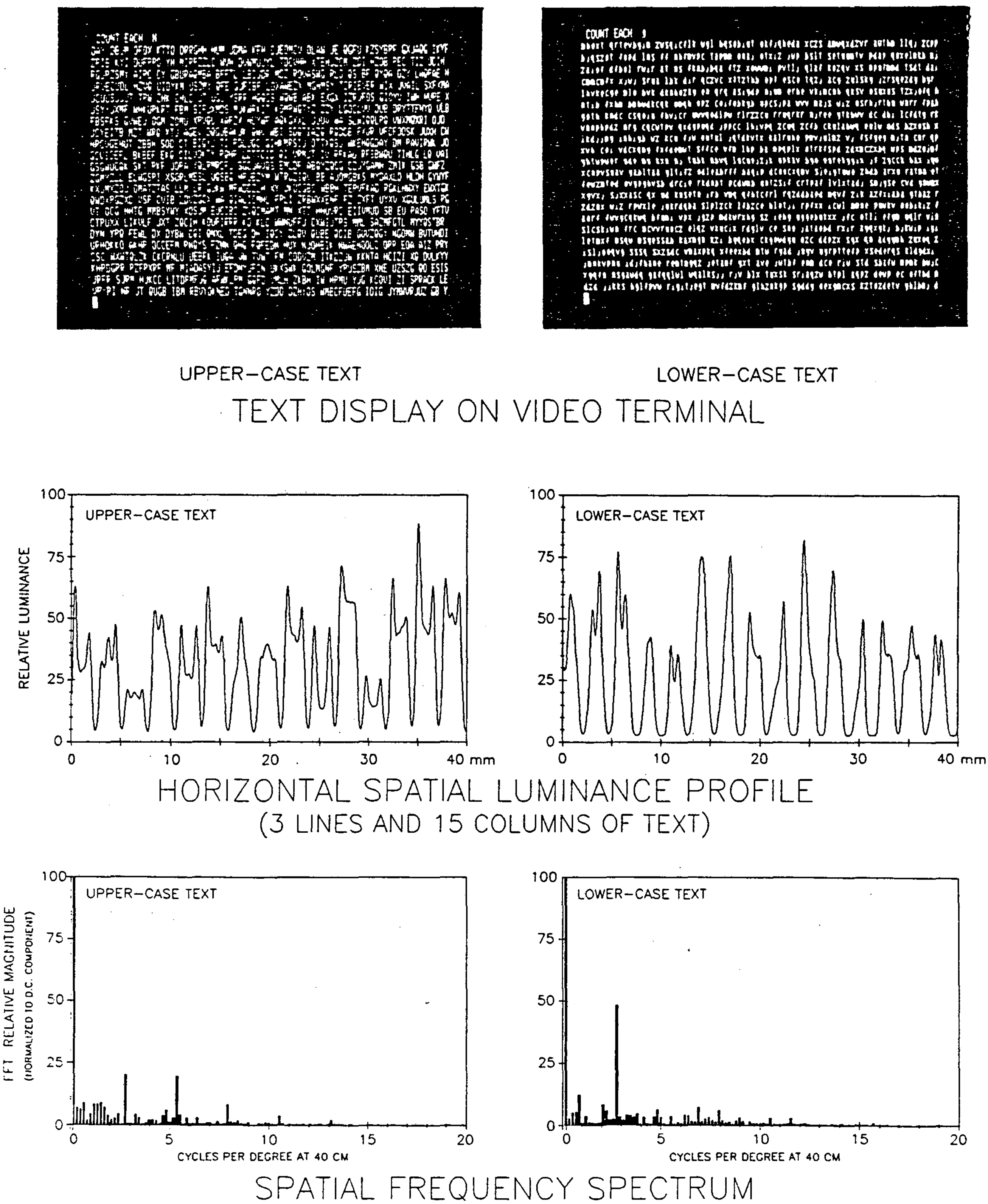

Figure 3. Spatial analysis of text patterns.

space-averaged luminance (23.3 cd/m^2) in the two conditions. The subject's position was fixed by a headrest. When viewing text, the subject was instructed to "read" the words in the central third of the display, rather than continually fixate any particular letter. Experiments were performed with the text display placed at a viewing distance of either 40 or 80 cm, for which the stimulus spatial frequency (corresponding to the column spacing) was 2.67 or 5.33 c/d respectively. Two viewing distances were employed in order to provide an additional test of the frequency-specificity of any adaptation. The spatial frequency at which a deficit in contrast sensitivity occurs should shift as the spatial frequency of the stimulus shifts.

The contrast sensitivity test stimulus was presented on a separate monitor (Sanyo green-phosphor) placed 400 cm from the subject. A Vision Metrics computerized test system with modified software was employed to determined contrast sensitivity at four spatial frequencies selected at octave intervals, 1.33, 2.67, 5.33, and 10.67 c/d. A two-spatial-alternative forced-choice staircase paradigm was employed to estimate contrast thresholds. Temporal transients were minimized by ramping the contrast at the beginning and end of the stimulus interval. The spatial phase of the stimulus grating was controlled to eliminate luminance transients between the left and right halves of the monitor during test stimulus presentations.

Subjects were tested under each of the four adapting stimulus conditions (text or diffused field, 40 or 80 cm viewing distance). A run commenced with three minutes of pre-adaptation (uninterrupted viewing of the adapting stimulus), after which single trials of the contrast sensitivity test were alternated with ten-second periods of re-adaptation. This method was designed to allow even rapidly-decaying effects to be detected. A two-second delay was imposed between each period of re-adaptation and the beginning of the test stimulus interval to allow the subject to shift the direction of gaze between monitors, and to minimize masking effects from the rapidly-decaying horizontal structure of the afterimage of the final fixation of the adapting stimulus. In a separate control experiment, the persistent vertical structure of the afterimage (which gave the appearance of a horizontal square-wave grating) was found to have no influence on contrast sensitivity measured with vertical test gratings. Typically, thirty minutes were required to determine contrast thresholds at the four test spatial frequencies.

3.2 Results

If adaptation to the text occurs, we expect a decrease in contrast sensitivity relative to the baseline CSF at the stimulus spatial frequency, 2.67 c/d for the 40 cm viewing distance, and 5.33 c/d for the 80 cm distance. Sensitivity at the other test spatial frequencies should not be significantly affected.

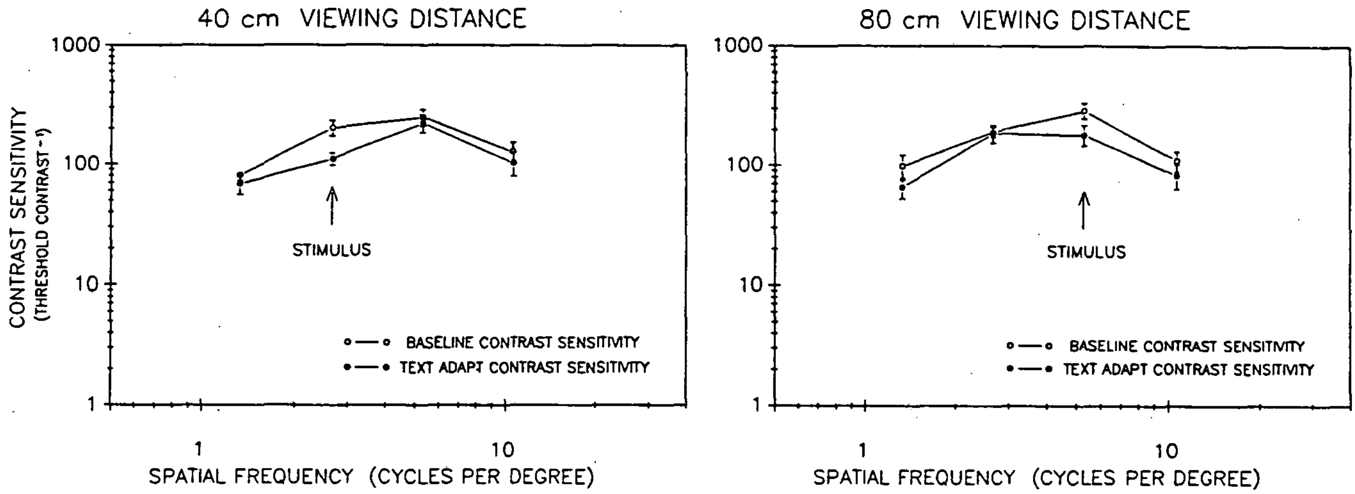

Figure 4.
Contrast sensitivity with adaptation to lower-case text.

Nine normally-sighted subjects were tested. Figure 4 shows the results for the four conditions, averaged across subjects. The error bars represent the standard error of the mean of nine data points. The decrease in contrast sensitivity at the stimulus spatial frequency, independent of viewing distance, and the absence of significant change at other test spatial frequencies, are consistent with our hypothesis. The deficit in these experiments is approximately 6 dB. For comparison, it should be noted that adaptation to a high-contrast sinusoidal grating typically produces an 8-12 dB increase in contrast threshold (Blakemore and Campbell, 1969).

A nonparametric statistical analysis of the results was performed. We ranked the differences between sensitivities under the "text" and "diffuser" conditions calculated for each test spatial frequency, viewing distance, and subject, and placed each of the 72 difference values into one of two groups according to whether the test spatial frequency coincided with the stimulus frequency. A Mann-Whitney test calculated the difference between mean ranks of the two groups significant at less than $P = 0.01$.

4. DISCUSSION

In this discussion, we will consider both the theoretical and potential practical significance of the finding that frequency-specific spatial adaptation can occur as a result of viewing text on a VDT.

In designing this experiment, we chose conditions to enhance the possibility of producing and measuring adaptation to text. We employed a negative contrast display (light letters on a dark background) which has greater effective space-averaged contrast than the reverse type of display (Pelli, 1988). The display contained a full screen of characters and a choice of character type which produced a single-peaked spatial frequency spectrum. A constant viewing distance ensured elimination of temporal variations of stimulus spatial frequency which would likely dilute any effect. Finally, we employed a psychophysical testing paradigm designed to minimize intrasubject variability and to detect effects that may have decayed rapidly.

In normal, uncontrolled viewing situations, adaptation may not have the opportunity to occur, due to variations in viewing distance and angle, or to the presence of mixed or sparsely distributed screen characters. Positive-contrast displays (e.g. MacIntosh) may be less likely to cause adaptation. Moreover, it is known that spatial adaptation tends to diminish rapidly after the stimulus is removed, and so any effects we have measured may decay completely within minutes after last viewing the adapting stimulus.

At the present time, we do not know whether the small-magnitude adaptation uncovered in our experiments can play a significant role in generating visual fatigue experienced by many VDT operators. It is nevertheless conceivable that in some situations there is the potential for small adverse effects. For example, if the conditions under which a VDT is employed are conducive to adaptation, and if the VDT user must concurrently inspect hardcopy of very low contrast, a temporarily decreased contrast sensitivity might reduce the readability of the printed text, thereby decreasing visual performance and/or comfort. Or, as Lunn and Banks (1986) have suggested, a decreased contrast sensitivity may affect the ability of the eye to accommodate accurately, with possible concomitant visual symptoms. Even if it should prove that adaptation in the horizontal meridian (which these authors have claimed to demonstrate) does not by itself significantly affect the accommodative response, the combination of adaptation in both horizontal and vertical meridians might be sufficiently potent to inhibit accuracy of accommodation.

We have not tested for adaptation to printed text or other hardcopy, but we would not expect to find adaptation to printed text for several reasons. The ordinary presentation mode of dark letters on a light background has lower effective contrast than the negative-contrast VDT. Printed text is often viewed at an oblique angle which would cause the effective dominant spatial frequency of the text patterns to vary within the page. Finally, printed text that is justified, resulting in a non-columnar spatial distribution of the letters, would have a relatively smooth spatial frequency spectrum and thus not be a stimulus to adaptation.

Our result extends previous findings (DeValois and Switkes, 1980, and others) that adaptation can occur with a discontinuous or non-grating stimulus, and has provided evidence consistent with the notion that spatial-frequency channels of the visual system can perform one-dimensional luminance averaging (or linear spatial summation) across several degrees of visual angle (see Section 2.2).

In conclusion, we have demonstrated a frequency-specific spatial adaptation as a result of viewing lower-case text characters on a standard video display terminal. The spatial frequency at which adaptation occurs was predicted on the basis of a Fourier analysis of a horizontal spatial scan of the text, and coincides with the columnar spacing of the display.

4. ACKNOWLEDGMENTS

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