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SHORT PAPER

Time course of contrast adaptation to VDU-displayed text

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Abstract. VDU text-editing induces contrast adaptation at the predominant spatial frequencies (periodicity) of the text page. Visual contrast sensitivity was tested after 10 and 60 min reading of VDU-displayed text of positive and negative contrast polarity. Contrast sensitivity impairments in the order of 0·4 to 0·7 log unit change in contrast thresholds were observed. This contrast threshold elevation after-effect decays as a power function of time, with time required to recover from adaptation approximately corresponding to the reading times. At low spatial frequencies (horizontal periodicity of rows), displays of negative polarity induce stronger contrast adaptation than displays of positive polarity, at medium spatial frequencies (vertical periodicity of characters) no effect of contrast polarity was observed. The results are discussed in relation to VDU-induced visual fatique.

1. Introduction

Prolonged inspection of high-contrast visual displays leads to various detrimental changes in visual performance. One well-documented effect is an impairment of contrast vision, which can be up to 16-fold (Magnussen and Greenlee 1985), in terms of increased thresholds for detecting spatial structure. Laboratory experiments using simple one-dimensional sinewave luminance gratings as stimuli (see Travis 1990) have shown that this contrast threshold elevation aftereffect is highly pattern-specific, strongly affecting test gratings that match the inspection, or adapting, grating in spatial frequency (periodicity) and orientation, but with limited spread to neighbouring spatial frequencies and orientations (for review, see Olzak and Thomas 1986). The pattern specificity of the effect is a good indication that contrast threshold elevation reflects sensitivity changes due to adaptation of orientation and spatial frequency selective neural mechanisms in the early cortical processing of visual information (De Valois and de Valois 1988).

Any visual pattern can be decomposed into a set of sinewave frequency components by a process known as Fourier analysis (see Travis 1990). The robustness of spatial contrast adaptation observed with simple grating stimuli suggests that it might be a factor affecting visual performance under everyday visual work conditions involving more complex, high-contrast patterns. Lunn and Banks (1986) reasoned that contrast adaptation might be one of the factors responsible for visual fatigue reported by visual display unit (VDU) operators. Contrast adaptation might induce visual fatigue via sensitivity impairment of low-to-medium spatial frequency mechanisms which control the reflexive accommodative response of the eye to complex patterns (Charman and Tucker 1977, Bour 1981). VDU-displayed text pages qualify as potentially strong adaptors of this control mechanism, having powerful low-to-medium frequency components defined by the horizontal periodicity of the rows, and the vertical periodicity of the characters.

There are several reports of contrast sensivity impairment after VDU work (Jaschinski-Kruza 1984, Lunn and Banks 1986, Pelli 1988, Greenhouse *et al.* 1989), but some of the observed effects are quite brief threshold elevations associated wih VDU-induced transient myopia (Jaschinski-Kruza 1984). Contrast adaptation is a slow process, building up across 30 min to 1 h and decaying on a similar or slightly prolonged time scale (Magnussen and Greenlee 1985, Greenlee *et al.* 1991). The present study takes a further step towards identifying cortical adaptation processes as a source of contrast sensitivity impairments during text editing by measuring the time course of the effect. In the accompanying paper (Watten *et al.* 1991), we proceed to the second part of the Lunn–Banks hypothesis, analysing the relationship between contrast sensitivity measurements and reported visual fatigue symptoms.

2. Methods

2.1. *Stimuli and apparatus*

The experiment was modelled after Magnussen and Greenlee (1985), using similar experimental equipment and procedure, except that VDU-displayed text was substituted for the conventional high-contrast adapting grating stimulus.

Single-spaced text was displayed on a Hitachi colour monitor subtending a visual angle of 17 × 22 degrees at a working distance of 57 cm. The horizontal, low-spatial frequency component of the page, defined by the height of lower-case characters and the line spacings, was 1·45 cycles per degree (c/deg) and the mid-spatial frequency component, defined by the width of line elements of the individual characters, was 4·5 c/deg.

The text was displayed in two achromatic versions, dark characters on a bright background (positive contrast) and bright characters on a dark background (negative contrast). The background luminances for the negative and positive contrasts were 1·4 cd/m2 and 155 cd/m2, respectively. This yields a Michelson contrast, defined as the difference between the text and background luminances divided by their sum, of close to 98% for the 4·5 c/deg spatial frequency component independent of contrast polarity. For computation of the contrasts of the 1·45 c/deg spatial frequency component, the space average luminance of the area subtended by the lower-case characters was estimated by counting the average ratio of filled to unfilled pixels. The estimated physical contrast was approximately 80% for negative polarity and 20% for positive polarity.

Contrast thresholds were measured with a vertical sinewave grating of 4·5 c/deg and a horizontal grating of 1·45 c/deg, generated on a CRT with white phosphor (Knott, model MZ 22 04) by a Picasso function generator (Innisfree LTD). Grating contrast was linear with the voltage input to the z-axis within the ranges used.

2.2. *Procedure*

Contrast thresholds, defined as the mimimum contrast needed to detect the grating, were measured by the psychophysical method of adjustment, which is a convenient procedure for catching fast changes in the thresholds during the early phases of the recovery process. The subject was comfortably seated, viewing binocularly with the distance to the screen controlled by a forehead rest. The contrast of the test grating was controlled using a ten-turn logarithmic potentiometer operated by the subject. During recovery a single setting was normally completed within 5–6 s, and the experimental procedure required 10–15 s intervals between separate threshold settings. When the subject had completed a setting, the value was automatically printed and the test-grating contrast was offset to an arbitrary subthreshold value. With the exception noted in the Results section the first point on the decay curve was determined by alternating 4 s test periods with 15 s reading periods, until 10 settings were completed. Adapting (text) and test displays were placed side-by-side, and the subject shifted

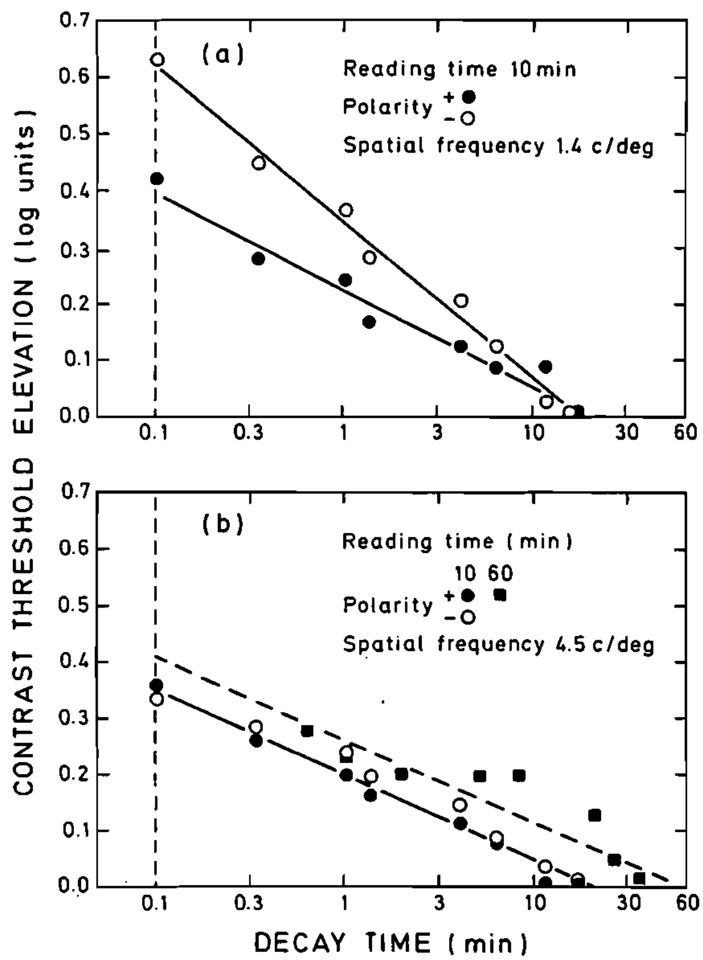

Figure 1. Recovery from contrast adaptation reading VDU-displayed text. Contrast threshold elevation, the difference between pre-and post-work contrast thresholds on a log scale, is plotted against time after reading, also on a log scale. Upper and lower panels (*a* and *b*) show results for contrast sensitivity measurements with respect to the low spatial frequency and the mid-spatial frequency component of the text, respectively, as indicated in the figure. Reading times were 10 and 60 min, and the contrast polarity of the display was either positive (●) or negative (O). Results are averaged across runs and subjects.

his gaze obeying an auditory signal. Following these initial measurements, settings were made continuously during the first few minutes of the recovery and later at regular intervals until pre-reading thresholds were attained as judged by the experimenter. Prior to the reading period, 10 threshold settings were made during a sequence of 6 s test periods interleaved with 15 s blanks. In separate experimental sessions decay functions were determined for 1·4 cd/deg and 4·5 c/deg test spatial frequencies, after 10 min reading of a positive and negative contrast polarity display, and 4·5 c/deg test spatial frequency after 60 min reading of a positive contrast polarity display.

2.3. *Subjects*

Detailed measurements were made on two emmetropic male subjects, aged 25 and 29 yrs.

3. Results

Due to both intra- and interindividual differences in speed of threshold adjustment, settings on the individual runs varied somewhat on the time scale. The records were therefore divided into fixed time bins and observations within each bin were pooled (Magnussen and Greenlee 1985). In figure 1 contrast threshold elevation, averaged across runs and subjects, is plotted against decay time in log–log co-ordinates and fitted with regression lines. It is well established that contrast adaptation decays as a power function of time (Magnussen and Greenlee 1985, Greenlee *et al.* 1991). This also provides a good description of the present results.

Figure 1*a* shows decay functions after 10 min reading periods for the low spatial frequency component of the text tested with a horizontal test grating of 1·4 c/deg. At this test frequency displays of negative contrast polarity induce an initial 0·2 log unit larger elevation in the contrast threshold than displays of positive polarity, confirming observations by Pelli (1988), but the effect decays on a steeper course, so the decay times are similar for the two reading conditions.

In figure 1*b* showing the decay functions measured with reference to a vertical test grating of 4·5 c/deg, parallel regression lines are fitted to the results for different reading times (Greenlee *et al.* 1991). Increasing the reading time from 10 min (circles) to one hour (squares) adds only a little to the magnitude of contrast threshold elevation, but prolongs the effect considerably on the time scale. There is no effect of display polarity for contrast threshold elevation induced by the mid-spatial frequency component of the text.

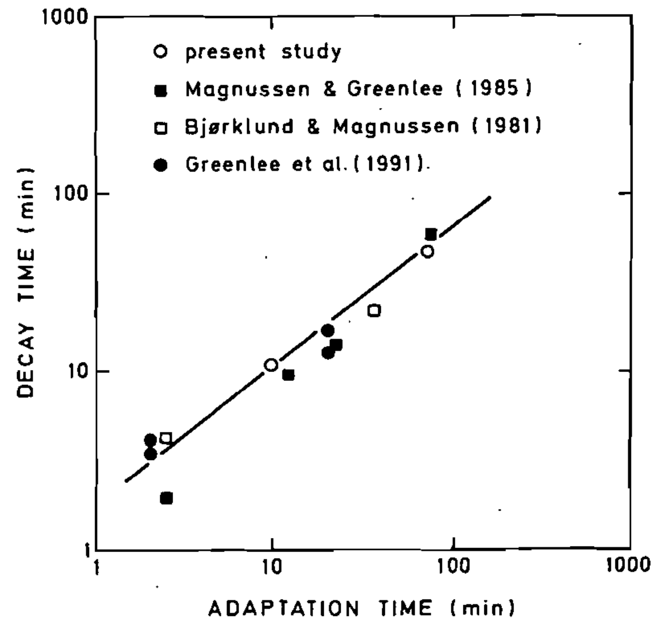

Figure 2. Estimated decay times of contrast threshold elevation after 10 and 60 min reading of VDU-displayed text (open circles) compared with decay times following various periods of grating adaptation (filled circles and squares) as measured by three previous studies.

4. Discussion

The results confirm and extend previous findings on VDU-induced impairments of contrast vision (Lunn and Banks 1986, Pelli 1988, Greenhouse *et al.* 1989), and show that the effects observed on contrast thresholds after text editing shares the time characteristics of contrast adaptation induced by the inspection of luminance gratings (Greenlee *et al.* 1991). Figure 2 provides a direct comparison between text and grating adaptation, plotting the relationship between adapting/reading time and the duration of the aftereffect based on the results of figure 1 and similar measurements by Bjørklund and Magnussen (1981), Magnussen and Greenlee (1985) and Greenlee *et al.* (1991). There is excellent quantitative agreement between the present results and the results of grating adaptation experiments.

The time it takes to return to normal contrast sensitivity is determined by reading time; the magnitude of the threshold change is, in addition, dependent upon the polarity of the display when tested at 1·4 c/deg but not when tested at 4·5 c/deg. This reproduces the pattern of results of Greenlee *el al.* (1991) on the time and contrast dependency of adaptation, remembering that text-displays of negative and positive polarity differ in terms of physical contrast at the fundamental, low-spatial frequency component, but not at the mid-spatial frequency component.

These results provide strong evidence that cortical adaptation processes play a major role in the impairments of contrast vision during VDU work. The fast dissipation of contrast adaptation after termination of the reading period with a reduction to half its initial strength in 1–2 min, might suggest that even quite brief rest pauses were sufficient to prevent build-up of visual fatigue during prolonged periods of concentrated work. However, it is known from laboratory experiments (Magnussen and Greenlee 1986) that contrast adaptation develops more rapidly in repeated sessions if the recovery is not complete between sessions.

Impaired contrast vision is but one aftereffect of visual work with high-contrast displays. It has long been known that patterns combining colour and achromatic contrast give rise to quite profound colour illusions in subsequently viewed achromatic displays, whose contours are then tinted with the opponent colour of the induction display. These are known as McCullogh effects (McCullogh 1965), and may be observed for days or even weeks even after fairly short induction periods (Stromeyer 1978). Many VDU-operators and most vision scientists have noted this effect after working at colour monitors (Gobba *et al.* 1988, Travis 1990). In a companion experiment to the present study (Magnussen 1989), we had subjects read displays with red or green text on achromatic dark backgrounds, and black text on red or green backgrounds, testing for McCullogh effects on achromatic text-displays of both positive and negative polarity. The results showed that vivid colour aftereffects were observed for the combination of induction and test displays of negative polarity: after reading green text on dark background, a white text version appeared reddish, whereas reading red text caused the white text to appear greenish. Other combinations of induction and test displays were not effective in inducing McCullogh effects.

Even if McCullogh effects are quite harmless, some operators find them disturbing. Thus colour displays of positive polarity may be preferable both on grounds of contrast adaptation and McCullogh effects.

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