Eye and Head Movements in Peripheral Vision: Nature of Compensatory Eye Movements

Abstract. *Simultaneous recordings of both eye and head movements in response to a peripheral signal indicated that the backward compensatory eye movement was initiated during the constant velocity of the head rotation. This compensatory movement began before the eyes had actually reached the peripheral signal.*

When a peripheral visual stimulus is located too far from our central field of vision, head rotation, as well as eye movement, is necessary for fixating the stimulus. Previous investigators have shown that the eyes begin to move first, followed by the rotation of the head. The eyes, moving with greater velocity, reach the signal first and then begin a backward movement with respect to the head to compensate for the continuing head rotation (*1*). The response is completed when the eyes are oriented directly toward the stimulus. However, measurements taken in our laboratory appear to show that the backward compensatory movement of the eyes is initiated prior to their reaching the peripheral stimulus, and that little information regarding the nature of the stimulus is available until the eyes are oriented directly toward the stimulus.

The subjects were three undergraduate men enrolled at Concordia College. An opthalmological examination showed them to be free of pertinent visual defects.

The peripheral stimuli were arranged in a horizontal semicircle 1.83 m from the subject and at eye level. The stimuli were Nixie Numerical Indicator tubes located at 55°, 40°, 20°, 10°, and 5° right and left, with a fixation light at 0°. The numerals in each tube subtended a visual angle of 14′, insuring a foveal image. Four of the numerals (4, 5, 6, and 9) were chosen as the stimuli to be identified by the subject.

Table 1. Extent of head and eye movements, at final resting position, for peripheral stimuli, and number of head movements. Values for the movements are means and standard deviations.

Stimulus position	Movements (deg) Head	Eyes	Combined	No. of head movements
Left 55°	19.4	35.2	54.6	64
	5.5	6.9		
Left 40°	7.3	33.0	40.3	48
	4.5	6.7		
Right 40°	6.5	34.6	41.1	50
	4.3	5.5		
Right 55°	16.5	38.4	54.9	61
	4.8	5.5		

Eye movements were recorded by an electrical method (*2*) with electroencephalographic electrodes taped behind the external canthi of each eye. The resultant signal was amplified and displayed as the upper trace on a dual-channel oscilloscope. The lower trace was the input from a potentiometer circuit which recorded head rotation. A lightweight epoxy skullcap was constructed for each subject and a flexible cable from a hub of this cap at the center of rotation of the head was connected to a sensitive potentiometer. The system had a minimum of friction, and subjects reported that it did not interfere with their normal head movements.

After 19 days of training in making responses, the experimental trials began. The start of each trial began with a verbal ready signal and the onset of the fixation light. After 1, 2, or 3 seconds, one of the numerals in one of the Nixie tubes came on and the subject moved his head and eyes away from the fixation light to the peripheral signal and verbalized the numeral into a throat microphone.

Each subject made 120 responses per day, in three blocks of 40 trials each. Each block contained all combinations of position and indicator numeral, and the combinations were randomized throughout each block. Because of the time required to operate the oscilloscope camera, only 10 to 12 of the 120 responses were recorded each day. These were picked at random from the list of combinations. A total of 548 records was made for the three subjects.

Each record was analyzed for a number of separate components in both eye and head movements. A copy of a typical record is shown in Fig. 1. The components in the *eye movement* were: L, latency, or the time (in hundredths of a second) before the eyes began moving; P, angular rotation of the eyes to peak of their movement (in degrees); F, angular rotation of the eyes to the final resting position in degrees). The components in the *head movement* were: L, latency (in hundredths of a second); PH, partial head rotation (in degrees), or the angle of head movement present when the eye movement had reached its peak; HM, total head rotation (in degrees).

Very few head movements were made to stimuli at less than 40°, so only responses to stimuli at 40° and 55° were analyzed. The number of head movements for the 40° positions was less than for the 55° positions, since occasionally the subject did not move his head for the 40° stimuli, but moved his eyes only.

Table 2. Extent of eye movements at peak (before compensatory eye movements) and of partial head movements at the same moment. Values for the movements are means and standard deviations.

Stimulus position	Movements (deg) Head (partial)	Eyes (at peak)	Combined	No. of head movements
Left 55°	9.7	41.8	51.5	64
	3.0	4.5	3.5	
Left 40°	2.3	35.8	38.1	48
	1.4	4.6	4.0	
Right 40°	2.0	36.4	38.4	50
	1.3	4.0	3.7	
Right 55°	9.2	43.0	52.2	61
	2.3	4.5	4.3	

Table 1 shows the components of the head and eye movements in the peripheral reaction. The extent of the eye movement shown is the value of F in Fig. 1, that is, the final extent of the eye movement. The extent of head movement is the value of HM in Fig.

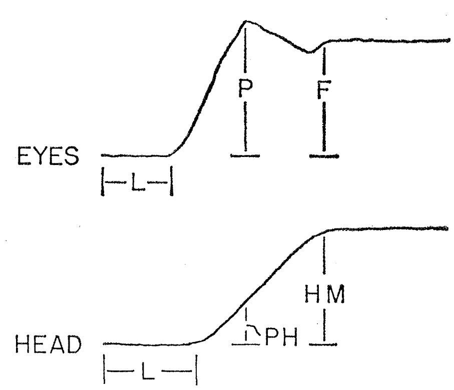

Fig. 1. Tracing of eye and head movements (full trace = 1.0 second). For meaning of the letters designating the components of the movements, see the text. The onset of a peripheral simulus is at extreme left. After a latency period the eyes begin to move toward the stimulus while the head remains stationary. The eyes achieve constant velocity as the head begins to move. By the time the head reaches constant velocity, the eyes have already begun to slow down and reach their maximum rotation while the head still moves at constant velocity. The eyes then compensate in a backward direction (with respect to the head) as the head begins to slow down. During this deceleration of the head, the eyes again rotate in the same direction as the head, and both eyes and head stop at about the same time.

1. The combined head and eye movements together were very nearly equal to the angle of the stimulus position, as would be expected, within the limits of accuracy of the recording system (*3*).

The results of Table 2 show the angular rotation of the combined PH and P of Fig. 1. The P value is the extent of eye movement from center fixation to the maximum excursion of the eyes prior to the backward compensatory movement. The PH value, or partial head movement, is the extent of rotation of the head at the time when the eye movement reaches its maximum. As can be seen, the combined eye and head movement fell considerably short of the stimulus angle. The differences between the actual combined movement and the display angle were significant beyond the .01 level, indicating that the eyes began their compensatory backward movement *before* they had reached the stimulus. This result is in disagreement with earlier studies (*1*).

A possible explanation for this finding would be that the initiation of the compensatory movement is provided by extra-foveal stimulation rather than foveal stimulation. In other words the eye would begin its compensatory movement when the peripheral signal came into the field of view on the retina, and would not require the signal to be represented on the fovea. The compensatory eye movements would be directed by the location of the stimulus, and would not necessarily involve an identification of the stimulus.

This hypothesis seems a possibility in light of some incidental observations made after the close of the experimental sessions. In this pilot study a decade interval timer was used to turn off the peripheral stimulus shortly after the eyes had reached the peak of their rotation. In no case was the subject able to identify the numeral in the indicator tube when the stimulus was turned off shortly after the compensatory movement began. In many cases identification was possible only when the stimulus was kept on until both eye and head movement had almost ceased. If the compensatory eye movements were initiated by foveal representation of the peripheral stimulus, it would seem that the purpose of the compensation would be to keep the peripheral stimulus foveally fixated. If such were the case, identification of the numeral should be possible during the compensatory backward movement.

The results of Table 2 would predict that eye movements would miss a foveal fixation by an increasing amount as the display angle increases. In a recent study (*4*) it was shown that proportionately more undershoots were made in a manual tracking task as the extent of movements required was increased. This result was confirmed for eye movements (*5*), and would support a hypothesis that the backward compensatory eye movement begins before foveal fixation and that the discrepancy between actual eye movement and the display angle is a function of the display angle.

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References and Notes

1. R. S. Woodworth and H. Schlosberg, *Experimental Psychology* (Holt, Rinehart and Winston, New York, 1954), p. 519; A. F. Sanders, *The Selective Process in the Functional Visual Field* (Institute for Perception RVO-TNO, Soesterberg, Netherlands, 1963), p. 62.
2. A. Ford and J. L. Leonard, *Navy Electronics Laboratory Report 839*, (1958); A. Bartz, *J. Exp. Psychol.* **64**, 318 (1962).
3. Since the eyes and head rotate about a different axis, the combined eye and head movements will not be equal to the display angle. The sum of their rotations, measured separately, is slightly less than the display angle. However, the difference was almost negligible in the present study, with the 55° stimulus showing a difference of less than 0.5°.
4. D. Trumbo, M. Noble, K. Cross, L. Ulrich, *J. Exp. Psychol.* **70**, 252 (1965).
5. A. Bartz, in preparation.
6. Supported in part by the USPHS, grant AC 00165. I thank Louis Banderet, Roy Welsandt, and Carol Dahl for technical assistance.

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Pesticide Residues in Total-Diet Samples: Bromine Content

Heywood's comments (3 June, p. 1408) in reference to the bromide and arsenic levels given in our report [R. E. Duggan, H. C. Barry, L. Y. Johnson, "Pesticide residues in the total-diet samples," *Science* **151**, 101 (7 Jan. 1966)] are quite appropriate. We did not mean to imply that the bromide or arsenic levels found were solely due to pesticides containing these elements. The qualifying statement in the report that the values were total bromide and arsenic was intended to draw attention to the natural content. Our Table 1 indicates the number of residues exceeding 25 parts per million. Pharmacologists have expressed interest in the total amount of bromides ingested from food since current petitions for bromide tolerances are under consideration. Although bromide tolerances range as high as 400 ppm, in our opinion bromide values exceeding 25 ppm in any composite warrant further investigation to determine the source, particularly if sustained increases are observed.

We appreciate Heywood's clarifying statement and hope our exchange has presented a clearer picture of the meaning to be derived from the bromide and arsenic values presented.

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Experimental Pain

Beecher has pointed out that experimentally induced pain differs from clinical pain in that the affective tone (anxiety) associated with the latter is missing in the former (*1*). He describes a method (*2*) of inducing this anxiety by using a tourniquet to produce sustained pain, and reports that the method is effective for laboratory tests of analgesics, whereas threshold pain produced by heat is not.

Hill found (*3*) that when subjects had no control over the pain stimulus they reported more severe pain than when they could turn the stimulus on or off at will. We have extended Hill's results to the measurement of pain thresholds (*4*). Our data indicate that pain thresholds for radiant heat are significantly lower when control of the stimulus is taken from the subject. The method is easier to use and less time-consuming than Beecher's tourniquet.

In at least two studies (*5*) in which the effect of analgesics could not be distinguished from placebo effects on radiant-heat pain, the subjects had control of the pain stimulus. We conclude that anxiety associated with lack of stimulus control is an important variable in experimentation on pain.

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References

1. H. K. Beecher, *The Measurement of Subjective Responses* (Oxford Univ. Press, New York, 1959).
2. ——, *Science* **151**, 840 (1966).
3. R. Melzak, *Sci. Amer.* **204**, 41 (1961).
4. R. Lepanto, W. Moroney, R. Zenhausern, *Psychonomic Sci.* **3**, 475 (1965).
5. J. Fangman, thesis, Fordham Univ. (1963); D. Sweeny, thesis, Fordham Univ. (1962).

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