

PERCEIVED POSITION AND SACCADIC EYE MOVEMENTS*

ARIEN MACK, ROBERT FENDRICH, DEBORAH CHAMBERS and FRIDERIKE HEUER
The Graduate Faculty, New School for Social Research, NY 10003, U.S.A.

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Abstract—Data are reported which support the conclusion that saccades which occur 600 msec or more after the brief, presentation of a target stimulus are directed to its perceived position when that differs from both its retinal and spatial position.

Saccade Control Perception Position

The question of whether saccades are programmed in terms of the retinotopic or spatiotopic coordinates† of positions has been the subject of considerable discussion and investigation (Robinson, 1973; Young and Stark, 1963; Robinson, 1977; Hallett and Lightstone, 1976a,b; Mays and Sparks, 1980). However, the related question of whether *perceived* position ever governs saccadic programming has been largely ignored. Since perceived position need not be based on either a retinotopic or spatiotopic coordinate system, but can be a function of the position of one visual stimulus in relation to another, this question merits independent investigation. Moreover, its answer could provide useful additional information about the levels of processing involved in eye movement control.

To our knowledge there is only one prior attempt to answer this question (Wong and Mack, 1981) and that produced results, which, with one possible exception, indicate that perceived position has no role in the control of saccades. In this earlier study the observer fixated a luminous point which was surrounded by a luminous elliptical contour. This display then vanished briefly and reappeared for 100 msec with either the surround or the point in a displaced position. When the surround was displaced, it induced an apparent shift in the position of the enclosed point opposite that of the surround. This perceived shift in position was equivalent to the perceived step of the point when it was actually repositioned. The observer's task was to refixate the enclosed point when the flashed display reappeared and to report whether or not it had appeared to shift. If perceived position influences saccades, then, when the step of the point was induced, the refixation saccade should have brought the eye closer to its

perceived than to its actual position. This did not occur. These saccades, like those to the actually stepped point, were accurate and clearly controlled by either retinotopic or spatiotopic position information which, here, were indistinguishable.

The only evidence that perceived position might influence the programming of saccades came from a related experiment in the same series using a somewhat modified procedure. The observer's task was extended to include a saccade back to the original, remembered position of the point following the initial, refixation saccade. Surprisingly, these look-back saccades reflected the point's perceived induced step even though the prior refixation saccade did not. For example, if the induced step of the point was rightward (the surround actually displaced leftward), there was no initial saccade, since the point's position had not actually changed, but there was a leftward look-back saccade, the amplitude of which was consistent with the point's apparent step.

These results suggested that the influence of perceived position on saccades might be limited to occasions in which saccades were directed to remembered locations, although, unfortunately another explanation seemed equally likely. It seemed just as likely that these results were simply a consequence of the observer's understanding of the task as they were a consequence of the influence of perceived position on saccade programming. If, when asked to look-back, the observers interpreted this instruction to mean that they *had* to look-back, then they had no choice but to move their eyes to where the point would have been had it actually stepped. Otherwise why look back at all? Along the same lines, it was also possible to account for the look-back saccades by assuming that the observers wished to appear self-consistent. Since they had perceived the point to step and reported it, the look-back saccade could easily have seemed obligatory. In either case, these results did not provide unequivocal evidence of the effect of perceived position on saccades. To obtain such evidence additional experimentation was called for in

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†Spatiotopic in contrast to retinotopic coordinates define position in relation to the head and thus require both retinal and eye position information.

which the testing conditions, like those previously used, permitted the effect of perceived position to be evident, but at the same time ruled out alternative cognitive explanations. The experiment we now report attempted to satisfy these criteria simply by introducing a delay between the presentation of the apparently stepped target point and the signal to saccade. Now, if these delayed saccades bring the eye to the target's perceived position, whereas immediate, nondelayed saccades are directed to its actual position, this difference could not be attributed to the demand characteristics of the task and would therefore constitute more convincing evidence for the hypothesis. Such a result would suggest that the representation of retinotopic stimulus position is of short duration or of insufficient strength to supersede the perceptual representation of position in the delay condition.

EXPERIMENT

Method

The visual display was presented on a fast phosphor CRT (P15)* and consisted of a rectangular surround, 5° by 1° , delineated by 6 points which marked its corners and middle. This surround enclosed a target point which was initially centered within it. A fixation point was located 1° below the lower edge of the surround and 1.5° directly below the enclosed target. At the beginning of a trial the entire display was visible and the observer fixated the fixation stimulus. The target point and surround blanked for 500 msec following which the target and surround were flashed for 100 msec. A 1 kHz tone presented for 100 msec served as the signal to saccade. In the immediate (no delay) condition, the tone was synchronized with the onset of the flashed display. In the delay condition the tone sounded 500 msec after the onset of the flashed display (see Fig. 1). The fixation point disappeared with the onset of the tone. Eye movements were monitored by a Double Purkinje Image eye-tracker (Crane and Steele, 1978) and were recorded on a 4-channel polygraph for later analysis.

There were 3 display conditions. In the critical, induced displacement condition, the frame stepped 1° to the right or left and the target point was not displaced. This caused the target point to appear to step opposite the surround. There were 2 control conditions. In the stationary control condition both target point and frame were flashed in their initial positions. This permitted assessment of the accuracy of immediate and delayed saccades to a spatially and

perceptually stationary target. In the target displacement control condition, the target point stepped 1° to the left or right but the frame was not displaced, which permitted assessment of the accuracy of saccades to an actually displaced target when spatial and perceptual displacement were congruent. There were 16 trials in each of the display conditions, half of which involved a delay and half of which did not. In the 2 displacement conditions (in which either the frame or target point stepped) half of the trials involved leftward and half rightward displacement. The order of the trials followed a predetermined random sequence. The observer's task was to saccade from the fixation point upward to the position of the flashed target point when the tone occurred, and then to report whether the target had appeared to step, and its direction. If a step was reported, 2 light points, either widely separated or contiguous, appeared on the CRT. Using a potentiometer, the observer adjusted the distance between these points so that it matched the perceived amplitude of the target step.

Subjects. Sixteen observers with normal, uncorrected vision participated in the experiment.

Results

The psychophysical data indicate that the induction condition effectively produced an apparent step displacement of the target. In the immediate (no-delay) trials, the mean perceived step was $107.2'$ ($SE = 13.18'$) and in the delayed trials it was $90.2'$ ($SE = 13.15'$). The perceived step was always in the expected direction. These means did not differ significantly from those obtained in the target displacement control condition. In this condition, the immediate trials yielded a mean perceived target step of $94.56'$ ($SE = 12.05'$) and the delayed trials yielded a mean of $103.34'$ ($SE = 13.20'$). In both conditions there was an overestimation of stimulus displacement. No step displacement was reported in the stationary control condition.

Because the fixation stimulus was located below the target, any saccade to the target, whether to its actual or perceived position, involved a vertical component. However, since only the horizontal component of the saccade indicated whether the eye was directed to the target's perceived or actual position, only the analysis of the horizontal component of the saccades is reported. (The vertical component, however, served to establish that a saccade toward the target actually occurred.) Any saccade which occurred 600 msec or more after the onset of the flashed target was treated as delayed, whether or not it occurred in the delay condition. With very few exceptions, delayed saccades occurred in the delay condition and immediate saccades occurred in the immediate condition. The mean latency of all immediate saccades was 343 msec ($SD = 118$ msec); the mean latency of all delayed saccades was 899 msec ($SD = 183$ msec).

A summary of the eye movement data appears in

*A P15 phosphor has an extremely fast decay time (10% in 28 microsec; 0.1% in 50 microsec) and virtually eliminates visual afterglow. On inspection the phosphor manifests no sign of the relatively long term visible phosphorescence associated with somewhat slower phosphors such as P31 which are more typically used.

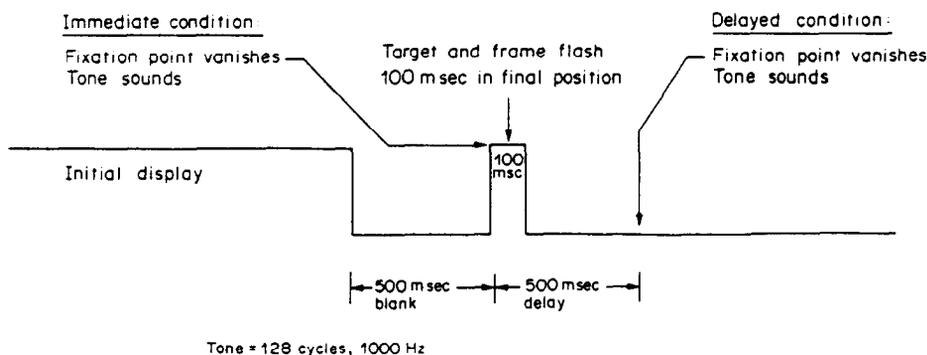


Fig. 1.

Fig. 2. The validity of the proposed hypothesis primarily rests on finding a difference between immediate and delayed saccades on induction trials and no difference between immediate and delayed saccades in the 2 control conditions. If perceived position influences saccades to remembered locations, then delayed saccades on induction trials should have a horizontal component which mirrors the apparent induced step of the target point, whereas immediate saccades should position the eye as accurately as the saccades in the stationary control condition. This, in fact, occurred. The mean horizontal amplitude of the immediate saccades on induction trials was 13' (SE = 3.5') and differed significantly ($P < 0.01$) from the mean amplitude of the delayed saccades which was 40' (SE = 6.4') in the direction of the induced target step. The possibility that this difference was simply a consequence of the delay between the presentation of the saccadic target and the signal to saccade is ruled out by the fact that there were no differences between immediate and delayed saccades in either of the 2 control conditions. As predicted there also was no difference between the immediate saccades in the induction condition and saccades in the stationary control condition. This prediction is, of course, based on the fact that the target point is unshifted in both these conditions. The immediate saccades in the induction condition positioned the eye accurately despite the misperception of target position.

A two way ANOVA of the eye movement data in which display condition and delay were the 2 main factors, confirmed this reading of the results. As expected, whether or not perceived position affected the programming of delayed saccades, the differences in display conditions significantly affected saccade amplitude [$F(30, 2) = 173.4, P < 0.001$]. This was expected because in one of the 3 conditions the target point actually stepped, and this ought to have had a predictable effect on saccade amplitude. More importantly for the hypothesis under consideration, introducing the delay between target presentation

and the signal to saccade significantly affected saccade size [$F(15, 1) = 8.33, P < 0.05$] which is expected if perceived position influences delayed saccades. Additional confirmation of the hypothesis is derived from the fact that the interaction between display condition and delay also proved significant [$F(30, 2) = 8.44, P < 0.001$], since this implies that the difference in saccade amplitude produced by the delay was a function of the display condition. This, too, is as it should be if perceived position influences delayed saccades, since only where perceived position differs from retinal or spatial position, as it does in the induction condition, can its impact become evident. Finally, the validity of the hypothesis is underscored by the results of *post hoc* comparisons of means.* As noted above, the only significant difference between immediate and delayed saccades occurred in the induction condition ($t = 26.4, P < 0.05$).

There is, however, an aspect of these results which is not consistent with the proposed hypothesis. This is the fact that the *post hoc* comparison of means also indicated that the amplitude of delayed saccades on induction trials was less than the amplitude of delayed saccades on target displacement trials [$t = 34.2,$

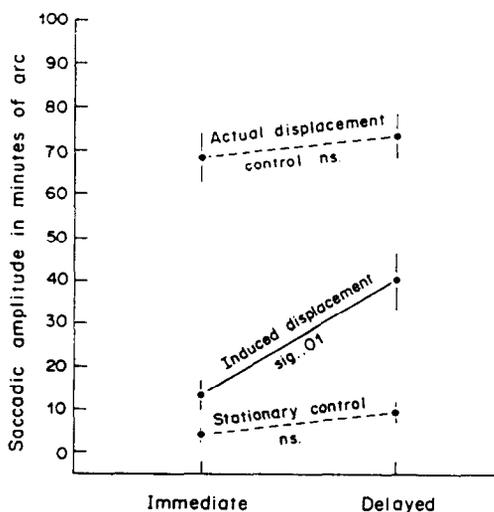


Fig. 2.

*Tukey ts were used to determine whether the differences between means were significant (Winer, 1971).

$P < 0.01$]. Had the perceived induced step been smaller than the perceived actual step of the target point, this would not have been a problem. However, the perceived steps were equivalent. Thus the fact that this difference nevertheless occurred, suggests that the actual position of the apparently stepped target may have continued to exert some influence over the programming, although another explanation has been suggested which also may account for this finding.*

The alternative account is based on 2 aspects of the results; on the fact that the mean amplitude of delayed saccades on the induction trials were less than anticipated, and on the fact that despite the apparent overestimation of the perceived target step in the target displacement condition, this perceived step enhancement did not influence the delayed saccades in that condition. This latter finding is explainable, if we assume that perceived position only influences delayed saccades when there has been a shift in "world frame". If this were so, and it was also the case that the eye movement system had information about this shift of the "frame",† then, since there is no frame shift in the target displacement condition, there is no reason to expect the memory for perceived position (based here on the overestimated target step) to affect these saccades.

This same reasoning can also account for the fact that the amplitude of delayed induction saccades was less than the amplitude of the induced step of the point. If, as was the case, the frame stepped 60' left or right on induction trials, and this step is registered at some level in the eye movement system, then this should cause a parallel reregistration of the position of the enclosed point. For example, if the frame shifts 60' left, then the re-registered position of the point also should be 60' left. Now since the perceived induced point step was approximately 100' to the right when the frame was stepped left, the delayed saccade should be directed 100' to the right of where the target was originally. But, since the original position of the point has been mistakenly reregistered as 60' to the left of current eye position, only a rightward saccade of 40' is called for and executed. Since the mean amplitude of the delayed saccades on induction trials was, in fact, 40' while the mean perceived step was 100', this explanation neatly accounts for this result.

Whether or not either of these explanations prove to be correct, the results do provide clear support for

the conclusion that perceived position, when discrepant with either retinal or spatial location, influences the programming of saccades when saccades are directed to remembered locations.

DISCUSSION

The finding that saccades to remembered positions are influenced by perception is consistent with what we know about the relation between perception and pursuit eye movements. That evidence also shows that perception, in this case perceived movement, governs pursuit only when the tracked target has no retinal counterparts (Mack *et al.*, 1981). The report that pursuit along a remembered motion path is determined by perceived rather than actual motion provides the closest analogy to the present results (Holtzman *et al.*, 1978).

These results are not only relevant to our understanding of oculomotor control. They also bear on recently proposed schema theories of perception (Hochberg, 1968; Neisser, 1978) and raise a more general question about the relation between perception and eye movement control. Their relevance to schema theories stems from the fact that these theories, which maintain that perception involves a process of schema development and testing, view eye movements as a primary vehicle for the testing and validation of schemas. According to these theories, the eyes are directed to some place in space which, if the schema is valid, will present some particular configuration. If this expectancy is confirmed, the eye may be sent to some other location for additional confirmation. If the expectancy is disconfirmed, the schema will be modified and the eye sent to a new location to seek confirmation. These schemas resemble cognitive maps. For example, according to Neisser, the schema, "represents the spatial arrangement of objects . . ." (p. 103) and "an anticipatory schema directs my looking from the first . . ." (p. 96). If these schema are perceptual constructs, then it would seem to follow that the eye movements initiated as tests of a schema would be directed to where things "appear" to be. Since the evidence now indicates that the capacity of perception or a perceptual map to govern eye movements is extremely limited, this aspect of the theory appears to be in need of further clarification.

Finally, these results raise a more general question.‡ If we assume, as most people do, that what we choose to look at is usually a function of what we perceive to be present in our environment and our interest in it, then it would seem to follow that the commands which initiate most eye movements must originate at the level of perception. Since it now appears that eye movements are only very rarely programmed in terms of perceptually defined position or motion, we must assume that somewhere between the perceptual initiation of the eye movement and its programming by the oculomotor system there is a transformation of the perceptually localized

*This explanation was suggested by Dr William Needham, one of the reviewers of the original version of this paper. We wish to express our gratitude to him for what we think is an ingenious explanation.

†This would mean that a saccade, for example, to the lower corner of the frame would be accurate even after the frame had displaced.

‡We are grateful to Hal Sedgwick for pointing out this problem.

target into spatial or retinal coordinates. Since at least the retinal coordinate information is present at an early stage of visual processing, it is as if there was a retranslation back into this coordinate system from a higher level one. We realize that this is highly speculative, but nevertheless that perception plays a minimal role in eye movement programming does create a problem for our understanding of the relation between perceiving and eye movements.

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