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Visual Display Units and Fluorescent Lighting Enlarge Movements of the Eyes across Text

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Summary

The size of movements of the eyes across text has been measured (a) when the eyes moved from one specified letter to another in response to an auditory signal, and (b) under conditions of natural reading. When the text was intermittently illuminated by a fluorescent light, or on a visual display terminal, the high-velocity saccadic eye movements were affected. When the movement was prespecified (2-4 degrees) saccades were slightly enlarged to an extent that depended on the frequency of intermittency, but was generally equivalent to the width of one letter. The effect of intermittency on the size of saccades during natural reading was more variable. The disturbance of ocular motor control by intermittent illumination might help to explain why reading is generally slower on computer display terminals than with printed text.

There is a large literature on the ergonomics of visual display terminals and Matula (1981) provides a bibliography. It has been widely reported (e.g. Wright and Lickorish, 1983) that text is more difficult to read when displayed on the surface of computer visual display units than when printed conventionally on paper. Computers typically use a cathode ray tube (CRT) to display text, and the textual displays that they provide differ from conventional text in many ways. The spacing of the lines, the aspect ratio of the letters, the spatial precision of the letter forms and their luminance contrast all differ, as do the viewing position, viewing distance and general familiarity. The differences are usually such as to render electronic text less legible than its more traditional counterpart. Thus Kruk and Muter (1984) found that wide letter spacing and single line spacing each reduced reading speed, but not by enough to explain all of the reading deficit associated with the use of a CRT display. Bauer and Cavonius (1980) found that identification of four-letter nonsense words was faster when the words were presented with negative contrast (dark letters on a white background) than when the contrast was positive, as is typically the case with a CRT display.

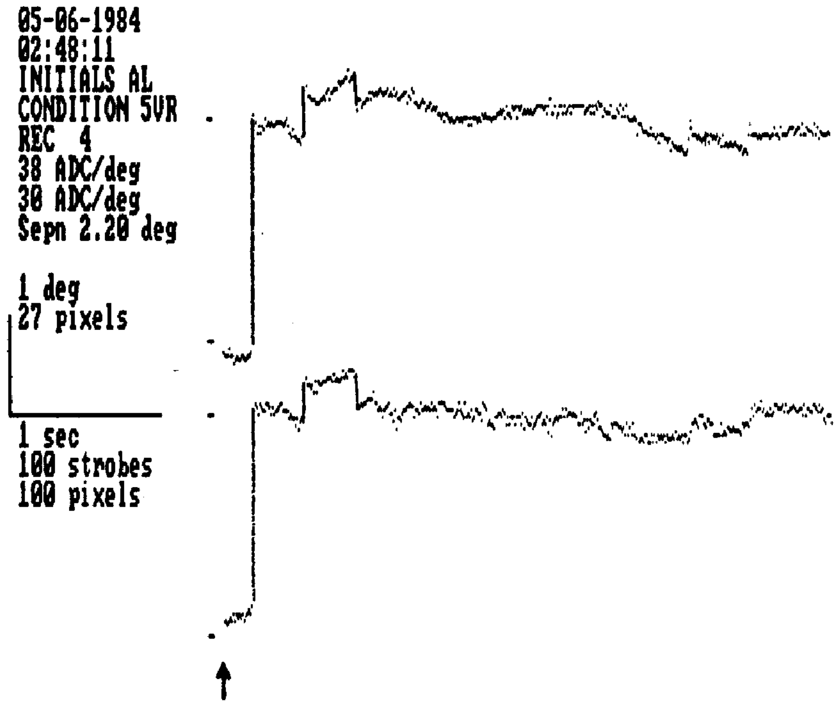

Figure 1. Typical eye movement tracings under conditions of 50Hz illumination. The recording from the left eye is shown above that for the right. Gaze was directed from one prespecified letter in a page of text to another letter on the same line in response to an auditory signal that occurred at the time shown by the arrow. The saccades (shown by continuous vertical lines) were recognised automatically on the basis of their speed, and their size measured by averaging samples before and after the movement.

The above differences between CRT and conventional displays are obvious and have received considerable attention. A less obvious but potentially important difference concerns the intermittency of illumination. CRT displays are typically illuminated intermittently at frequencies in the range 50-100Hz, usually above the threshold at which flicker is perceptible. Three recent experiments suggest that eye movements across text are affected when the text is intermittently illuminated at these frequencies.

Wilkins (1986) asked volunteers to look at text fixing their gaze alternately on one specified letter and then on another letter from the same line of text in response to an auditory signal. In the first of two experiments a paragraph of text was displayed on the surface of cathode ray tubes with different refresh rates. The textual displays comprised photographic negatives of typewritten text mounted in front of an oscilloscope screen on which a raster scan was generated with a frame frequency of either 50 or 100 Hz. This rather crude technique had the advantage of providing a reasonable simulation of a raster scan display whilst ensuring that the spatial characteristics of the text were independent of the frame frequency. The eye movement records were analysed automatically by a computer algorithm that

Table 1. Mean size (and SD) of main saccades between letters in text (min. arc).

A. Experiment 1

Refresh rate	Target spacing 132 min.arc
50Hz	154 (38)
100Hz	139 (36)

B. Experiment 2

Lighting frequency	Target spacing 94 min.arc	257 min.arc
100Hz	102 (53)	261 (49)
20kHz	97 (36)	253 (51)

recognised the high-velocity movements (saccades) on the basis of their velocity and then measured their size from the stable parts of the record before and after the flight of the eye (see Figure 1). The main saccade was defined as the largest saccade that occurred in a one-second observation period following the signal (usually the first saccade), and was found to be 11% larger for the 50Hz display than for the 100 Hz display (see Table 1a). The number of subsequent saccades was also greater for the 50 Hz display, suggesting that as a result of the overshoot subjects found it necessary to correct fixation. These effects accounted for about 10% of the experimental variance.

In Wilkins' second experiment the page of a book was illuminated by two types of fluorescent lighting, one intermittent and the other effectively continuous. The task was performed under two levels of illumination, one twice the other, and performance was similar at both levels. Two pairs of letter targets were used, one closely spaced and the other further apart. The records were calibrated by averaging the transducer signal whilst the eyes were fixating their targets, and the closer spaced targets therefore provided a calibration that contained more noise. Perhaps for this reason the increase in saccade size shown in Table 1b, which accounted for a very small proportion of the variance, was significant only for the wider spaced targets. (It may be observed from Table 1b that under steady illumination the eyes consistently undershoot their targets when the targets are widely spaced. This is to be expected on the basis of previous work: Carpenter, 1977 p57).

Both experiments were consistent in showing that saccadic movements of the eyes across text can be enlarged to an extent that depends on the frequency with which the text is illuminated. The effects were small in amplitude and in the percentage of the variance they explained. It is conceivable that they are too small to affect reading. Unfortunately, little work has been done to establish the degree of ocular motor precision required during reading. The evidence suggests that eye movements are closely linked to the processing of text and are guided by it (Rayner and McConkie 1976; McConkie 1979); information gained from the parafovea or periphery on one fixation is used to determine the location of the next fixation, but it is not clear whether the precise location of the point of regard is critical. O'Regan, Levy-Schoen, Pynte & Brugaillere (1984) attempted to answer this question by presenting words on a screen in different positions relative to fixation. The latency to perform a naming or camparison task was measured as a function of position. Reaction times were smallest (around 700 msec) when the fixation was just to the left of the centre of the word, and increased by 20-30 msec for every letter by which the fixation deviated form the optimum position. This result suggests that the position of fixation may be important but does not indicate whether under conditions of natural reading the eyes are positioned optimally.

From the above considerations it will be clear that with current knowledge we cannot predict whether the effects of intermittent illumination on the size of saccades would be sufficient to help explain the slower reading from CRT terminals. This question has recently been addressed by Craven (in preparation).

Craven asked subjects to read a passage of prose that was illuminated continuously or intermittently at frequencies of 50 or 100Hz. The material was typewritten, left-justified and back-illuminated by light from a DC lamp that was interrupted by a sectored disc so as to produce a 100% luminance modulation with square-wave luminance profile. Eye position data was recorded as the subject of the text and was analysed by computer. Progressive movements and flybacks (from the end of one line to the beginning of the next) were studied separately.

For over half the subjects significant effects of intermittent illumination on mean flyback size were demonstrated. While these were sometimes quite large – up to 5% change, equivalent to three or four letters – their direction was variable; almost as many subjects showed a decrease in flyback size as showed an increase. As a result, the effect of intermittent light on saccade size for the group as a whole showed an overall enlargement that was not significant. The effects of intermittency on the smaller progressive movements were weaker and rarely reached significance. Reading speed was not affected by the frequency of illumination in this experiment.

The above findings are consistent in demonstrating a weak effect of intermittent illumination on the size of saccadic movements of the eyes across text. The disruption of ocular motor control may be connected with the complaints of visual discomfort with which visual display terminals and fluorescent lighting have been associated, particularly in view of the fact that these complaints are related to the depth of modulation of the light output (Laubli et al, 1980). Wilkins (in press) reported that the majority of his subjects preferred the high frequency display without being able to give consistent reasons.

West and Boyce (1968) were the first to show an effect of intermittent illumination on the size of saccades. They investigated the distribution of the size of microsaccades occurring during fixation. At frequencies of intermittency above those at which flicker was perceived the distribution of saccade size was not identical to that for steady light, although West and Boyce do not comment on the statistical significance of the difference apparent from their graphs. In a similar experiment, Haddad & Winterson (1975) failed to show any effect of intermittent light on saccades, but found that intermittent light at frequencies of up to 10 Hz increased the tendency of the eye to drift away from the target. At low frequencies (2 Hz and below) the eye showed oscillations synchronised with the flicker. In this experiments subjects were asked to maintain fixation on a target without making any saccades, a rather unnatural task.

It is far from obvious why intermittent light should affect eye movements, not least because it can do so at frequencies that appear as steady to the eye. There is, however, evidence that high frequency intermittent light can be resolved by the human visual system, even if no flicker is apparent. Brindley (1962) showed that beats between concurrent periodic luminous and electrical stimulation of the retina could be perceived when the frequency of stimulation was as high as 120Hz and above that at which either form of stimulation would, on its own, produce a sensation of flicker. Evidently high frequencies are resolved at least at the level of the retina and they may perhaps give rise to uncharacteristic phase-locked excitation in the lateral geniculate nucleus similar to that observed in the cat by Eysel and Burandt (1984). Eysel and Burandt showed phase-locked responding of neurons in response to the light from a fluorescent tube. As they point out, all subcortical structures receiving inputs from lateral geniculate neurons via short neural chains should receive phase-locked inputs. Such structures would include the superior colliculus which is involved in the control of eye movements.

Saccades are sometimes held to be ballistic, or at least preprogrammed, and not subject to feedback control (e.g. Carpenter, 1977). If the effects of intermittency are to be interpreted on the basis of current theory it is necessary to assume that high-frequency intermittent illumination had its effect more than 80ms prior to the flight of the eye (Findlay and Harris, 1984).

There is limited evidence that this may be too restrictive a viewpoint, at least for saccades that are long enough to outlast the visual reaction time. Under certain circumstances the trajectory of a saccade may appear to alter in flight, although whether this alteration can occur in response to an in-flight change in target position is uncertain. Nevertheless it remains a possibility that the brain controls eye movement using visual information acquired both before and during the flight of the eye (Hallett and Lightstone, 1976), as discussed by Howard (1982, p319). When the eye moves from one point of regard to another the retinal input is 'smeared' during the movement. If a display is intermittently illuminated with repeated brief flashes, clear images of the display will occur at different retinal positions whilst the eye is in motion, and in general the 'smear' will be reduced. There are circumstances under which the smear can be used to provide information as to the magnitude of eye movement (Festinger and Holtzman, 1978) and it is conceivable that this retinal 'smear' is important for the control of the eyes during reading.

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