Reprinted from the Archives of Neurology
November 1972, Volume 27

Hemispheric Control of Eye Movements

II. Quantitative Analysis of Smooth Pursuit in a Hemispherectomy Patient

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The quantitative analysis of the smooth pursuit eye movements in a patient who had a left hemispherectomy 11 years previously showed that although the remaining right hemisphere could generate normal pursuit to the right, leftward pursuit was always slower than the target velocity and required corrective saccades. The number of saccades was greatest at lower target speeds and decreased at higher target speeds but the average amplitude of saccades increased monotonically with target velocity. The proportion of the pursuit attempt accomplished by saccades was always about 80%, and the velocity gain of the pursuit system was 0.24 to 0.34.
(27:449-452, 1972)

We are presenting an investigation of the smooth pursuit eye movements in a patient who had a left hemispherectomy 11 years previously and whose saccadic eye movements are reported in the preceding paper.[1] Saccadic and smooth pursuit eye movements have different physiological, control system, and clinical characteristics and should be regarded as emanating from separate eye movement systems.[2,3] Saccades are under voluntary control and serve to bring peripherally placed objects into our central field for foveal scrutiny. Smooth pursuit eye movements maintain foveal fixation on moving targets with speeds up to 30° to 50°/sec. Under ordinary circumstances, a target motion is required to elicit smooth pursuit; without such a stimulus, subjects attempting to move their eyes smoothly actually generate a series of small saccades.[4] Unique situations may allow smooth pursuit with proprioceptive or after-image techniques,[5,6] but smooth pursuit of imagined targets is controversial.[7] Unlike the saccadic system, the smooth pursuit control system appears to be "continuous" in nature[8]; and whereas the primary stimuli necessary to evoke saccades are volition or an eccentric target position, the situation with smooth pursuit is more complex. Target position, target velocity, and retinal slip velocity have all been

Accepted for publication June 16, 1972.

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Characteristics of Leftward Pursuit								
Target Velocity (degrees per second)	5	10	15	20	25	30	40	50
Average No. of Saccades	11 ± 1.4 standard deviation (SD)	7 ± 1.7	5.7 ± 1.7	4.7 ± 1.3	4.2 ± 0.5	3.9 ± 0.7	2.8 ± 0.4	2.7 ± 0.5
Average Saccade Amplitude (degrees)	2.1 ± 0.7	3.2 ± 1.0	4.1 ± 1.9	5.1 ± 2.0	5.8 ± 2.5	5.9 ± 1.9	8.8 ± 2.5	8.8 ± 3.0
% $\overline{m}$S*	77.5	75.4	78.4	78.6	82.2	76.3	81.7	77.9
Average Velocity of Pursuit (degrees per second)	1.2 ± 0.03	2.8 ± 0.8	3.7 ± 2.2	6.3 ± 2.5	8.1 ± 6.6	9.4 ± 3.8	10.2 ± 1.8	16.9 ± 2.1
Velocity Gain	0.24	0.28	0.25	0.32	0.32	0.31	0.26	0.34

* The average percentage of movement accomplished by saccades, % $\overline{m}$S = 78.5 ± 2.4.

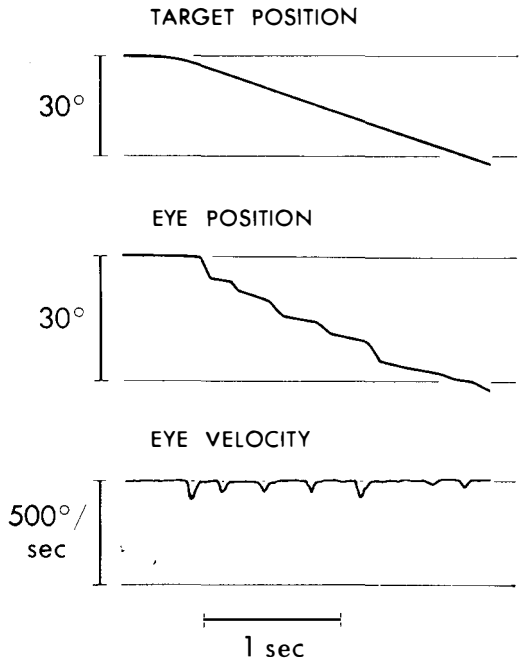
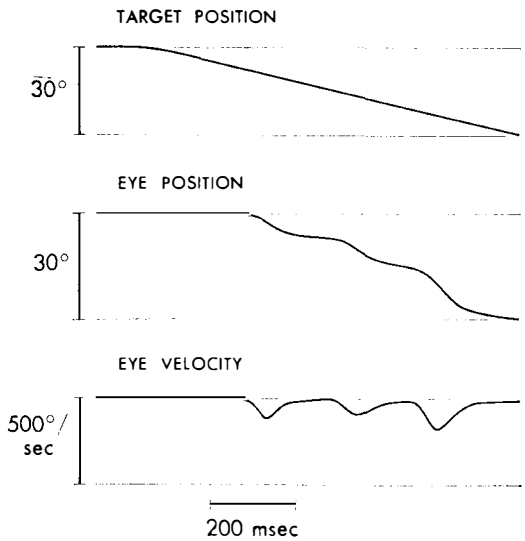


Fig 1.—Leftward pursuit of 15°/sec target, showing multiple small saccades, despite encouragement.

related to the generation of smooth pursuit movements,[9] but none of these alone is adequate. All the cited stimuli, in addition to efferent information concerning eye position or velocity probably are utilized.[10]

The exact anatomical substrate subserving smooth pursuit eye movements is unknown. These eye movements have not been produced by cortical stimulation in experimental animals nor have discrete lesions resulted in their abolition. Based upon clinical-pathological correlation and established pathways, Daroff and Hoyt[11] proposed an operational anatomical schema for the pursuit system incorporating occipitocollicular and tectotegmental connections.

Fig 2.—Leftward pursuit of 40°/sec target, showing two large amplitude saccades following initial saccade.



Report of a Case and Method

The subject was the same 29-year-old man reported in our previous paper.[1] These experiments were performed in separate recording sessions when the patient was well-rested. We used the relatively noise-free infrared recording technique and the tracking target was a 1 cm light spot subtending a visual angle of 0.5° when projected on a translucent screen viewed by the subject, who was 44 inches behind the screen. A custom-designed apparatus projected the target which moved at constant velocities in either leftward or rightward directions. We used ramps of 5°, 10°, 15°, 20°, 25°, 30°, 40°, and 50° per second and recorded both target and eye movements on an oscillograph.

The subject viewed the stationary light in the center of the screen and was instructed to keep his eyes fixed on the light. Constant velocity ramps moved through visual angles of 40° to 60° right and left, and then returned to central position. An analysis of the intial 30° of pursuit attempt was made.

Results

The subject smoothly tracked ramps moving to his right, without the interspersion of small saccades, at velocities from 5° to 50°/sec. For velocities greater than 30°/sec, he made saccade-free ramps only if encouraged verbally. We interpreted his rightward pursuit function as "normal."

Leftward pursuit was characterized by frequent saccadic interruption (Table). The number of saccades was greatest with slower target velocities and decreased at higher velocities (Fig 1 and 2). Conversely, the amplitude of the saccades increased with faster target speeds (Fig 2). The percentage of the actual movement accomplished by the small saccades, exclusive of the initial onset saccade, (abbreviated with the symbol %mS) was calculated by the following formula:

%mS = average number of saccades × average amplitude of saccades/30 × 100.

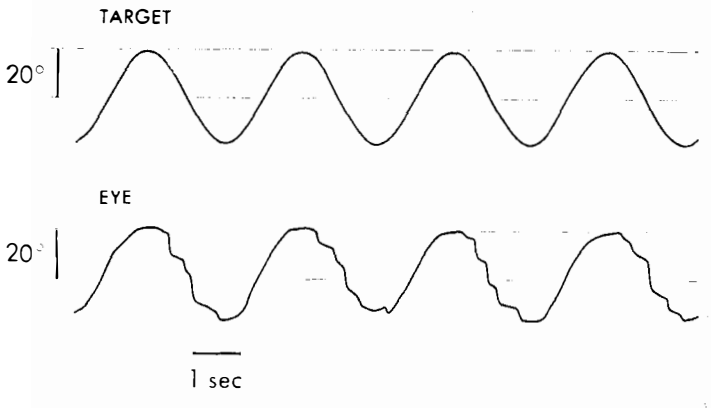


Fig 3.—Pursuit of sinusoidal target at 0.3 cycles per second, showing smooth rightward pursuit and saccadic leftward pursuit.

We showed that the saccadic:pursuit amplitude ratio was virtually independent of target speed. An average (abbreviated %mS) of 78.5% of all leftward movements was accomplished by saccades and the remainder by smooth pursuit movements.

If one assumes, as a first order approximation, that the saccadic corrective movements occupy a negligible proportion of ramp time, the pursuit duration is equal to the ramp duration. The ratio of pursuit to ramp amplitude then approximates the ratio of pursuit to ramp velocity, the average velocity gain of the system. We determined a more accurate value for the gain by subtracting the saccadic time from the duration of the ramp, and using the resulting pursuit time to calculate the average velocity and velocity gain (Table).

Since we were measuring ramps of 30° amplitude, the sensitivity of our recording system was not sufficient for accurate analysis of saccades less than 1°. We recognize that fixation microsaccades may be present normally during pursuit.[12] Although not included in this analysis, pursuit of a sinusoidal target also showed smooth pursuit to the right and saccadic pursuit to the left (Fig 3).

Comment

Smooth pursuit eye movements are extremely vulnerable to central nervous system dysfunction and are frequently disturbed clinically.[11] The characteristic abnormality is the appearance of small step-like saccades termed "cogwheel" or "saccadic" pursuit. This occurs during fatigue, inattention, under the influence of drugs, as well as in parkinsonism and diffuse cerebral, cerebellar, and brainstem disease.[13-16] When bilateral, these defects are obviously of no localizing value to the clinician. Unilateral saccadic pursuit is most commonly associated with an ipsilateral posterior hemispheric lesion.[17,18] The fact that the pursuit abnormality is ipsilateral to the diseased posterior hemisphere prompted Mowrer[19] and later others[11] to deduce that each hemisphere mediates smooth pursuit to the ipsilateral side. This speculation is not readily verified experimentally in normal subjects and alternative explanations have been proposed.[17,20]

The only previous study of ocular tracking in hemispherectomy patients disclosed the expected saccadic pursuit abnormality ipsilateral to the removed hemisphere,[20] but quantitative data was not obtained. Our patient with a left hemispherectomy exhibited normal smooth pursuit eye movements while tracking objects moving to the right, into his blind (hemianopic) field. One might anticipate that tracking into a hemianopic field would be best accomplished by keeping the eye "ahead" of the target, thus maintaining it in the "seeing" hemiretina and field. Analysis of the recordings, however, indicated that his eyes never preceded the target. An initial saccade is a constant feature of ramp tracking and is required to correct the target-fovea position error produced during the latency between target movement and actual eye movement. The amplitudes of the initial saccades were always appropriate to the error in our patient and never overshot. The occasional corrective saccades during rightward tracking were always to the right, indicating that the eye lagged behind, rather than ahead of the target. At the onset of

target movement to the right across the small area of "seeing" fovea, the subject must have gained sufficient information about target velocity and the accurate initial saccade was based on the correctly estimated target position. During subsequent pursuit, all or part of the target image must lie on the seeing hemiretina. If eye velocity was too slow, due to inattention, the target would fall into the blind field. Again, based on previous information of eye and target velocity, the subject was able to estimate the error, make the proper corrective saccade, and thereby resume tracking.

Smooth pursuit velocities *to the left*, were always less than that of the target. Normally, subjects can match smooth pursuit velocity to target velocity in ramp tracking, establishing a smooth pursuit velocity gain (output/input) of unity for this task. The output saturates at approximately 40°/sec and the gain, therefore, drops. At very high velocities, the pursuit system is no longer operable and tracking functions are performed entirely by saccades. Even within the usual velocity limits of the system, the output may vary in normals depending upon the state of concentration and attentiveness to the task of target tracking. Inattention results in decreased pursuit velocity, the appearance of "catch-up" corrective saccades, and an apparent reduction in the gain of the system. This variability renders the system difficult to analyze and necessitates, for quantitative determinations, that only the best or maximum output be measured. Subjects must be encouraged to attend to the task of tracking in order to obtain saccade-free recordings. Such was often the case with rightward pursuit movements in our patient, particularly at fast speeds. However, the patient was absolutely unable to sustain continuous smooth pursuit to the left, despite strong encouragement, and his leftward pursuit system exhibited a gain of approximately 0.24 to 0.34.

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