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Research Note

Exploring the flicker effect: the influence of in-flight pulsations on saccadic control

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Summary

The pulsating illumination of visual display units is known to induce systematic changes in saccade extent. In two experiments reported in this paper, we further examined this effect, by looking at the location of pulsations relative to saccade onset. Both saccade extent and velocity were shown to increase as a function of the number of 'in-flight' pulsations. This result indicates that part of the so-called 'flicker effect' originates during the saccade itself. From a more general point of view, the present data suggest that saccadic control can be modulated by intra-saccadic visual stimuli. © 1999 The College of Optometrists. Published by Elsevier Science Ltd. All rights reserved

Introduction

Pulsating illumination of visual display unit (VDU) displays is usually regarded as an important source of visual discomfort (Jaschinski-Kruza *et al.*, 1994; Wilkins, 1995) affecting both reading or text-processing strategies (Baccino, 1996). Recently this topic has been brought to light by the findings of Kennedy and co-workers showing that adverse effects of refresh rate could affect eye movements, especially saccadic control, during reading (Kennedy and Murray, 1993a,b; Kennedy and Baccino, 1995). Several times, Kennedy and co-workers reported a systematic decrease of the extent of the first saccade to enter a word under conditions of pulsed illumination. These changes in saccade extent are likely to reduce the proportion of initial landing at the 'optimal viewing position' (O'Regan *et al.*, 1984; O'Regan, 1990) which in turn increases the probability of making within-word refixations. However, these data are quite controversial. In contrast, early studies (West and Boyce, 1968; Haddad and Winterson, 1975; Wilkins, 1986; Neary and Wilkins, 1989) indicated that flicker can increase the

amplitude of saccades involving, as a consequence, a greater number of corrective saccades. While a consensus on the effect of flicker on oculomotor control does exist, the question of the type of effect observed remains open.

The effect reported by Kennedy and colleagues is important because it suggests that saccade size can be modified 'in-flight' by pulsating illumination. Pulsations may be related to transient events that can interrupt or disrupt saccadic control and consequently deviate landing positions. From this point of view, it can be compared to the findings of Becker *et al.* (1987) that saccades can be disrupted by either auditory or visual signals delivered after saccade onset. Both results contrast, however, with the idea that saccades are ballistic in nature and as such are insensitive to visual stimuli occurring while the eyes are moving (Bouma, 1980; Levy-Schoen and Findlay, 1984).

Interestingly, disruption is not reduced by increasing the screen refresh rate. Systematic changes in saccade extent have been obtained with refresh rate well above the 40–50 Hz critical flicker fusion threshold. Pulsation-induced reduction in saccade extent have been found to increase at least up to 100 Hz (Kennedy and Murray, 1993b) suggesting that the number of

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pulsations occurring either before or after saccade onset might play an important role.

However, these experiments have generally failed to match each individual saccade with the corresponding number of pulsations (only the refresh rate factor was manipulated and not the number of pulsations). Moreover, they have failed to locate pulsations relative to saccade onset, and it is thus difficult to determine whether those pulsations occurring while the eyes are moving can actually exert any influence. With refresh rates that have been used, pulsations typically occur every 10 msec or so (every 8 msec at 125 Hz) and they are distributed across the saccade. Consequently one or several pulsation(s) are likely to occur both prior and after saccade launch and it is thus difficult to isolate the role of within-saccade pulsations from other potential effects. For example, prior-to-onset pulsations might trigger an early saccade launch (e.g. before the computation of landing position is totally achieved), with systematic deviations in landing site (either undershot or overshoot) as a consequence.

The aim of the series of experiments reported in this article was to investigate further the effect of refresh rate on saccade extent by examining the nature of the relationship between saccade extent and number of pulsations, with a specific interest for within-saccade pulsations. If such pulsations could be shown to be responsible for the deviation found (or for part of it), this would have important consequences for our understanding of saccadic control.

Subjects were required to search for a target letter included in a string and the moment when each pulsation occurred (i.e. the screen refresh signal) was recorded and stored together with eye-movement data for off-line analysis. Saccades were distributed *a posteriori* in different categories depending on the number of pulsations recorded after saccade onset. The question we are interested in is whether this factor can influence saccade parameters (landing position, velocity), which would indicate that saccadic control may be modulated by intra-saccadic visual stimuli.

Methods

Two experiments were carried out. In experiment 1, stimuli were presented at one degree of eccentricity (see below), while in experiment 2, a seven-degree eccentricity was used. Apart from this difference, the procedure was identical for both experiments, and they will be reported together here.

¹As the vertical refresh signal was synchronised with the monitor refresh frequency, the stimulus on the screen was written as soon as the computer sent the video signal and no lag was present.

Subjects

Thirty students participated in the experiments, 12 in experiment 1, and 18 in experiment 2. All subjects had normal vision or corrected-to-normal vision (contact lenses, but not glasses were accepted).

Apparatus

Experiments were controlled by two 486 DX computers connected via their parallel port. These two computers are referred to below as CpA (in charge of stimulus presentation), and CpB (in charge of eye movement collection). Stimuli were presented in positive polarity (dark characters on white background) via a Sony GDM-17E01 T monitor (P22 phosphor) interfaced to a Trident VGA 9000 graphic card (640 × 350 pixels resolution). The monitor was located at 60 cm from subjects (viewing distance) and luminance was maintained constant during the whole experiment (91.7 cd/m²), including across refresh rates (checked by photometer). Eye movements from the right eye were monitored by means of an infrared photoelectric system (Bouis, Karlsruhe) and digitized every millisecond using a Lab-PC 12-bit A/D Converter (National Instruments). While CpB was busy collecting eye movement data, the video registers were monitored by CpA, and each pulsation (detected by reading the vertical retrace signal of the cathode ray tube controller) was signalled to CpB.¹ A marker was then included into the eye movement data file for off-line usage. The subject's head was strapped securely using a front and chin frame. Eye movements were calibrated every five trials using a five-point calibration procedure.

Procedure

Subjects first looked at a fixation point located in the middle of the screen and pushed a button in order to display the stimulus. Stimuli were seven-character strings (six Xs plus a target letter which was either 'O' or 'M') which represented 2.4° of visual angle. Each character was written on the screen using a 8 × 8 matrix. For experimental trials, the target letter was always located in the middle of the string (4th position). Filler trials were included in the experiments in order to vary the target letter location (all other target locations were used the same number of times). The stimulus was displayed for 1000 msec, then subjects were instructed to decide whether the target letter was 'O' or 'M'.

In experiment 1, the stimulus appeared at one degree left or right of the central fixation point. The refresh rate was either 125 or 140 Hz. In experiment 2, the

Table 1. Mean number of pulsations as function of refresh rates and target eccentricities

Eccentricity (°)	1°			7°	
Frequency (Hz)	125	140	75	100	125
Nbr Pulsations	2.38	2.7	2.56	3.17	3.71

stimulus appeared at seven degree-left or right of the central fixation point and the refresh rate was either 75, 100 or 125 Hz. These frequencies were chosen in order to provide several in-flight pulsations. The correspondence between refresh rates and the average number of in-flight pulsations is presented in *Table 1*.

The experiments consisted of two (experiment 1) or three (experiment 2) successive sessions (one session for each refresh rate), separated by a break of a few minutes. The order of these sessions was counterbalanced using a Latin square. The experiment began with six practice stimuli. Each session contained 40 experimental trials and 20 filler trials (33% of all trials); see *Figure 1*.

Data analysis

Data analyses have been focussed mainly on the spatial position of fixations (distributions of landing fixations) and saccade parameters (saccade extent, velocities). The program that reduced eye movement data as a collection of fixations/saccades was based on sac-

cade detection using a template-matching filter (Stampe, 1993). After filtering the data by linear smoothing filters, saccades were determined by their velocities.

Results

Distributions of landing positions in the various experimental conditions are presented in *Figure 2*.

As far as the one-degree eccentricity condition is concerned, most saccades received either two or three in-flight pulsations, and a one-character difference in saccade extent is apparent between the two corresponding curves in *Figure 2a* (landing on the 3rd character vs the 4th character on average for the two-pulsation and the three-pulsation cases respectively). By contrast, no significant difference in saccade extent is apparent in *Figure 2b* and *2d*, where landing position is plotted directly across refresh-rates, $F(1,10) = 2.57$ nsec for one-degree and $F(2,22) = 2.97$ nsec for seven-degree eccentricity. This suggests that the number of in-flight pulsations, not refresh-rate *per se*, is the relevant factor here. A greater variability in landing positions is observed for the seven-degree eccentricity condition. Nevertheless, saccade extent still varies as a function of number of pulsations (as far as the two-, three-, and four-pulsation cases are concerned at least, see *Figure 2c*). The correlation between saccade extent and number of pulsations was significant for both the

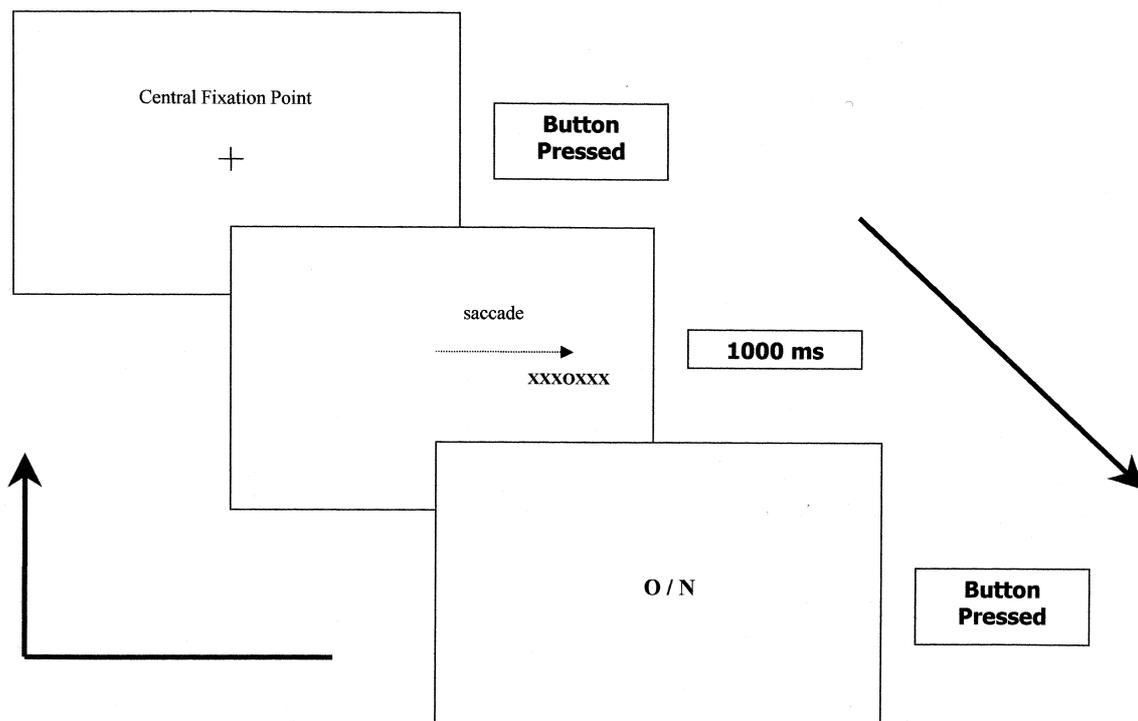


Figure 1. Illustration of the visual search task used in these experiments.

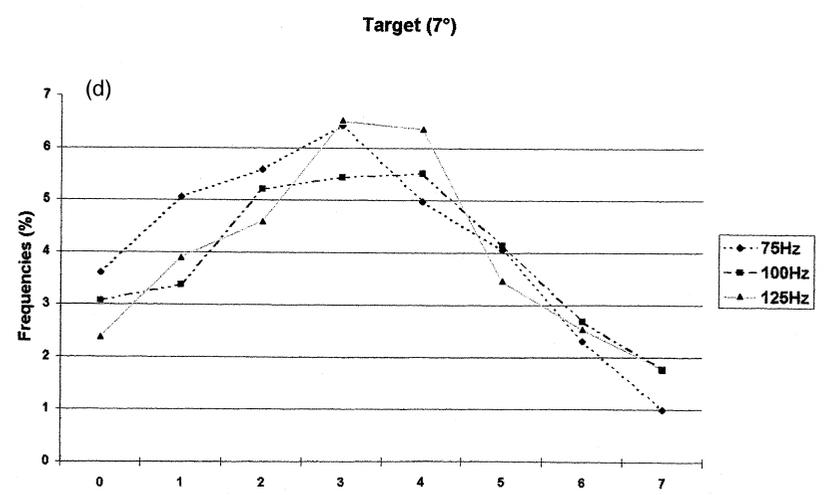
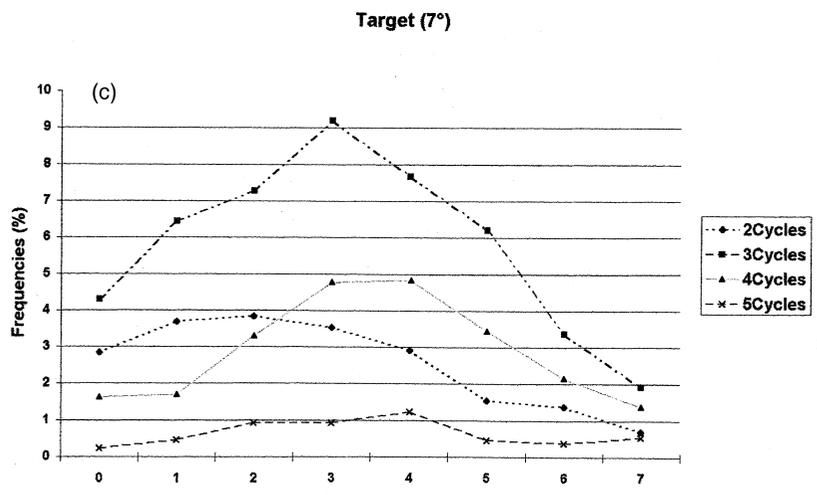
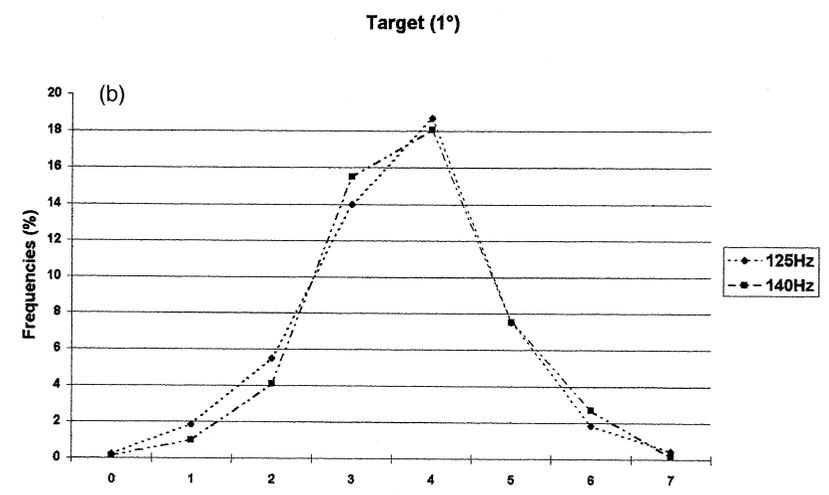
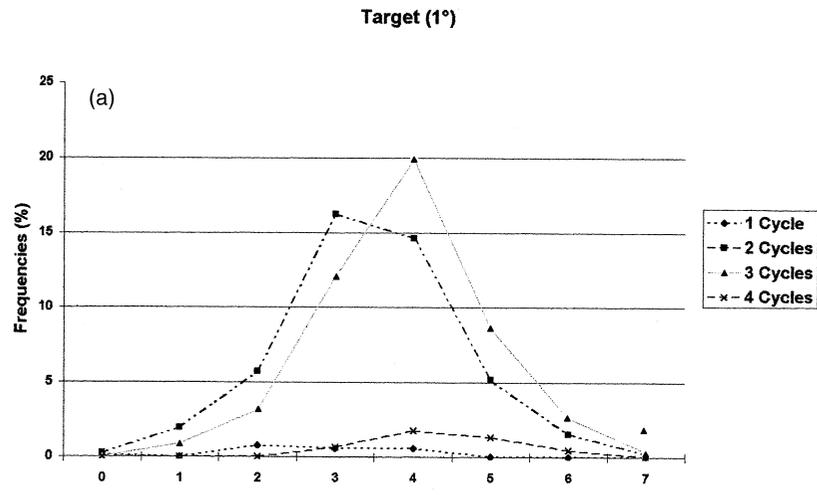


Figure 2. Distributions of landing positions according to the one-degree and seven-degree target eccentricities and as function of number of 'in-flight' pulsations or refresh rates.

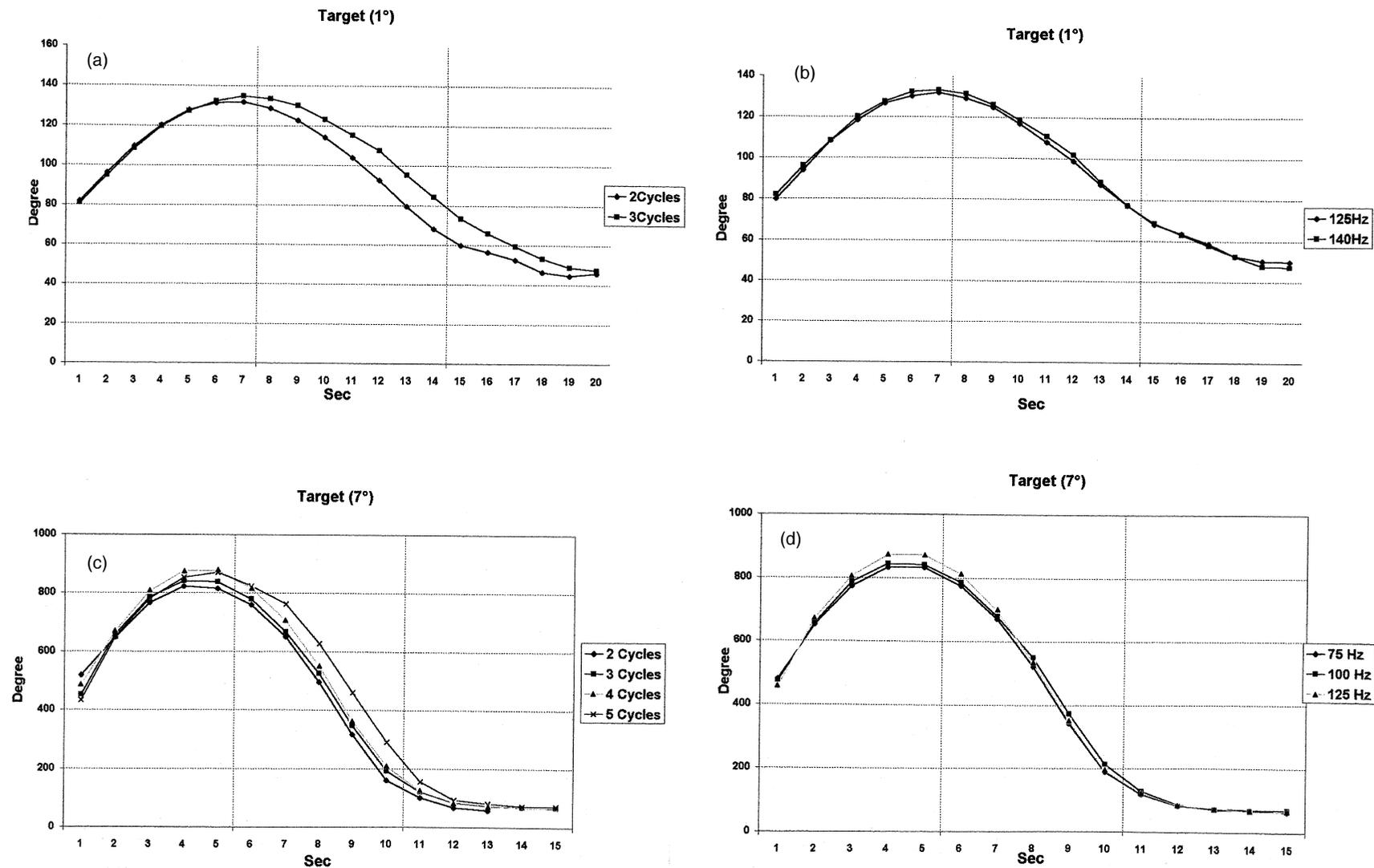


Figure 3. Velocity curves of saccades (Deg/sec) as function of one-degree and seven-degree target eccentricities and as function of number of 'in-flight' pulsations or refresh rates.

one-degree and the seven-degree eccentricity conditions ($r(960) = 0.27, p < 0.01$; and $r(1440) = 0.17, p < 0.05$, respectively).

In order to disentangle the sense of this correlation (does saccade extent vary as a function of number of pulsations or the other way around?), it is necessary to take the duration of each saccade into account. Obviously, large saccades are likely to take a longer time than short ones, and it could thus be argued that the opportunity to receive extra pulsations was greater for large saccades. A covariance analysis was carried out, with saccade extent as the dependant variable, and saccade duration as co-variate in order to estimate the effect of number of in-flight pulsations on saccade extent independently of their durations.

Results of that covariance analysis showed that the saccade extent is significantly increased as function of number of 'in-flight' pulsations for target of one-degree eccentricity, $F(1,10) = 5.135, p < 0.05$ but not for seven-degree eccentricity, $F(1,30) p < 1$. In this latter case, the lack of significance might be due to the great variability of landing positions generally observed for large saccades (Levy-Schoen and Findlay, 1984) while the means linearly increased as a function of the number of pulsations. One could argue that the saccade extent might be affected by the number of pulses occurring prior to the saccade itself but no evidence has been found by analysing the effect of pulsations during saccade latencies (For one-degree and seven-degree, all $F < 1$).

Obviously, if the number of pulsations exerts an influence on the size of saccades independently of their duration (at least for one-degree eccentricity), an effect on saccade velocity can be expected. Velocity curves are presented in *Figure 3*.

Speed increased dramatically as a function of target eccentricity (Global average velocity; one-degree eccentricity = 90 Deg/sec; seven-degree eccentricity = 449.72 Deg/sec). In *Figure 3a* (one-degree eccentricity), a speed increase is apparent in the three-pulsation case relative to the two-pulsation case. A similar effect is apparent in *Figure 3c* for the seven-degree eccentricity, (speed increase as a function of number of pulsations). In keeping with saccade extent

data presented in *Figure 2b* and *2d*, no difference can be found in *Figure 3b* and *3d* where velocity curves are plotted across refresh rates.

Separate analyses of variance were carried out for the one-degree and the seven-degree eccentricity conditions. Moreover, trajectories was divided in three parts (saccade beginning, saccade middle, and saccade end). Each part was then treated independently. The corresponding mean values are presented in *Tables 2a and 2b*.

The effect of the number of pulsations was not significant for the saccade beginning in the one-degree condition ($F < 1$). In all other cases, a significant effect was found ($F(1,11) = 28.44, p < 0.001$; $F(1,11) = 22.89, p < 0.001$ for the one-degree condition, middle and end of saccade respectively; and $F(3,33) = 3.4, p < 0.05$; $F(3,33) = 57.52, p < 0.001$; $F(3,33) = 3.5, p < 0.05$ for the seven-degree condition, beginning, middle, and end of saccade respectively). As far as the middle/seven-degree analysis is concerned, planned comparisons revealed significant differences between the two-pulsation and the three-pulsation conditions (440 vs. 510 Deg/sec, $F(1,11) = 38.66, p < 0.001$), the three-pulsation and the four-pulsation condition (510 vs. 550 Deg/sec, $F(1,11) = 10.23, p < 0.001$), and between the four-pulsation and the five-pulsation condition (550 vs. 600 Deg/sec, $F(1,11) = 16.04, p < 0.001$).

Discussion

The role of the pulsations induced by refreshed screen displays on saccade size was investigated in two experiments. The actual number of pulsations occurring during each saccade, not just refresh-rate, was examined, and saccade extent was found to be positively correlated with the number of in-flight pulsations (the more pulsations, the larger the saccade). Moreover, this effect was found to be independent of saccade duration in a covariance analysis (saccade extent being treated as the dependent variable and saccade duration as the co-variate), at least for the one-degree condition. A significant effect of the number of

Table 2a. Mean velocity (Deg./sec) for saccades launched to one-degree and seven-degree target eccentricities at the beginning, middle and end of the movement as function of the refresh rate and number of 'in-flight' pulsations

One-degree target eccentricity											
Beginning [1–7 msec]				Middle [8–14 msec]				End [15–21 msec]			
125 Hz		140 Hz		125 Hz		140 Hz		125 Hz		140 Hz	
2	3	2	3	2	3	2	3	2	3	2	3
110	110	110	120	100	110	90	110	50	60	50	60

Table 2b.

	Beginning [1–5 msec]			Middle [6–10 msec]			End [11–15 msec]		
	75 Hz	100 Hz	125 Hz	75 Hz	100 Hz	125 Hz	75 Hz	100 Hz	125 Hz
2	720	670	670	480	440	390	80	120	100
3	710	730	760	500	530	510	90	100	110
4	700	810	770	550	560	540	90	90	90
5	730	710	720	600	620	580	130	100	90

in-flight pulsations on saccade velocity was found for both the one-degree and the seven-degree conditions.

These results have important implications for both our understanding of the flicker effect, and theories of saccade control in general. Concerning the first aspect, the present results suggest that the locus of the flicker effect has to be looked for during the saccade itself, and not, or not only, before saccade onset. It could be argued that the effect observed here is not the same as the one reported by Kennedy and Murray (1993a). In terms of landing position, what we observed was, in fact, an improvement in performance (the more pulsations, the closer the landing position relative to the target), in contrast with Kennedy and Murray's suggestion that pulsations result in a landing position displacement, relative to the generally preferred location in reading. Unfortunately, we do not know what the landing position would have been in the absence of any pulsation. However, it should be noted that the generally preferred landing position is located well on the left of the word for left-to-right entering saccades (McConkie *et al.*, 1988). Undershoots are thus to be expected in the case of word-like stimuli such as those used in the present experiments, and one can reasonably interpret the saccade lengthenings we observed as unexpected displacements, relative to the would-have-been landing positions. The alternative interpretation, namely that pulsations were beneficial in the present case, seems highly unlikely.

From a more general point of view, the present data supports the view that saccades are sensitive to in-flight stimuli, which suggests that they cannot be considered as purely ballistic movements. More precisely, in-flight pulsations were found to affect saccade velocity. The mean velocity of saccades receiving three pulsations was higher than the velocity of saccades receiving two pulsations in the one-degree condition (Figure 3a). A similar tendency was observed in the seven-degree condition (as far as the middle of trajectories is concerned at least), with a regular velocity increase as a function of number of pulsations (436.68, 510.92, 550.22 and 602.62 Deg/sec for the two-, three-, four- and five-pulsation cases respectively). An important question concerns the time period during which

pulsations are likely to exert an influence. Figures 3a and 3c suggest that the oculomotor program might become sensitive to pulsations quite early (a speed increase is visible on the curves from the 1st third of the trajectory after saccade onset). Moreover, since each new pulsation seems to increase velocity, it can be concluded that the oculo-motor program remains open to modulations for quite a long time. These hypotheses will be investigated further in future experiments by using a true control condition with no pulsations.

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