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No evidence for prolonged latency of saccadic eye movements due to intermittent light of a CRT computer screen

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Despite previous studies it remains unclear, whether saccadic eye movements across computer screens may be adversely affected by the intermittency of light of cathode ray tubes (CRT). We measured the latency of simple saccades to peripheral targets presented on a CRT-screen, operated at refresh rates of 50, 100 and 150 Hz, compared with a special fluorescent lamp display (FLD). Our results suggest that the intermittent light of CRT screens does not prolong the latency of saccades not even relative to a control condition of unmodulated steady light at the FLD. Further, there was no evidence for any individual effect in possibly susceptible subjects, e.g. at high critical flicker frequencies (CFF).

1. Introduction

Cathode ray tubes (CRT), used for television and for visual displays at computer workstations, produce intermittent light with a temporal modulation corresponding to the actual refresh rate of the rasterscan. This frequency should be near, or better above the critical flicker frequency (CFF) in order to avoid adverse visible flicker. CFF lies between 50 and 100 Hz, with a mean of about 75 Hz, for a screen size and luminance normally used at computer screens (Bauer 1987; Burr 1991; Jaschinski *et al.* 1996). Apart from the visibility of flicker intermittent light with frequencies near or even above CFF are represented in the retinogram and in cortical potentials (Jaschinski *et al.* 1996) and these may have effects on visual functions such as accommodation (Owens and Wolfe 1985, Neary and Wilkins 1989, Flitcroft 1988, 1991, Chauhan and Charman 1992, Jaschinski *et al.* 1996), pupil size (Wiebelitz and Schmitz 1983, Jaschinski *et al.* 1996), or eye movements (Wilkins 1986, Kennedy and Murray 1991, 1993, 1996, Montegut *et al.* 1997, Kennedy *et al.* 1998, Baccino 1999, Baccino *et al.* 2001).

The present study focuses on stimulus induced saccadic eye movements, i.e. the fast ballistic eye movements that we perform in order to shift our attention (and the fixation point of the eyes) to other locations in the visual field. The saccadic latency (or reaction time) of stimulus induced eye movements is defined as the period between the sudden appearance of a new saccadic target and the start of the actual eye movement. The latency is regarded as the period of neural motor programming,

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in which two parameters of the eye movement, i.e. its direction and destination (amplitude), are extracted from the visual input and determined to start the ballistic movement. Previous research provided evidence that saccadic latency may be prolonged in conditions that resemble (more or less) intermittent light on CRTs.

Describing the ‘remote distractor effect’ Findlay and Walker (1999) showed that information and qualities in the visual input that do not belong to the saccadic target itself can have an impact on the programming time of the saccadic eye movement: when two visual stimuli are presented simultaneously—one saccadic target and one distractor at any other location in the visual field—the saccade is accurately made toward the target with no change in amplitude, whereas the saccade latency is markedly prolonged by the distractor. The amount of the ‘remote distractor effect’ depends on distractor properties, e.g. the size, the eccentricity or the relative position of target and distractor; the effect is strongest for distractors at the starting position of the saccade (Weber and Fischer 1994, Walker *et al.* 1997). While in these studies the distractor was a bright point of light on a dark background, Reingold and Stampe (2000) used as a distractor a single flash of a bright area (above and below the horizontal axis, where the saccades were made) that appeared at different moments in time during the latency. This later condition resembled the repetitive flashes of light at CRT screens with a bright background. The saccades tended not to be started (i.e. inhibited) at constant delay (70 ms) after distractor onset. Consequently, the latency distribution revealed a dip with the average saccade latency being prolonged. This phenomenon was called ‘saccadic inhibition’ (Reingold and Stampe 2000).

In their second experiment, Kennedy *et al.* (1998) presented the fixation point and rectangle target on a CRT-screen with a fast phosphor (P4) and reported that saccade latencies were 9 ms longer for light frequencies of 50 Hz and 75 Hz (which did not differ) compared to 100 Hz and 125 Hz (which did not differ).

Baccino *et al.* (2001) used a special fluorescent lamp display (FLD) with a bright background that was modulated in time so that a series of light pulses (of 50 Hz frequency) was switched on at target onset and presented during the latency. The latencies were 23 ms longer compared to a control condition of unmodulated light, produced by direct current (DC) in the fluorescent lamp.

These previous studies have shown that distractors with high frequency spectral components like light flashes or series of light pulses (presented during the latency) prolonged the saccadic latency—suggesting that intermittent light with high frequencies, i.e. that at CRT computer screens, and above the CFF may affect the saccadic latency. From an ergonomic point of view, the reported effects could mean that at CRT screens with intermittent light the saccadic latencies, and therefore the correct programming of the eye movement, may be prolonged—with the background consisting of series of light pulses contributing to that prolonging effect as a kind of ‘remote distractor’. Making saccades across the surface of CRT screens or reading texts displayed on CRT screens might possibly be impaired by the rasterscan frequency. However, the viewing conditions in the studies mentioned above differed considerably—in some aspects—from those at CRT screens that are actually used at computer workstations. The aim of the present study was therefore to measure saccadic latency at different refresh rates (50 Hz, 100 Hz, 150 Hz) at ordinary bright background CRT monitors of current technology.

Any effect of light frequency should best be compared with a control condition of unmodulated light. However, this is not possible with CRT screens that have to be operated with some rasterscan frequency to generate the image. As alternative control condition we tried two possibilities: (1) we operated the CRT-screen with an unmodulated, but dark background; (2) we presented all frequencies (50 Hz, 100 Hz, 150 Hz) on a fluorescent lamp display as well, which allows one to present unmodulated light with direct current. Although subjects differ markedly in CFF, the individual susceptibility of other visual functions to intermittent light has only been taken into account in a few studies (Tse *et al.* 2002, Andrews and Coppola 1999, Jaschinski *et al.* 1996, Lindner and Kropf 1993). Lindner and Kropf (1993), for example, reported that subjects who complain more than others about fluorescent lighting are predominantly female, aged 20–30 years, and possess a higher psychovegetative instability, diminished power of concentration, and reduced binocular and stereoscopic vision. Further, effects in accommodation above CFF and pupil size at 50 Hz differed not only in amount, but also in direction among subjects (Jaschinski *et al.* 1996). In order to investigate the reliability of possible individual effects, we repeated all tests on a separate day.

2. Method

2.1. *Displays*

Our CRT screen was a Samtron 89P Plus Colour monitor with a phosphor decay time of 1.4 ms to 10% of its maximum brightness.

The fluorescent lamp display (FLD) provides homogeneous white light on a circular milk-glass screen (19 cm diameter), which is back-illuminated by a circular fluorescent lamp (32 cm diameter) inside a white hollow sphere. With the phosphor of the special fluorescent lamp we produced light pulses of 2 ms duration at half intensity, or unmodulated light by applying DC-current. With this display, it is not possible to generate any visual target; therefore three laser diodes were mounted on a frame at the outside of the FLD to beam target points of unmodulated red laser light onto the test field of bright white light. For details see Baccino *et al.* (2001).

The temporal luminance profile of both displays was measured with a fast photodetector and is shown in figure 1.

2.2. *Experimental conditions and design*

On both displays we presented a circular field (diameter 19 cm; viewing distance 55 cm) with a luminance of 55 cd/m^2 (except for 0 cd/m^2 in the dark background CRT condition). No room lighting was provided. The stimuli were three red points of light (diameter 2 mm) with a luminance of 5 cd/m^2; one central point was used for pre-saccadic fixation, while two points 5° horizontally to the left or right served as saccadic targets. The central fixation point was visible for 750 ms. Then the target appeared randomly to the left or to the right without any delay (no gap). Subjects were instructed to follow the stimuli with saccadic eye movements. The nineteen subjects—12 female and 7 male, aged from 20 to 30 years—had a visual acuity of 1.0 or better (in decimal units) in both eyes. The critical flicker frequency (CFF) was measured at both displays using a forced-choice staircase method.

The frequencies of 50 Hz, 100 Hz and 150 Hz were used on both displays in order to test possible differences in frequency effects between the FLD and a normal CRT. As a control condition without intermittent light, we used unmodulated bright light at the FLD and a dark background at the CRT. The later condition can only be regarded as a control condition if our data confirm

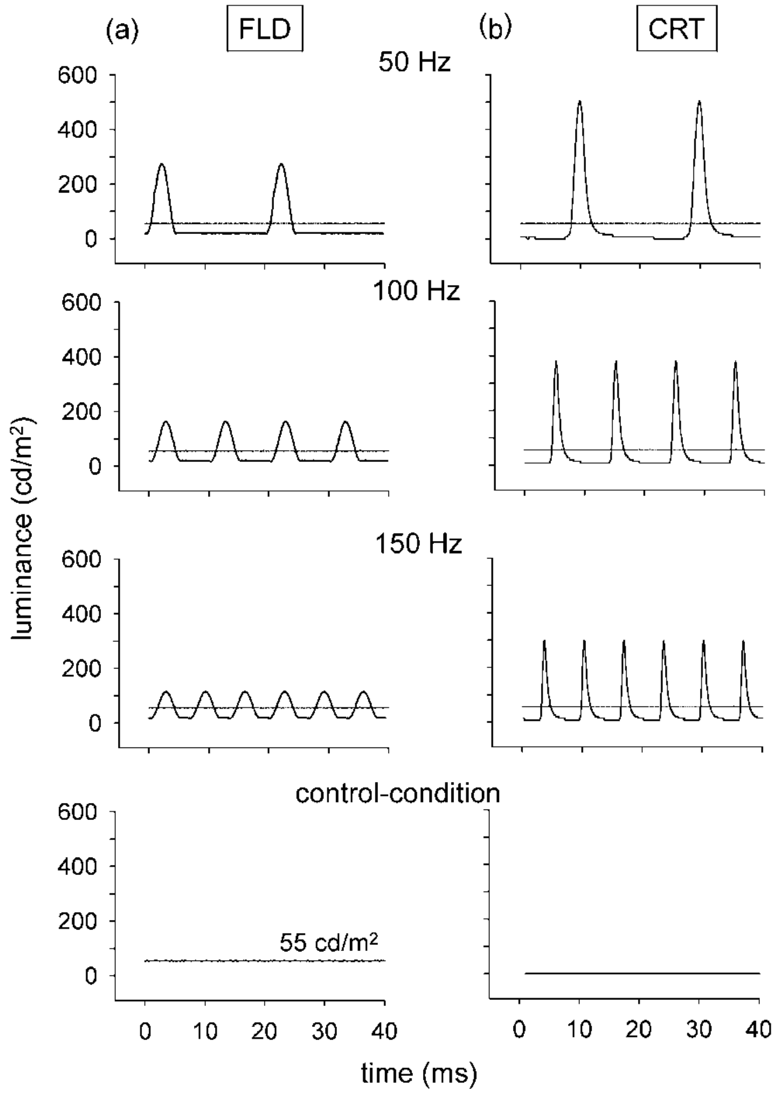

Figure 1. Dynamic measurements of series of light pulses for the frequencies of 50 Hz, 100 Hz and 150 Hz for (a) the fluorescent lamp display (FLD) and (b) the cathode ray tube (CRT); for the FLD the control condition of unmodulated *bright* background and for the CRT of unmodulated *dark* background are shown in the lowest panels. Note that these measurements were made at the central fixation point and $t = 0$ means the moment of triggering the refresh rate. Consequently, at the CRT screen the light pulses appear delayed by a period that depends on the refresh rate. The latency data have been corrected for this effect.

that it produces the same results as the true control condition with unmodulated bright light at the FLD.

Conditions were counterbalanced across subjects. The complete session was repeated on a second day (mean time between sessions: 8 days, SD = 5.5) in order to check for reliability of effects and measurements.

2.3. *Eye movement recordings*

Eye movements of both eyes were measured with an apparatus built in our laboratory. The technical principle is described by Reulen *et al.* (1988). Infrared light emitting diodes, infrared detectors and pre-amplifiers were mounted on a spectacle frame worn by the subject. The eyes were illuminated with infrared light of uncritical intensity of less than 3 mW/cm^2. Horizontal eye movements were detected as the difference signal between two detectors arranged horizontally below each eye. The signal was digitized with a rate of 1 kHz. The heads of the subjects were stabilised with a forehead and chin rest.

The onset and offset of each saccade was detected online with an algorithm that detected eye velocity: at each sampling point in time t(i) two logical conditions on the actual eye position signal S(t(i)) in millivolt were tested, i.e. $\mathrm{abs}[S(t(i\text{-}3)) - S(t(i))] > T(\mathrm{sacc})$ and $\mathrm{abs}[S(t(i\text{-}1)) - S(t(i))] < T(\mathrm{fix})$ (Stampe 1993). The first condition is fulfilled when the increase in voltage exceeds a threshold value of $T(\mathrm{sacc}) = 12$ mV; the second condition with $T(\mathrm{fix}) = 10$ mV prevents stretching of saccades and erosion of the fixation following the saccade; this resulted in a threshold velocity of about 30°/s. The detected saccade onset was used to mark the end of saccade latency, which started with target onset. This supra-threshold velocity criterium is an inverse procedure compared to the criterion of stable fixation used by Kennedy *et al.* (1998).

We took into account that the saccadic target (in the centre CRT-line) appeared with a temporal delay after the start of the rasterscan at the top of the screen (see figure 1); this delay depended on the scan frequency. Calibration of the eye movement system was carried out online by using the mean of the values for the positions ‘central’, ‘left’, and ‘right’ per experimental condition as calibration value for every trial.

The design comprised two display types, four levels of frequency and two sessions. For each of these 16 experimental conditions a block of 20 saccades—10 to the left and 10 to the right—were recorded, with saccade latency as the dependent variable. Only 10.1% of the saccade recordings had to be removed from the data set because of eye blinks, drifts, and glides. Since the latencies of the two eyes were very similar (Becker 1991), they were averaged and then the median of each condition was taken as the subject’s latency for further analyses.

3. Results

3.1. *Saccade latency*

The mean latencies are given in figure 2. The corresponding 2 × 4 × 2 ANOVA with repeated measures and Greenhouse–Geisser adjusted error probabilities showed no significant main effect of *frequency* ($F(3,54) = 2.84$, $p = 0.07$), *display type* ($F(1,18) = 1.46$, $p = 0.24$) or *session* ($F(1,18) = 0.77$, $p = 0.39$). Only the interaction *display type* × *frequency* ($F(3,54) = 10.94$, $p < 0.01$) was significant.

In order to check for the source of variance contributing to this significant interaction, a so called ‘simple effect analysis’ (Dixon 1992) was calculated by keeping first the *frequency* and second the *display type* constant. Holding the *frequency* constant, the main effect of *display type* was significant for three frequency conditions: 50 Hz ($F(1,18) = 6.93$, $p = 0.02$), 150 Hz ($F(1,18) = 7.01$, $p = 0.02$), and the control condition ($F(1,18) = 15.55$, $p < 0.01$). While keeping the *display type* constant, the main effect of the *frequency* was significant only for the CRT (*CRT*: $F(3,54) = 9.86$, $p < 0.01$; *FLD*: ($F(3,54) = 2.40$, $p = 0.10$)). Further calculations of

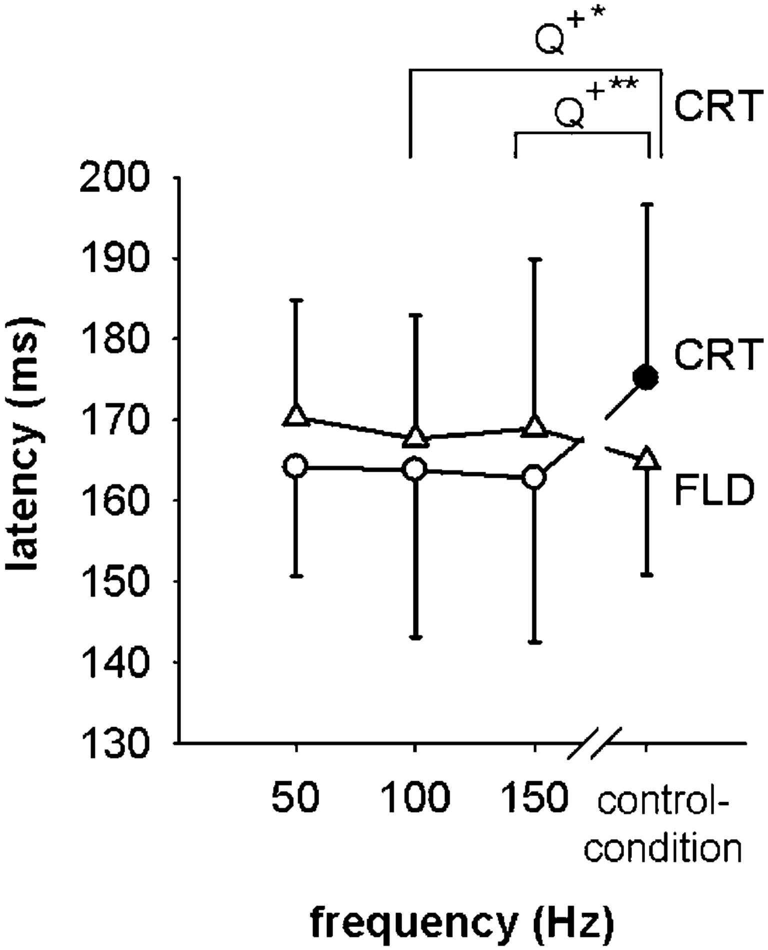

Figure 2. Saccade latencies (ms; SD) are averaged over the two sessions and plotted for the CRT (closed circles) and FLD (open triangles) as a function of *frequency*. Note that the control condition at the FLD consisted of unmodulated *bright* background whereas the control condition at the CRT consisted of a unmodulated *dark* background. Q^+ statements show significant contrasts for frequency conditions measured at the CRT-screen (*: $p<0.05$; **: $p<0.01$). At the FLD, no effect of frequency was observed.

Tukey-Q^+-contrasts for this significant main effect of *frequency* at the CRT-display showed that it was based on the two significant contrasts: 100 Hz vs. control condition and 150 Hz vs. control condition (see figure 2). In sum, the significant interaction *frequency* × *display type* in the 2 × 4 × 2 ANOVA was based on the significant main effect of the *frequency* at the CRT-display, which resulted from the fact that the unmodulated dark background produced longer latencies than the frequencies of 100 Hz and 150 Hz on a bright background. We conclude that these differences were due to the dark background (Becker 1991), which—therefore—is not an appropriate control condition, as we had intended. A new 2 × 3 × 2 ANOVA was calculated with the control conditions at both displays excluded. While the factors *frequency* ($F(2,36) = 0.66$, $p = 0.47$) and *session* ($F(1,18) = 1.23$, $p = 0.28$)

remained insignificant, the mean difference in saccade latency of ca. 4 ms between the two displays was now significant (F(1,18) = 26.28, $p < 0.01$; $\eta^2 = 0.11$).

The average CFF for the FLD and CRT were ca. 77 Hz (SD = 8.1) and ca. 68 Hz (SD = 9.1), respectively (see table 1). This difference of ca. 9 Hz between the two displays was significant (F(1,18) = 17.26, $p < 0.01$) in a 2 × 2 ANOVA with repeated measures (Greenhouse–Geisser adjusted error probabilities).

For the saccade latencies, test-retest-reliability reached satisfying average correlation of r(tt) = 0.66 (between sessions) and the mean parallel-test-reliability was r(pt) = 0.78 (within sessions). For the CFF measurements the test-retest-reliabilities amounted to r(tt) = 0.85 for the CRT and r(tt) = 0.43 for the FLD; the latter was surprisingly low.

3.2. *Individual differences*

The group mean data reported above showed no evidence for effects of the frequency of light on saccadic latency, i.e. the majority of subjects showed no effect. In further analysis we used the theory of generalizability (Cronbach *et al.* 1972) to test whether effects may be present in a minority of susceptible subjects. By means of factorial variance analysis we divided the data variance into variance components in order to identify the important sources of variability, i.e. possible individual effects (Shavelson and Webb 1991, Schütte and Nickel 2002). For a practical interpretation, the relative magnitude of each estimate of variance component (EVC) is calculated as a percentage of the sum of all variance components (Shavelson and Webb 1991). The factor *subjects* accounted for the largest part of variance (EVC = 242.27; 56% of total variance). 15% of total variance was caused by the interaction *subjects* × *session* (EVC = 64.48) and 11% by the interaction *subjects* × *session* × *display type* × *frequency* (EVC = 49.32). In particular, the *subject* × *frequency* interaction resulted in negligible amounts of variance, indicating that subjects did not differ in the effect of frequency on saccadic latency.

In further ANOVAs we divided the subject group at the median of their ages (Med = 22, Iq = 3) or at the median of the CFF (Med = 72, Iq = 9.2); however, these grouping variables were not significantly related to effects on saccade latencies.

4. Discussion

Although some authors (Baccino *et al.* 2001, Kennedy *et al.* 1998) reported prolonged saccade latency when subjects followed visual targets on bright, intermittently illuminated backgrounds, the results of the present study showed no such effect. None of the three frequencies of intermittent light, i.e. 50 Hz, 100 Hz or 150 Hz, caused remarkable effects on saccade latency—not even when compared to the control condition, an unmodulated bright background at the FLD. The missing

Table 1. Average CFF (Hz; (SD)) as a function of *display type* and *session*.

	Display type	
Session	FLD	CRT
First	76 (± 8.9)	66 (± 9.1)
Second	77 (± 10.1)	69 (± 9.7)

effect of frequency was confirmed by a complete internal replication since the effects of *frequency* and *display type* were tested in two sessions that showed substantial test-retest-reliabilities.

Considering sources of null effects the statistical power of the experimental design is of formal interest. First, our design was able to statistically ensure the very small latency difference between the two displays of 4 ms (corresponding to a proportion of explained variance of $\eta^2 = 0.10$), which is only 2.5% of a typical latency. Further, according to Cohen (1988), we could account for an effect size of the factor *frequency* that ranged around 4% ($\eta^2 = 0.04$) of experimental variance without a loss of statistical power ($\alpha = 0.05$; $(1\text{-}\beta) = 0.80$). These figures are comparable with the 5% explained variance, which we estimated for the 9 ms effect in latency reported by Kennedy *et al.* (1998) (Seifert 1991).

A review of previous studies of saccadic latency at displays with intermittent light revealed that the phosphor decay time may be relevant. The phosphor decay time indicates how long the phosphor remains bright after excitation by the electron beam. The shorter the decay time, the more the luminance deviates from steady light and the larger the expected adverse effects of the intermittency. Accordingly, Kennedy *et al.* (1998) found effects on saccadic latency using a very fast phosphor (P4; decay time of around 0.06 ms) but not with a slow phosphor (P22; decay time of around 1ms). In the present experiment we had decay times of 1.4 ms at the CRT and of 2 ms at the FLD, respectively, and no effect of intermittency could be observed. (All decay times refer to 10% of the maximum brightness). Thus the phosphor decay time might account in part for the conflicting results in previous studies. Further, the large effect on latency reported by Baccino *et al.* (2001) appears to be a result of the fact that the series of 50 Hz light pulses had been switched on at the moment of target onset. However, from an ergonomic point of view we conclude that no change in latency was observed with phosphor decay times of CRT screens currently used at computer workstations.

At the FLD the latency was about 4 ms longer than at the CRT; this effect appeared at all frequency conditions (with the same luminance). Note that the unconventional FLD was included in the present study only to have a true control condition of unmodulated light. Although the present FLD-data have no ergonomic implications for vision at displays, the following conclusions on the nature of light intermittency effects can be drawn.

At the FLD we observed both a higher CFF and a longer saccadic latency, i.e. both effects reflect more adverse conditions at the FLD. This can neither be explained by the phosphor decay time (which was similar for both displays) nor by the peak amplitude of the light pulses (Brundrett, 1974) (which was higher at the CRT despite the same mean luminance (see figure 1). Rather, it is plausible that the different effects at our two displays are a result of the different spatial nature of the intermittent light. The light of the FLD flashes homogeneously across the entire screen, whereas at a CRT the scanning electron beam produces a bright bar moving repetitively from top to bottom. Most observers are exposed to the latter kind of intermittent light from television or computer screens; thus, the visual system might be adapted to and less sensitive to rasterscan light presentations but not to the unfamiliar FLD-light. These arguments are in line with the reported adaptation for top-to-bottom scanning, but not for other possible rasterscan directions on CRTs when measuring the CFF, or asking for comfort of viewing (Thomson and Saunders 1997, Corbett and White 1976).

In conclusion, we replicated the common finding that some subjects have reliably longer latencies then others; however, we did not find evidence that saccadic latency might be prolonged by the intermittency of light at CRT screens, neither in the group mean, nor in individuals that might be particularly sensitive. Thus, for the ergonomics of workplaces we conclude that the refresh rate of common CRT computer screens appears not to have an impact on the reaction time of reflexive eye movements across the screen. Although the individual CFF was not relevant for saccadic latency, it must be taken into account for choosing a refresh rate that avoids visible flicker.

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