Vision Research Vol. 19, pp. 105 108
Pergamon Press Ltd 1979. Printed in Great Britain

LETTER TO THE EDITORS

MINIATURE SACCADES: EYE MOVEMENTS THAT DO NOT COUNT

(*Received* 14 *December* 1977; *in revised form* 1 *May* 1978)

INTRODUCTION

In a recent paper (Kowler and Steinman, 1977) we investigated the relationship between eye movement and counting and found that saccades do not improve counting accuracy for repetitive visual patterns (the bars of a square-wave grating). Counting was as accurate when no saccades were made as when saccades were made frequently. We did find, however, that saccades improved counting accuracy when the patterns were not repetitive and the items in the display formed perceptual groups. These results led us to conclude that counting accuracy is limited primarily by perceptual confusion rather than by oculomotor skill. Motor skill comes into play only after perceptual confusion is removed. We obtained these results with relatively large displays (2° dia) which left open the question of whether benefits derived from making saccades were confined to relatively large displays in which it might be difficult to shift attention over large distances without using saccades to move the line of sight. This consideration led us to ask whether saccades contributed to counting accuracy when displays are confined to a very small region within which shifts of attention might be as useful as shifts in the line of sight. We found that miniature saccades, unlike large saccades, are not beneficial when displays are small and perceptually organized.

METHOD

Two-dimensional movements of the right eye were recorded with a contact lens optical lever (Haddad and Steinman, 1973). The r.m.s. noise level of the instrument as used in this experiment corresponded to 6″. The left eye was closed and covered and the head was stabilized by an acrylic dental biteboard. The voltage output of the optical lever (filtered at 50 hz) was fed on-line to a 12-bit ADC (analog to digital converter). The ADC, under the control of a minicomputer (Nova 2/10), sampled eye position at 100 Hz. Digitized voltages were stored on tape for later analysis.

The displays were generated by the same minicomputer on a storage monitor (Tektronix 603) located 1.3 m from the subject's right eye. The displays contained from 7 to 16 dots located at randomly selected positions within a square matrix that subtended either 30′ (small) or 120′ (large) on a side. The random dot displays naturally grouped by proximity into perceived clusters of 2–4 dots.

The subject fixated a centrally located fixation point and started each trial when ready. 1 sec later the fixation point disappeared and the dot display appeared and remained visible for 7.6 sec. At the end of 7.6 sec the stored display was erased. The erasure produced a bright flash which eliminated any visible afterimages. Immediately after the trial the subject reported the count (see Kowler and Steinman, 1977, for the rationale underlying the choice of trial length and numerosity of the displays).

Two types of oculomotor behavior were allowed while counting. One (*Scan*) allowed the subject to count by making any pattern of saccades he chose. The other (*Stay*) required the subject to maintain his line of sight in the center of the display without making saccades and count by shifting attention rather than by moving the eyeball.

The authors served as subjects. Both were experienced eye movement subjects and had participated in the previous study of counting (Kowler and Steinman, 1977).

RESULTS

Both of us were able to follow the oculomotor instructions. We made many saccades when we were required to use them to count and very few when we were required to count while staying in place. This is summarized in Table 1.

The contribution of saccades to counting depended on display size. This is shown in Table 2. Saccades did not improve counting accuracy for small displays. EK counted small displays only slightly more accurately when she made saccades than when she did not, and her 3% difference was not statistically reliable ($\chi^2 = 0.11$, $P > 0.7$). RMS counted small displays more accurately when he did not use saccades. His 2% difference was also not statistically reliable ($\chi^2 = 0.21$, $P > 0.5$). Both subjects counted large displays more accurately when they used saccades. These differences were statistically reliable (EK's $\chi^2 = 8.2$, $P < 0.01$; RMS's $\chi^2 = 19.3$, $P < 0.001$). This result confirms our previous findings with large perceptually organized displays.

How were saccades different for the small and large displays? They differed in size. Saccades used to scan the small displays were much smaller than those used to scan large displays (EK's mean saccade length for

Table 1. The mean number of saccades in a 7.6 sec trial (No. S) of subjects EK and RMS when confronted with *Small* and *Large* dot displays under instructions to use saccades (*Scan*) or to suppress them (*Stay*)

	Subject EK		Subject RMS	
	No. S	*N*	No. S	*N*
Scan				
Small	9.2 (3.1)	100	12.0 (3.2)	100
Large	12.4 (4.6)	100	11.7 (4.3)	99
Stay				
Small	0.3 (0.6)	100	0.3 (0.6)	98
Large	0.6 (0.7)	100	0.5 (0.8)	100

Standard deviations are given in parentheses and the number of trials (*N*) are also shown.

Table 2. Percent correct counts (%c) of subjects EK and RMS when confronted with *Small* and *Large* dot displays under instructions to use saccades (*Scan*) or to suppress them (*Stay*)

	EK				RMS			
	Small		Large		Small		Large	
	%c	*N*	%c	*N*	%c	*N*	%c	*N*
Scan	77	100	98	100	78	100	97	99
Stay	74	100	86	100	80	98	76	100

The chance expectation was 10% and the number (*N*) of counting tests is also shown.

small displays = 13.0′, S.D. = 9.5, $N = 902$; for large displays = 25.2′, S.D. = 14.7, $N = 1199$. RMS's mean saccade length for small displays = 9.9′, S.D. = 6.4, $N = 1160$, for large displays = 28.5′, S.D. = 19.1, $N = 1136$). The saccades used to scan the small displays were as small as the microsaccades human beings make when they maintain fixation of a stationary target (Ditchburn and Foley-Fisher, 1967).

The sizes of saccades made while counting small displays did not differ as a function of the number of items in the displays. This is shown in Fig. 1.[1] Sizes of saccades made while counting the large displays, however, did change as a function of the number of items, but the two subjects performed differently (see Fig. 2). EK tended to *reduce* saccade size slightly when counting the large displays that contained more items. RMS tended to *increase* saccade size when counting the large displays that contained more items. These idiosyncracies with the large perceptually organized displays were observed with large perceptually organized displays in the prior experiment (Kowler and Steinman, 1977). This confirms our previous finding that even when saccades are beneficial in counting, their size need not closely correspond to the spacing of the items.

DISCUSSION

We found that microsaccades do not improve counting accuracy. Large saccades do. Why might this be? There seem to be three possibilities. First, large saccades may be useful because they compensate for poor visual acuity for items at the periphery of the large display. Saccades made within small displays would not be useful for this reason. We doubt that acuity was important because we had no difficulty distinguishing all of the items in both the large and the small displays while we maintained the line of sight at the center of the displays. Our subjective impressions and our observation that at least one subject (EK) counted large displays more accurately than small displays when saccades were not made (see Table 2) agree with reports of other investigators who found that counting accuracy falls off well before the limit of spatial resolution is reached (Atkinson, Campbell and Francis, 1976).

Second, microsaccades may not be beneficial

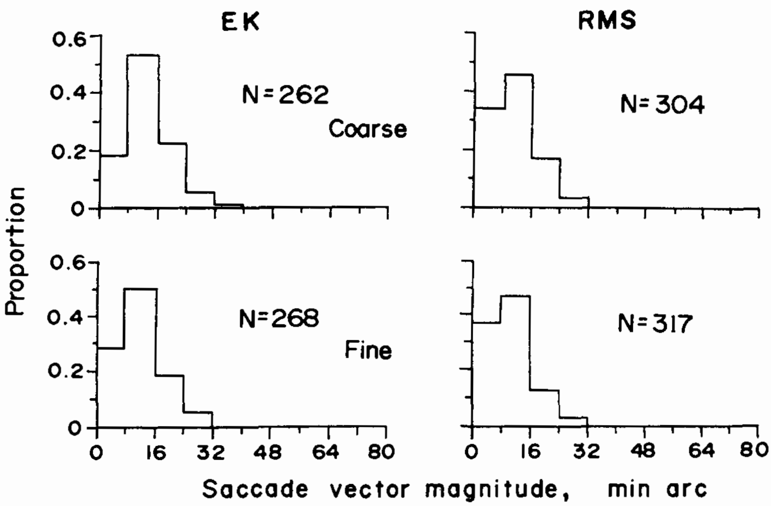

Fig. 1. Proportions of saccade vector magnitudes of EK and RMS counting *small* dot displays under instructions to *Scan*. Each histogram is based on measurement of saccades in trials with the three coarsest dot displays (7–9 dots) and trials with the three finest dot displays (14–16 dots). The number of saccades (*N*) measured for each subject with the coarse and fine dot displays is also shown.

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[1] Figures 1 and 2 show saccade lengths (vector magnitudes) for displays with the fewest number of items (the most widely spaced items) and saccade lengths for displays with the greatest number of items (the most closely spaced items). The relationship of saccade size to number of items was illustrated this way in our previous paper (Kowler and Steinman, 1977) and is being illustrated in the same way here to facilitate comparison with our prior work. The comparison is of interest because the displays, although they had some similar properties, differed in a number of ways.

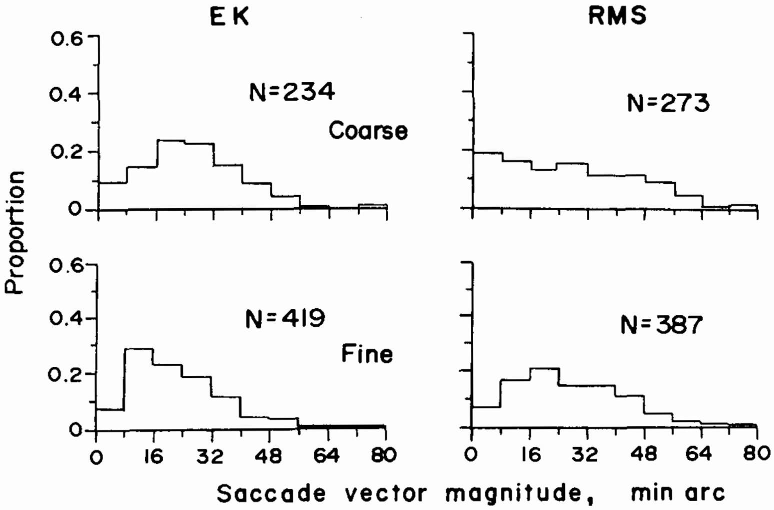

Fig. 2. Proportions of saccade vector magnitudes of EK and RMS counting *large* dot displays under instructions to *Scan*. Each histogram is based on measurement of saccades in trials with the three coarsest dot displays (7–9 dots) and trials with the three finest dot displays (14–16 dots). The number of saccades (N) measured for each subject with the coarse and fine dot displays is also shown.

because their size and direction cannot be controlled well enough to allow the line of sight to arrive at the intended location. Large saccades may suffer less from this limitation. We do not believe that this is the explanation because neither of us noticed any greater difficulty in looking at what we wanted to see when we scanned the small displays than when we scanned the large displays. Our subjective impression is difficult to test directly. An examination of eye position relative to dot location would not be enlightening because this would only tell us the position of the eye at the end of saccades. We would need to compare the intended position of the eye at the end of saccades to the observed position of the eye at the end of saccades to estimate the accuracy of the saccades. We have no objective way of knowing the intended position. There is, however, indirect objective evidence that the size and direction of microsaccades can be controlled as accurately as the size and direction of larger saccades. For example, it has been shown that (1) microsaccades can be made voluntarily to look away from stationary visual targets in any specified direction (Haddad and Steinman, 1973), (2) microsaccades can be used to track target steps as small as 3.4′ (Wyman and Steinman, 1973), and (3) small (5′) steps can be tracked as accurately as large (180′) steps (Timberlake, Wyman, Skavenski and Steinman, 1972). For these reasons we do not believe that differences in saccadic accuracy can explain our results.

Third, large saccades may be useful and small saccades may not be useful because it may be difficult to shift the center of attention over large distances without moving the line of sight—a requirement when displays are large. If this were the reason why saccades were beneficial while counting large displays, their advantage should disappear when small displays are counted because all of the items would fall near the center of attention. We found evidence for this explanation. But we cannot accept this explanation because we have data that contradicts its basic assumption, namely, that attention shifts are more difficult to make over relatively large spatial distances. If attention shifts over large distances were difficult to execute without saccades and attention shifts over small distances were easier, then counting accuracy should have been better with the small displays than with the large displays when saccades were not made. One subject, RMS, performed in this manner. EK did not. She counted large displays better than small displays when she did not make saccades. These conflicting results are disappointing but not really surprising because we have already reported that it is dangerous to use oculomotor performance to make inferences about attention shifts (Kowler and Steinman, 1977, p. 145). Thus, there does not seem to be any single straightforward explanation of why only relatively large saccades help when perceptually organized displays are counted.

There is, however, a clear implication of our results; namely, microsaccades, common in the human oculomotor pattern, serve no useful purpose. Ours is not the first evidence for this. It has already been shown that microsaccades are not needed to maintain the line of sight during fixation (Steinman, Haddad, Skavenski and Wyman, 1973; Steinman, Cunitz, Timberlake and Herman, 1967), nor are they used to perform finely guided visuomotor tasks (Winterson and Collewijn, 1976). Even their usefulness for preserving vision by preventing fading has been questioned (Cunitz and Steinman, 1969; Steinman, 1975), and recent work with stabilized images indicates that low velocity eye movements are sufficient to maintain image visibility (Gerrits and Vendrik, 1974).

Our present findings also support the suggestion that microsaccades are not necessary to prevent visual targets from fading for two reasons. First, neither subject noticed any fading of either large or small displays during the relatively long periods (7.6 sec) of counting when saccades were not made. Second, the accuracy with which small displays were counted would have suffered when microsaccades were not made because the items would have disappeared. We found, however, that counting small displays was as accurate without microsaccades as with them. This could not have occurred if items disappeared.

In conclusion, we knew that microsaccades are not necessary for maintaining fixation, performing finely guided visuomotor tasks, or maintaining image visibility. We have now shown that microsaccades serve no useful purpose in a cognitive task. Why human beings have the skill to make tiny high velocity eye movements remains a mystery.

Acknowledgements—This research was supported by Grant 00325 from the National Eye Institute and Grant BNS 77-16474 from the National Science Foundation.

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