Vision Research Vol. 20, pp. 271 to 272
Pergamon Press Ltd 1980. Printed in Great Britain

LETTER TO THE EDITORS

THE FUNCTION OF SMALL SACCADES

(*Received* 1 *May* 1979)

The eye-movements of fixation may be divided into three groups:

(i) Saccadic movements which displace the visual axis through distances having median values of 3′ to 6′ in about 25 msec; maximum speeds of 200′/sec are involved.

(ii) Drift movements, during the intersaccadic intervals, with an exursus of about 2.5′ and a speed of about 4′/sec.

(iii) Tremor movements: these are irregular movements of excursus less than 1′ and speeds ranging up to more than 10′/sec.

The magnitudes quoted are from Ditchburn and Foley-Fisher (1967).

Several experimenters have found that some subjects can reduce the frequency of saccades by voluntary control (Barlow, 1952; Clowes, 1961, 1962; Fiorentini and Ercoles, 1966; Steinman, Cunitz, Timberlake and Herman, 1967). The median intersaccadic interval is about 0.6″. Steinman *et al.* find that many subjects can suppress saccades at least for times of 10 sec (Steinman *et al.*, 1973; Timberlake, Wyman, Skavenski and Steinman, 1972; Kowler and Steinman, 1977; Steinman and Kowler, 1979).

Steinman *et al.* have also shown that subjects who suppress saccades can maintain fixation and can carry out certain visual tasks with good performance. Steinman and Kowler (1979) extend earlier results of Kowler and Steinman (1977) which show that saccades do not improve accuracy of counting elements of repetitive patterns and conclude by saying "why human beings have the skill to make high velocity eye-movements remains a mystery". This letter is intended to elucidate the mystery.

In normal vision, large saccades of several degrees are used to move the eyes rapidly towards a new target, e.g. when an animal hears a small sound which may indicate the presence of prey or of a predator. Rapid eye-movements have considerable survival value in this situation and it is easy to understand why human beings should have acquired the skill to make them. The only question is why small saccades should occur during fixation.

Numerous experiments show that the function of the eye-movement control system, during fixation, is to keep the visual axis within a certain small target area. Very precise fixation would produce the loss of vision which occurs when the retinal image is stabilized. The drift and tremor movements are mainly random and they move the visual axis in such a way that, from time to time, it strays outside the target area. This stimulates a saccade which usually returns the visual axis to the target area, though not precisely to the centre of this area (Ditchburn and Ginsborg, 1953; Nachmias, 1959, 1961; Boyce, 1967). For some subjects drift movements are almost entirely random but for others more drifts are more corrective than would be expected if they were random as a whole. It appears that some subjects can learn to control the drifts well enough to keep the visual axis within the target area for 10 sec or more. The stimulus for saccades is absent and "suppression" of saccades then follows.

It has been shown (Ditchburn and Drysdale, 1977a, b) that, when a subject views a target with sharp boundaries between areas of different *luminance*, the drift movements, by themselves, are capable of maintaining fairly good vision. However, Clowes (1962) recorded eye-movements of subjects who fixated a boundary between areas of different *hue* (e.g. green and blue) with a fairly small luminance difference. He found that, when they suppressed saccades, colour-fusion occurred i.e. the two areas appeared to be of the same hue. When the subjects were instructed to move the eyes so as to prevent colourfusion, numerous saccades occurred. Clowes (1961) also found that when subjects were allowed and encouraged to move their eyes freely, luminance contrast discrimination was considerably better than it was when they fixated as accurately as possible. Recently, Ditchburn and Foley-Fisher (to be published) have found that when saccades and tremor have been removed by stabilization, imposed movements of the same speed as the natural drifts do not maintain perception of hue differences. Artificial "drifts" of 5–10 times the normal speed do maintain perception of hue.

Normal eye-movements produce signals which vary with time in receptors near boundaries in the retinal image. The primary visual signal is probably proportional to dL/dt where L is the retinal illuminance, though higher derivatives of L with respect to t may be involved. A certain minimum signal is needed for threshold vision. dL/dt is proportional to vs where v is the component of velocity of the image perpendicular to the boundary and s is the steepness of slope of L at the boundary i.e. the value of dL/dx (where x is a distance measured in a direction perpendicular to the boundary). If the target has sharp boundaries with high contrast a high value of s is obtained and a low value of v, such as that given by the drifts is enough to produce a value of vs which is sufficiently high to give good vision of the boundary. If s is small because the boundary has low contrast and/or diffuse edges, then higher values of v are needed and saccades become important in generating information. The fact that boundaries of hue-difference (where luminance difference is small) can be made to disappear without stabilization (McCree, 1960; Clowes, 1959) implies that receptor fields involved in hue discrimination are large. Thus large values of v are required for perception of hue-differences (when the luminance difference is small) and saccades again appear to be needed.

Rattle and Foley-Fisher (1968) have suggested that saccades may be associated with the interruption of information processing in the visual system. Periodic interruption would appear to be necessary to prevent the processor from being overloaded but it is uncertain whether the normal frequency of interruption is maintained when saccades are absent.

Some acrobats can walk on their hands with amazing agility and most young people can learn to do this tolerably well. Certain tasks, such as following a line marked on the floor can be performed with reasonable accuracy. Yet no one suggests, from these facts, that it is mysterious that feet have evolved. Similarly the fact that many subjects can perform certain kinds of visual tasks in the absence of frequent saccades does not conflict with the view that saccades play an important and, indeed, an esssential part in normal vision.

Acknowledgement—I wish to thank Dr J. A. Foley-Fisher for discussion of this letter.

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