

LETTER TO THE EDITORS

SMALL SACCADES SERVE NO USEFUL PURPOSE: REPLY TO A LETTER BY R. W. DITCHBURN*

(Received 3 July 1979)

Although it is now almost thirty years since the first accurate measurements of miniature fixational eye movements (Ratliff and Riggs, 1950; Ditchburn, 1955), it is still possible to debate the functional properties of the different types of miniature eye movements. Although we, like Ditchburn, have faith that organisms develop capacities that are in some way useful to them, we believe that finding a functionally significant role for the microsaccade presents a formidable challenge. We have been attempting to do this experimentally for more than a dozen years. The overwhelming body of evidence, from our laboratory and elsewhere, indicates that microsaccades contribute nothing of consequence to either oculomotor control or vision (cf. Steinman *et al.*, 1973; Steinman, 1975, 1976).

Microsaccades can be suppressed without training and when they are suppressed, smooth eye movements, not microsaccades, maintain the line of sight on a stationary target. Ditchburn says that microsaccades, in most subjects, are required to correct deviations in the line of sight from the target that are produced by "random" drift movements. He says that some subjects can suppress saccades provided that they "learn to control the drifts well enough to keep the visual axis within the target area for 10 sec or more." There are two issues contained in these assertions. First, how easy is it to suppress microsaccades, and second, what happens to the line of sight when microsaccades are suppressed? Ditchburn does not recognize that these are two distinct questions because he believes that the microsaccade is elicited reflexively by positional errors introduced by "random" drifts. We, and others, have found that this is not the case.

First, microsaccades are easily suppressed—only a simple verbal instruction is required. Learning, training and practice are unnecessary. This is true for all subjects, not only knowledgeable subjects who were familiar with the oculomotor literature when they served in the various experiments. These knowledgeable subjects did not, however, receive any training in saccade suppression before data were collected (Steinman *et al.*, 1967; Haddad and Steinman, 1973; Kowler and Steinman, 1977, 1979; Haddad and Winterson, 1975). Their performance was not different

from the performance of naive subjects who also received no training before suppressing saccades. Winterson and Collewijn (1976) asked 5 naive subjects to suppress saccades by simply telling them that they made jumps of the eye when they looked at the target, and that they were to stop making such jumps and ignore the fact that their line of sight might appear to be moving away from the target when they did so. All 5 subjects succeeded in following this instruction and reduced their saccade rates. Similar results were obtained by Schor and Hallmark (1978) and Ciuffreda *et al.* (1979) with amblyopic subjects. Note that in the experiments with amblyopes microsaccades were suppressed in the presence of high drift velocities and rapidly accumulating fixation errors. Microsaccades can also be suppressed in normal subjects whose eyes are caused to drift rapidly by flickering the fixation target (Haddad and Winterson, 1975).

Instructions to suppress microsaccades are not always necessary. Some subjects rarely make microsaccades when they fixate (Fiorentini and Ercoles, 1966; Winterson and Collewijn, 1976). So, the suppression of microsaccades requires neither training nor that the eye does not drift. Subjects can either make microsaccades or not make microsaccades. Their occurrence depends primarily on what subjects are asked to do or on what they have decided to do.

The second and more important point, however, is that when microsaccades are not made, slow eye movements (what we now call slow control) maintain line of sight on the fixation target (Steinman *et al.*, 1967; Steinman *et al.*, 1973; Winterson and Collewijn, 1976; Kowler and Steinman, 1977). Standard deviations of eye position during slow control are about 3 min arc i.e. the same or less than the standard deviations found during fixation when saccades are frequent (see Murphy *et al.*, 1974). Effective slow control is typical: 23 of the 27 visually normal subjects who were asked to suppress saccades (in our and in other laboratories) show such stability. (The remaining 4 subjects show systematic low velocity drifts in one direction ranging from 2 to 11 min arc/sec.) Effective slow control in 85% of the normal population tested makes it unlikely that the capacity to make microsaccades evolved to enable human beings to maintain the fixation target in the circumscribed retinal area.

Evolutionary considerations, as well as these facts, argue against the importance of microsaccades for

* Supported by NSF grant BNS 77-16474 to R. M. Steinman and NIH postdoctoral fellowship F32EY05235 to E. Kowler.

maintaining fixation. The fixational microsaccade has only been observed in the human being. Neither the rabbit (Collewijn and Van Der Mark, 1972) nor the cat (Winterson and Robinson, 1975) make microsaccades. The rhesus monkey, whose visual and oculomotor systems are quite similar to ours, makes saccades frequently during fixation, but they are large. It requires several months of training before monkeys make microsaccades (Skavenski *et al.*, 1975). In all of these animals the line of sight is maintained in intervals between large saccades by a slow control subsystem. Our demonstration that there is an effective slow control subsystem in human beings, then, is consistent with oculomotor characteristics of other species. It is also consistent with another class of eye movements found in human beings, namely, smooth pursuit. Nachmias (1961), when he demonstrated the corrective drift component during highly saccadic fixation, suggested that slow control may be smooth pursuit of a target moving at zero velocity (see Murphy *et al.*, 1975, for a recent discussion of this possibility).

We believe that an effective slow control subsystem in human-beings makes evolutionary sense for essentially the same reasons that have been proposed by Walls (1962). Walls describes what he calls "collicular field-holding reflexes" (commonly studied in lower animals in the laboratory as optokinetic nystagmus). These reflexes are used to maintain full-field image stability. In foveate animals these reflexes are elaborated so that small stationary and moving targets are kept relatively stationary on the fovea. It would be odd, indeed, if as a result of evolution of the fovea, human beings lost such a valuable and highly developed automatic stabilizing mechanism which is prominent in other animals and used to keep images stable on the retina.

Smooth eye movements, not microsaccades, are optimal for maintaining clear vision. Ditchburn points out that when stimulus contrast is high and edges are sharp, retinal image motions on the order of a few min arc/sec (velocities characteristic of slow control) are sufficient to maintain clear vision. He also points out that these low velocities may not be sufficient to maintain vision when stimulus contrast is low, or when the luminance gradient across a border is shallow. With such stimuli, higher retinal velocities are

needed to produce an effective visual signal. He offers as evidence for this assertion his observations (with Foley-Fisher) that high retinal image velocities are required to perceive a chromatic border between two regions of equal luminance. Ditchburn infers from these observations that microsaccades are responsible for providing the higher retinal image velocities.

We have no quarrel with the notion that higher retinal image velocities than those produced by slow control are sometimes necessary to maintain clear vision. This notion is not new. A consistent finding in studies of visibility and contrast sensitivity with stabilized targets is that clearest vision is obtained when the velocity of imposed smooth retinal image motion is higher than eye velocity commonly observed during slow control (Riggs *et al.*, 1953; Ditchburn *et al.*, 1959; Clowes, 1961; Keeseey and Riggs, 1962; Sharpe, 1972; Gerrits and Vendrik, 1974; King-Smith and Riggs, 1978). Also, when targets are not artificially stabilized, contrast sensitivity for low spatial frequency sinusoidal gratings is improved when retinal image velocity is increased either by moving the grating or by having subjects smoothly pursue a moving point over the grating (Van Nes, 1968; Arend, 1976). Furthermore, high velocity image motion (up to about 2 deg/sec) does not impair either contrast sensitivity for 5 c/deg sinusoidal gratings (Murphy, 1978) or vernier acuity (Westheimer and McKee, 1975).

However, even though relatively high velocity retinal image motion may be necessary for vision under some conditions, microsaccades are not a good way to produce such motion and they are unnecessary in natural situations. Ditchburn tries to prove that microsaccades are necessary by citing Clowes' (1961) observations that the discrimination of luminance differences was better when subjects were instructed to look around than when they were instructed to fixate. Clowes (1961) did not describe their eye movements, thus it is not possible to know whether microsaccades were responsible for improvements in discriminability. Clowes (1962) instructed himself to fixate the border between two equally bright regions of different hue in such a way as to prevent fusion of the colors. His eye movement record, when he tried to prevent fusion, shows large saccades (about 20') and high velocity intersaccadic drifts, as well as microsaccades. How successful these eye movements were in preventing fusion and the effectiveness of the microsaccades relative to the larger saccades and high velocity drifts were not reported. There would be many advantages if the higher velocity drifts, rather than the saccades, were responsible for preventing fusion of the colors. Saccades are not the best way of increasing retinal image velocity. They are very brief, and infrequent, and thus at best could provide intermittent periods without fusion.

Such intermittent stimulation may, however, have long lasting value. Abrupt step displacements can regenerate a faded stabilized image for a few seconds (King-Smith *et al.*, 1977; Ditchburn and Drysdale,

* King-Smith and Riggs (1978) found that imposed square-wave motion could be as effective in improving contrast sensitivity as imposed constant velocity oscillations at amplitudes $\leq 4'$. At such low amplitudes contrast sensitivity with these two types of motion did not differ significantly (see their Fig. 4). This similarity of effects with both types of motion is consistent with their other observations that at such low amplitudes, only the amplitude of motion determines contrast sensitivity. Frequency and velocity are irrelevant (see also King-Smith *et al.*, 1977). At larger amplitudes, however, when contrast sensitivity improves and velocity becomes the major determinant of contrast sensitivity, the imposed constant velocity oscillations are consistently better than the imposed square-wave motions.

1977a, b). But the quality of vision with such a re-generated stabilized image may not be optimal because step displacements do not improve contrast sensitivity of stabilized targets more effectively than imposed constant velocity oscillations (King-Smith and Riggs, 1978)*—a finding that contradicts Ditchburn's suggestion that microsaccades are most valuable when contrast at a border is low. Microsaccades are made even less attractive as a means of enhancing vision by noting that they may be preceded, accompanied and followed by threshold elevations (Ditchburn, 1955; Beeler, 1967).

If higher image velocities than those typical of slow control are optimal for vision and if microsaccades are not the best way of providing them, how do we obtain such high image velocities in natural situations? Fortunately, there is a way of increasing retinal image velocities without making microsaccades. It is sufficient to get off the bite board.

Skavenski *et al.* (1979) have shown that, when the head is free, average retinal image speed is at least twice as high as average retinal image speed when the head is artificially supported—this is when the free-headed subject is sitting or standing *as still as possible*. Under these conditions retinal image speed is 20 to 40 min arc/sec—quite high enough to maintain vision without microsaccades. If the subject is allowed to move his head normally, average retinal image speed climbs to more than 3 deg/sec (Steinman and Collewijn, 1980). Thus, the kind of retinal image speeds that Ditchburn and other investigators have shown to be optimal for vision on the bite board are normally encountered in everyday life when our heads are not artificially restrained. Once we know that natural retinal image speed is high, it seems unnecessary to suggest that microsaccades evolved to improve vision.

Microsaccades are not needed for visual information processing. Ditchburn credits Rattle and Foley-Fisher (1968) with suggesting that "saccades may be associated with the interruption of information processing in the visual system... to prevent the processor from being overloaded." It is not likely that such interruptions are necessary. Kowler and Sperling (1980) have recently shown that saccade-like stimulus perturbations (extra onsets and rapid displacements) do not aid information processing during a visual search task. In fact, even Rattle and Foley-Fisher's (1968) data contradict Ditchburn's suggestion because they found that vernier acuity improved as the length of time between saccades increased. Furthermore, microsaccades are not helpful in tasks requiring more complex visual information processing. Microsaccades do not improve counting accuracy when items were confined to small regions (30 min arc diameter) (Kowler and Steinman, 1979). Microsaccades also do not help perform finely guided visuomotor tasks, such as threading a needle or aiming and shooting a rifle (Winterson and Collewijn, 1976). Naive subjects, performing these finely guided visuomotor tasks, either

elected to suppress their microsaccades as the task became critical near its successful completion or avoided making microsaccades throughout the task.

The functional significance of microsaccades remains a mystery. In summary, the evidence indicates that microsaccades (1) are not needed to maintain the line of sight, (2) are not needed to produce visually useful high velocity retinal image motions when the head is not restrained artificially, (3) are not optimal for producing high velocity image motions when the head is stabilized artificially, and (4) do not enhance visual information processing.

We believe that this creates an evolutionary puzzle. Why should human beings, and only human beings, exhibit a penchant for making such small high velocity eye movements if they serve no useful purpose? We do not know. Perhaps these movements are merely a kind of nervous tic. During normal viewing, we are accustomed to making large saccades combined with head movements to inspect our environment. Perhaps when the head is fixed artificially and the line of sight is constrained by verbal instructions to a small part of the visual array, our habit of looking around persists with saccadic amplitude reduced so that the line of sight is not taken away from the small region in which we have been directed to confine our attention. Such an explanation may be correct, but it is not satisfying because this behaviour does not seem to have any obvious survival value. We do not think, however, that it is plausible that these miniature high velocity eye movements evolved solely to aid vision (and aid it inefficiently) when human beings view equal-luminance chromatic borders while clenching a biteboard.

Department of Psychology
New York University
New York, NY 10003, U.S.A.

EILEEN KOWLER

Department of Psychology
University of Maryland
College Park, Md 20742, U.S.A.

ROBERT M. STEINMAN

REFERENCES

- Arend L. E. (1976) Temporal determinants of the form of the spatial contrast threshold MTF. *Vision Res.* **16**, 1035–1042.
- Beeler G. N. (1967) Visual threshold changes resulting from spontaneous saccadic eye movements. *Vision Res.* **7**, 769–775.
- Ciuffreda K. J., Kenyon R. V. and Stark L. (1979) Suppression of fixational saccades in strabismic and anisometric amblyopia. *Ophthal. Res.* **11**, 31–39.
- Clowes M. B. (1961) Some factors in brightness discrimination with constraint of retinal image movement. *Optica Acta* **8**, 81–91.
- Clowes M. B. (1962) A note on colour discrimination under conditions of retinal image constraint. *Optica Acta* **9**, 65–68.
- Collewijn H. and Van Der Mark F. (1972) Ocular stability in variable feedback conditions in the rabbit. *Brain Res.* **36**, 47–57.
- Ditchburn R. W. (1955) Eye movements in relation to retinal action. *Optica Acta* **1**, 171–176.

- Ditchburn R. W. (1980) The function of small saccades. *Vision Res.* This issue, pp. 271-272.
- Ditchburn R. W. and Drysdale A. E. (1977a) The effect of retinal image movements on vision: I. Step-movements and pulse-movements. *Proc. R. Soc. B* **197**, 131-144.
- Ditchburn R. W. and Drysdale A. E. (1977b) The effect of retinal image movements on vision: II. Oscillatory movements. *Proc. R. Soc. B* **197**, 385-406.
- Ditchburn R. W., Fender D. H. and Mayne S. (1959) Vision with controlled movements of the retinal image. *J. Physiol.* **145**, 98-107.
- Florentini A. and Ercoles A. H. (1966) Involuntary eye movements during attempted monocular fixation. *Atti Fond. Giorgio Ronchi* **21**, 199-217.
- Gerrits H. J. M. and Vendrik A. J. H. (1974) The influence of stimulus movements on perception in parafoveal stabilized vision. *Vision Res.* **14**, 175-180.
- Haddad G. M. and Steinman R. M. (1973) The smallest voluntary saccade: Implication for fixation. *Vision Res.* **13**, 1075-1086.
- Haddad G. M. and Winterson B. J. (1975) Effect of flicker on oculomotor performance. In *Basic Mechanisms of Ocular Motility and their Clinical Implications* (Edited by Lennerstrand G. and Bach-y-Rita P.). Pergamon Press, Oxford.
- Keesey U. T. and Riggs L. A. (1962) Visibility of Mach Bands with imposed motions of the retinal image. *J. opt. Soc. Am.* **52**, 1-2.
- King-Smith P. E. and Riggs L. A. (1978) Visual sensitivity to the controlled motion of a line or edge. *Vision Res.* **18**, 1509-1520.
- King-Smith P. E., Riggs L. A., Moore R. K. and Butler T. W. (1977) Temporal properties of the human visual nervous system. *Vision Res.* **17**, 1101-1106.
- Kowler E. and Sperling G. (1980) Transient stimulation does not aid visual search: Implications for the role of saccades. *Percept. Psychophys.* In press.
- Kowler E. and Steinman R. M. (1977) The role of small saccade in counting. *Vision Res.* **17**, 141-146.
- Kowler E. and Steinman R. M. (1979) Miniature saccades: Eye movements that do not count. *Vision Res.* **19**, 105-108.
- Murphy B. J. (1978) Pattern thresholds for moving and stationary gratings during smooth eye movement. *Vision Res.* **18**, 521-530.
- Murphy B. J., Haddad G. M. and Steinman R. M. (1974) Simple forms and fluctuations in the line of sight: Implications for motor theories of form processing. *Percept. Psychophys.* **16**, 557-563.
- Murphy B. J., Kowler E. and Steinman R. M. (1975) Slow oculomotor control in the presence of moving backgrounds. *Vision Res.* **15**, 1263-1268.
- Nachmias J. (1961) Determiners of the drift of the eye during monocular fixation. *J. opt. Soc. Am.* **51**, 761-766.
- Ratliff F. and Riggs L. A. (1950) Involuntary motions of the eye during monocular fixation. *J. exp. Psychol.* **40**, 687-701.
- Rattle J. D. and Foley-Fisher J. A. (1968) A relationship between vernier acuity and intersaccadic interval. *Optica Acta* **15**, 617-620.
- Riggs L. A., Ratliff F., Cornsweet J. C. and Cornsweet T. N. (1953) The disappearance of steadily fixated test objects. *J. opt. Soc. Am.* **43**, 495-501.
- Schor C. and Hallmark W. (1978) Slow control of eye position in strabismic amblyopia. *Invest. Ophthalmol.* **17**, 577-581.
- Sharpe C. R. (1972) The visibility and fading of thin lines visualized by their controlled movement across the retina. *J. Physiol.* **222**, 113-134.
- Skavenski A. A., Robinson D. A., Steinman R. M. and Timberlake G. T. (1975) Miniature eye movements of fixation in the rhesus monkey. *Vision Res.* **15**, 1269-1273.
- Skavenski A. A., Hansen R. H., Steinman R. M. and Winterson B. J. (1979) Quality of retinal image stabilization during small natural and artificial body rotations in man. *Vision Res.* **19**, 675-683.
- Steinman R. M. (1975) Oculomotor effects on vision. In *Basic Mechanisms of Ocular Motility and their Clinical Implications* (Edited by Lennerstrand G. and Bach-y-Rita P.). Pergamon Press, Oxford.
- Steinman R. M. (1976) The role of eye movements in maintaining a phenomenally clear and stable world. In *Eye Movements and Psychological Processes* (edited by Monty, R. A. and Senders, J. M.), Erlbaum, Hillsdale.
- Steinman R. M. and Collewijn H. (1980) Binocular image motion during active head rotation. *Vision Res.* In press.
- Steinman R. M., Cunitz R. J., Timberlake G. T. and Herman M. (1967) Voluntary control of microsaccades during maintained monocular fixation. *Science* **155**, 1577-1579.
- Steinman R. M., Haddad G. M., Skavenski A. A. and Wyman D. (1973) Miniature eye movement. *Science* **181**, 810-819.
- Van Nes F. L. (1968) Enhanced visibility by regular motion of retinal image. *Am. J. Psychol.* **81**, 367-374.
- Walls G. L. (1962) The evolutionary history of eye movements. *Vision Res.* **2**, 69-80.
- Westheimer G. and McKee S. P. (1975) Visual acuity in the presence of retinal image motion. *J. opt. Soc. Am.* **65**, 847-850.
- Winterson B. J. and Collewijn H. (1976) Microsaccades during finely-guided visuomotor tasks. *Vision Res.* **16**, 1387-1390.
- Winterson B. J. and Robinson D. A. (1975) Fixation by the alert but solitary cat. *Vision Res.* **15**, 1349-1352.