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THE SMALLEST VOLUNTARY SACCADE: IMPLICATIONS FOR FIXATION[1]

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SACCADES are not required: (1) to keep the line of sight on a fixation target (NACHMIAS, 1959; FIORENTINI and ERCOLES, 1966; STEINMAN, CUNITZ, TIMBERLAKE and HERMAN, 1967; FILIN and MIZINOVA, 1969; MATIN, 1969) or (2) to keep the target visible when its retinal image is stabilized (GERRITS and VENDRIK, 1970, 1972; ALPERN, 1972). Why, then, does a subject make saccades when he is asked to maintain fixation?

STEINMAN *et al.* (1967) suggested that the tiny saccades made during maintained fixation serve the same function as the large saccades used to scan the visual array. During maintained fixation, the subject scans a small region near the fixation target. During ordinary visual search, he also scans, using larger saccades to shift his line of sight to whatever detail in his visual field captures his momentary interest. This speculation is gaining acceptance (ALPERN, 1972). It is in agreement with the findings of: (1) ZUBER, STARK and COOK (1965) who showed that small fixation and large scanning saccades have similar velocity–amplitude characteristics; (2) with the findings of CUNITZ and STEINMAN (1969) who showed that the maximum average saccade rate during fixation and reading are the same, and also that microsaccades very rarely occur during reading pauses, and (3) with the findings of TIMBERLAKE, WYMAN, SKAVENSKI and STEINMAN (1972), WYMAN and STEINMAN (1971) and WYMAN (1972) who showed that position errors produced by target steps as small as 3·4 min arc can be reduced by small voluntary saccades. These findings suggest that small fixation and large scanning saccades differ only in size: all saccades are provoked and controlled by a single high velocity oculomotor system.

But, it is important to show that subjects are able to make voluntary saccades in the presence of a *stationary* target that are as small as fixation saccades before it is plausible to suggest that fixation saccades can serve a scanning function. This paper shows that they can.

RECORDING METHOD

Horizontal and vertical eye movements were recorded by means of a two-dimensional contact lens optical lever. A narrow beam of collimated light from an attenuated HeNe laser (0·15 mW at the detector) falls on a plane first surface mirror attached by a stalk to a tightly fitting molded scleral contact lens held by suction (30–100 mm of mercury) on the right eye. The mirror is oriented to be normal to the visual axis, permitting horizontal and vertical rotations to be recorded free from contamination by torsions of the eye. The plane mirror eliminates contamination by translations of the head. The collimated light, after reflection from the contact lens mirror, falls on the surface of a photoresistive photodetector, which gives an indication of the total radiant flux received, and simultaneously gives two-dimensional indications of the position of the laser spot on the detector surface. The detector is a Schottky barrier silicon photodiode made by United Detector Technology (UDT) (PIN-SC/25). It differs from the more familiar four quadrant type in that there is no gap between the quadrants. This proprietary UDT device gives analogue electrical signals that correspond to the position of a light beam falling on the 10 cm^2 sensitive area. A separate intensity signal is also provided, which was used to compensate, automatically, for fluctuations in total light. In the familiar 4 separate quadrant detector type, when an input light beam is all in one quadrant, no position information is

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available except that the beam is somewhere in the quadrant. In the UDT optical tracking indicator, a continuous analogue signal is generated that gives the location of the incident beam no matter where it is on the active area. Its position sensitivity is 0·2 μA/mW per 0·025 mm. The spot size can be any diameter since the transducer detects the centroid of the incident radiation beam. The detector's linearity is better than 5 per cent (our calibrations). Non-linearities are completely reproducible and were corrected to better than 1 per cent statistically.

The recording limits were 1·0° arc on each meridian with the optical lever length used, permitting resolution of eye position to about 3″ arc. Eye movement calibration curves were made for each subject by recording average eye position during 10 sec periods of fixation of 16 equally spaced targets located within a 1·0° arc field (8 on the horizontal and 8 on the vertical meridians). These calibrations were confirmed with a modified sextant placed in the approximate position of the subject's right eye. The 2 voltages, for horizontal and vertical deflection, were each recorded in 2 ways: (1) continuously on a strip chart (Bandpass 0–2 kHz) and (2) digitally from samples taken periodically. Before digital conversion (by Vidar IDVM) the 2 voltages were averaged by RC integrators. Sampling periods and RC time-constants were selected according to experimental needs. A special circuit for each integrator permitted its output to be set equal to its input immediately at the start of an averaging period (instead of being left at some previous value) to save the time that might otherwise be required to approach a new average value. Analogue and digital signals were recorded on a Honeywell 1508 Visicorder-Visiprinter.

The fixation target was a sharply focused oscilloscope point (1·6 log units above absolute foveal threshold) located 2·04 m directly in front of the right eye of the subject. At this distance the target subtended less than 2′ arc at the eye. The left eye was covered and closed, and the head was stabilized by a dental acrylic bite board.

Two contact lens subjects (the authors) participated in the various experiments. One (RS) was highly experienced, and the other (GH), comparatively inexperienced with fixating a target. Both were emmetropic once the contact lenses were in place.

EXPERIMENTS

Experiment 1. Voluntary saccades can be as small as fixation saccades

The subject was asked to make his smallest possible voluntary saccade while looking at a target that remained stationary throughout the trial. A saccade was considered voluntary if it was made in a specified direction at a signalled time. Voluntary saccades, so defined, can be easily studied in our laboratory because we can suppress all other saccades and only make the required response.

Before each trial, the experimenter told the subject the direction (up, down, right or left) in which to make the smallest possible saccade. The subject started the 3 sec trial whenever he felt ready and used slow control exclusively to hold his eye in place. An auditory tone (1 sec after the trial began) signalled when the small voluntary saccade should be made. After each trial, the experimenter informally described the subject's performance to him (e.g. "a bit big", "great"). Eye position on the significant meridian was recorded in both analogue and digital form. Recording was only done on the significant ("voluntary") meridian in order to insure that eye position would be sampled frequently enough to accurately measure the size of saccades and size of the visual error present at the beginning of each saccade. This strategy was justified by a preliminary experiment in which eye position was recorded on both meridians with alternating digital outputs, permitting comparison of the size of the voluntary saccade vector on the non-voluntary meridian to the size of the vector on the voluntary meridian. This experiment was recorded at a paper speed sufficient to allow the maximum possible number of digital samples each second (5 cm/sec with 12 digit samples written each sec). Figure 1 shows RS making a voluntary saccade when eye position was recorded on both meridians. Notice that the saccadic component on the non-voluntary meridian is smaller than the component on the voluntary meridian. We made 68 high speed two-dimensional recordings for each subject (17 voluntary saccades in each of 4 directions) and found that the non-voluntary component was, on the average, 33 per cent as large as the voluntary component for GH and 38 per cent for RS.

In the first experiment the analogue record showed only the "significant" meridian as did the digital record which averaged eye position during the first second of the trial by means of a specially designed RC integrator. We assume (as Cornsweet and others have done) that the average eye position is the "preferred fixation position" in which the line of sight falls directly on the target. The integrator was taken out when the auditory signal was given to make the small voluntary saccade, and momentary eye position samples ($16\frac{2}{3}$ msec averages) were written in digital form at the rate of 6/sec for the remaining 2 sec of the trial. These momentary samples gave indications of eye position near the beginning of the saccade

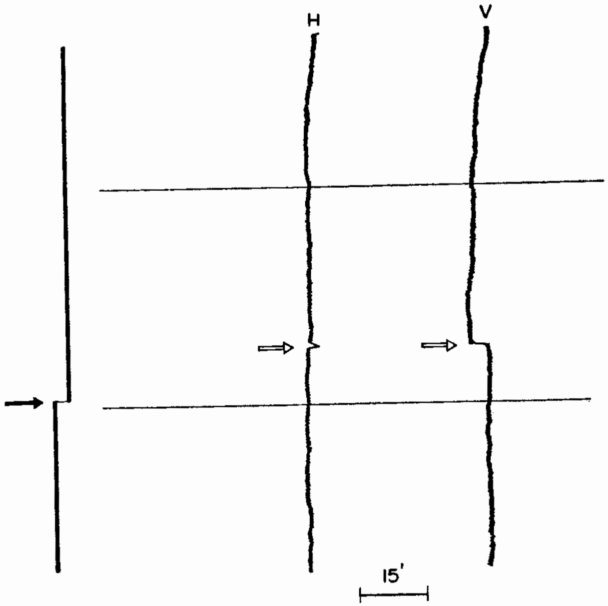


FIG. 1. Sample two-dimensional record of subject RS making his "smallest voluntary saccade up" when the target remained visible. The trial starts at the bottom of the record. The filled black arrow at the left indicates when the signal to make the saccade was given. The faint open arrow near the vertical (V) eye trace points to the significant (voluntary) component of the saccade. The faint open arrow near the horizontal (H) eye trace points to the saccadic component on the other meridian. Repetitive horizontal lines indicate 1-sec time intervals and the black bar at the bottom of the eye position trace shows 15′ arc.

and immediately following the saccade, allowing computation of the size and direction of the voluntary saccade and visual error at saccade-onset. This latter computation was used to determine whether the subject looked away from or towards his preferred fixation position when he made his small saccade in the specified direction. Voluntary saccade latency (time from the auditory signal until the beginning of the saccade) was also written in digital form at the end of each record.

Results

Saccades were always in the direction specified by the experimenter and their mean latency was 270 msec (S.D. = 133) for GH and 195 msec (S.D. = 93) for RS. The saccades were not only always in the appropriate direction; they were also made a reasonable reaction time after the signal. We, therefore, accept them as voluntary responses. These voluntary saccades were small. GH's mean voluntary saccade was 5·6′ arc (S.D. = 2·3) and RS's was 5·7′ arc (S.D. = 3·1). These means and standard deviations fall well within the range of "involuntary fixation" saccades described by many prior investigators [see DITCHBURN and FOLEY-FISHER (1966) for a compilation of fixation patterns of 30 contact-lens eye-movement subjects in 14 different experiments and see LÉVY-SCHOEN (1969) for comparisons of saccade latencies under different conditions]. Mean voluntary saccade sizes in each of the 4 directions are summarized in Table 1 and representative records of small voluntary saccades are shown in Figs. 2 and 3.

TABLE 1. ALGEBRAIC MEAN SIZE (′ arc) OF VOLUNTARY SACCADES AND VISUAL ERRORS AT SACCADE ONSET FOR SUBJECTS GH AND RS IN THE FOUR INSTRUCTED DIRECTIONS WHEN THE TARGET WAS VISIBLE

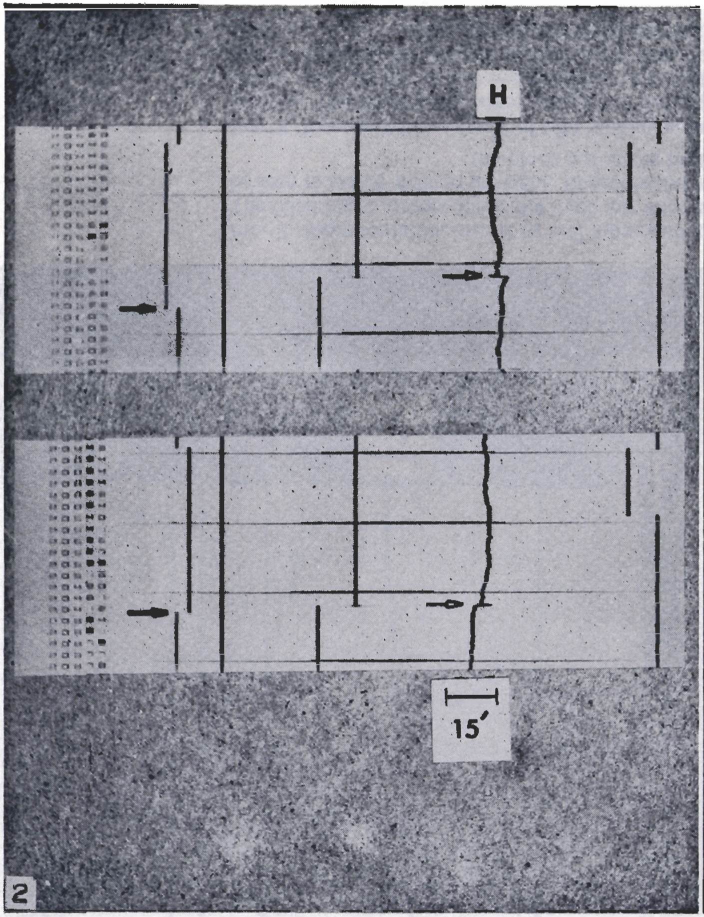
Instruction[1]	Saccade size	Visual error[2]
GH		
Up (30)	4·8 (2·5)	0·4 (1·2)
Down (39)	6·0 (3·3)	0·3 (2·0)
Left (50)	6·0 (1·5)	−0·8 (1·8)
Right (33)	5·5 (1·6)	−0·9 (3·0)
RS		
Up (28)	6·9 (2·8)	0·4 (1·9)
Down (33)	4·4 (2·6)	−0·1 (1·5)
Left (30)	5·9 (2·8)	−1·1 (2·3)
Right (31)	5·8 (3·6)	0·9 (2·3)

[1] Saccades *always* occurred in the same direction as the instruction.

[2] Minus signs indicate that the algebraic mean visual error was opposite in direction to the saccade. No sign indicates visual error was in the same direction as the saccade.

The number of trials is given in parentheses after each instruction and standard deviations are given in parentheses after the means.

Voluntary saccades created, rather than reduced, visual errors (the distance of the line of sight from the preferred foveal fixation locus was larger after a saccade than before the saccade). On the average, the eye was very near (< 1·2′ arc) its preferred fixation position when the saccade began, and much farther away (> 4′ arc) after the saccade. Moreover, the mean visual error present at saccade-onset was not systematically opposite in direction to the subsequent saccade. This means that saccades did not simply overshoot the target in an attempt to reduce fixation errors. For example, when GH was asked to go *up*, she was already looking, on the average, 0·4 min arc *above* her preferred on-target position. Her average visual error at saccade-onset was in the same direction as her average saccade. Her average saccade *increased* visual error markedly. Saccades also increased visual errors when GH made her voluntary saccade to the *left*, the condition in which the saccade was *towards* the preferred fixation position. In this condition GH was looking, on the average, only 0·8′ arc to the right of her preferred position at saccade-onset. Her saccade was in the direction that would correct the existing visual error, but it overshot the preferred fixation



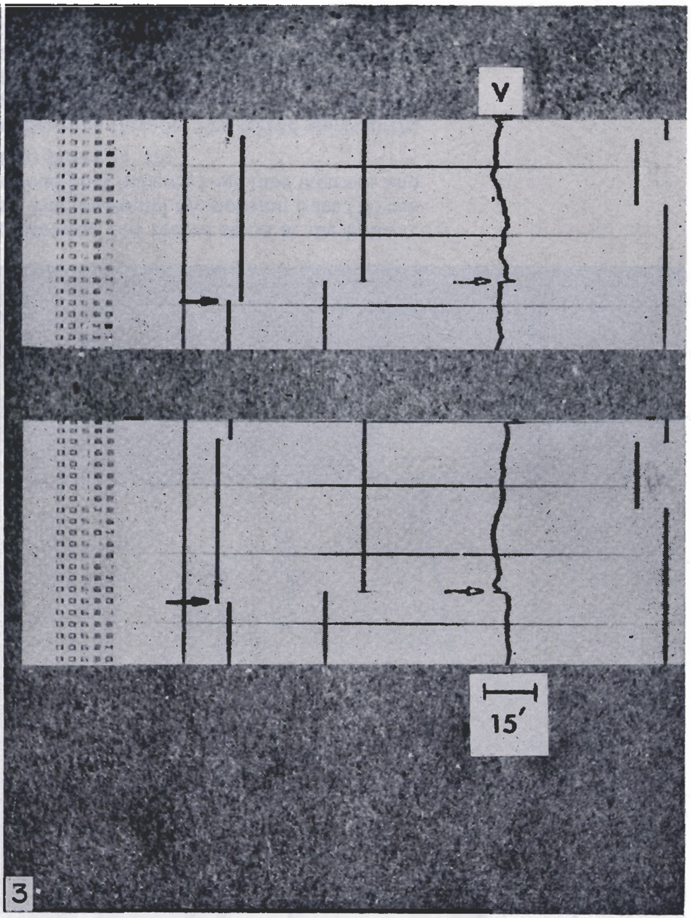
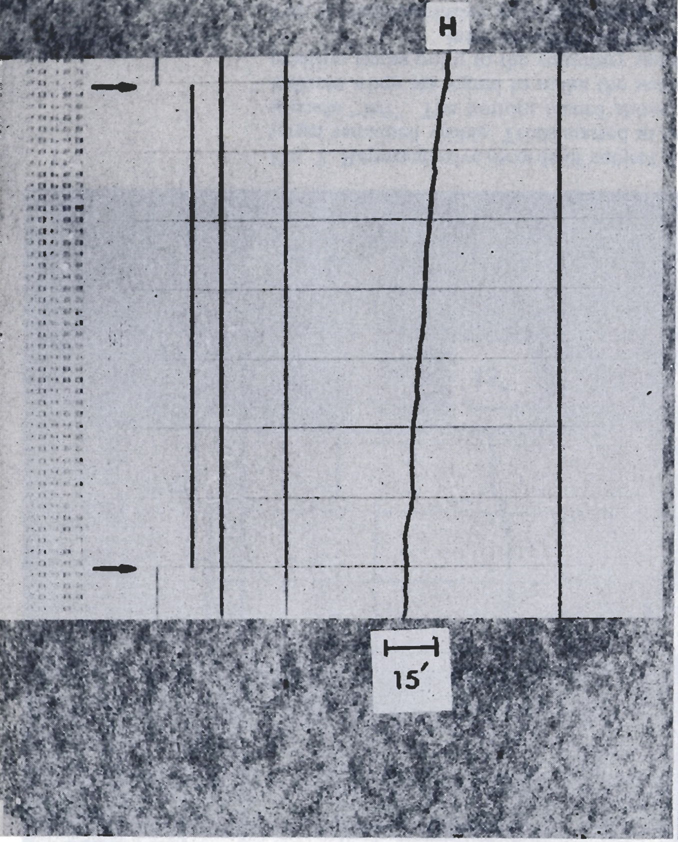


FIG. 2. Representative records of subject RS making a voluntary horizontal saccade when the target remained visible. Trials started at the bottom of each record. The top record shows a saccade "left". The bottom record shows a saccade "right". Filled black arrows at the left indicate when the signal to make the saccade was given. The faint open arrows near the eye position traces point to the voluntary saccades. Repetitive horizontal lines indicate 1-sec time intervals and the black bar at the bottom shows 15′ arc.

FIG. 3. Representative records of subject RS making a voluntary vertical saccade when the target remained visible. Trials started at the bottom of each record. The top record shows a saccade "down". The bottom record shows a saccade "up". Filled black arrows at the left indicate when the signal to make the saccade was given. The faint open arrows near the eye position traces point to the voluntary saccades. Repetitive horizontal lines indicate 1-sec time intervals and the black bar at the bottom shows 15′ arc.



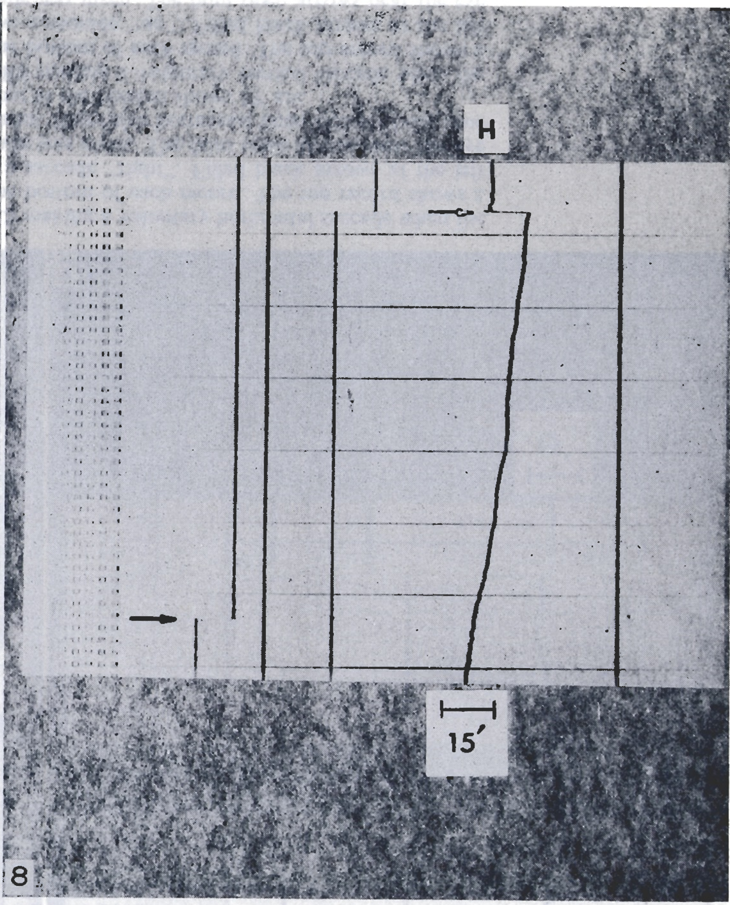


FIG. 7. Representative record of GH suppressing saccades. The record starts at the bottom. The filled black arrows define the 7-sec test interval. The horizontal eye position trace (H) can be seen to slowly drift to the right. Repetitive horizontal lines indicate 1-sec time intervals and the black bar at the bottom shows 15′ arc.

FIG. 8. Representative record of GH making a spontaneous saccade. The record starts at the bottom. The filled black arrow points to the beginning of the 7-sec test interval. The open arrow near the horizontal eye position trace (H) points to the spontaneous saccade, which occurred during the seventh second of the trial. Repetitive horizontal lines indicate 1-sec time intervals and the black bar at the bottom shows 15′ arc.

position by 5·2′ arc, on the average, leaving her line of sight far to the left of the target. RS's performance was similar.

These findings show that subjects are able to make voluntary saccades as small as those observed during "fixation" and that these small voluntary saccades can be made without the presence of a visual error.

Experiment 2. Very small voluntary saccades require a fixation target

If a visual error signal is not required for the subject to make a small voluntary saccade, can he make such a saccade without any visual error signal whatsoever? What, if anything, does the target do? To answer this question, the first experiment was repeated except that the target was removed from view when the auditory signal was given.

Results

The results of this experiment show that a visible target is vital. As in the previous experiment, saccades (always in the appropriate direction) were made within a reasonable time after the signal to do so (for GH, mean saccade latency = 258 msec, S.D. = 224; for RS, mean saccade latency = 298, S.D. = 196). But, voluntary saccades made without a visible target were much larger than those made when the target was visible. GH's mean voluntary saccade in this experiment was 21·9′ arc (S.D. = 10·6); RS's was 15·8′ arc (S.D. = 7·1). Four and three times larger, respectively, than the smallest average voluntary saccade made by each subject when the target remained visible. The frequency of saccades of various sizes on the horizontal and vertical meridians are shown for GH in Fig. 4. RS's distribution was similar.

The visual error at the beginning of the saccade was larger when the target was removed than the visual error observed in the prior experiment when the target remained visible.

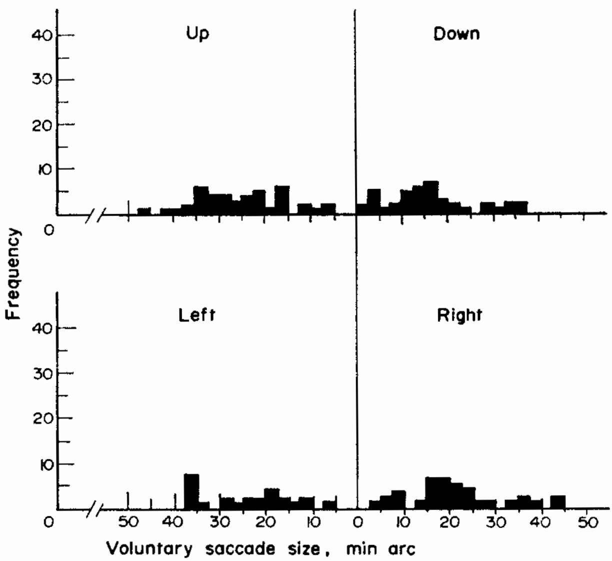


FIG. 4. Frequency histograms of voluntary saccade sizes when the target was removed for subject GH. Vertical saccades are shown in the top graph and horizontal saccades in the bottom graph.

Such large visual errors, a few hundred msec after a target is turned-off, are to be expected because the eye is known to drift faster in the dark than when a fixation target is visible (NACHMIAS, 1959; MATIN, MATIN and PEARCE, 1970; SKAVENSKI and STEINMAN, 1970). However, even this large visual error was not systematically opposite in direction to the subsequent saccade. The relatively large voluntary saccade made after removal of the target also produced, rather than reduced, visual errors.

This experiment shows that the absence of a visual target, or perhaps simply the absence of light, greatly increases the size of the smallest voluntary saccade that a subject can make. Whether this would continue to be the case with extensive practice is not known, but we suspect that this oculomotor characteristic would not change markedly with practice, and that very small voluntary saccades, like fixation saccades, require target detail to guide the visual search.

Experiment 3. Spontaneous saccades do occur and when they occur, subjects can report them

In the next experiment, an explicit attempt was made to study the occurrence and awareness of "spontaneous" saccades. (Saccades occurring when the subject tries to suppress them.)

The subject was instructed to suppress saccades completely while looking for 7 sec at the stationary target. He started each trial when he was ready. If he succeeded in suppressing saccades for the whole trial, he pressed a button to indicate that he had made none. When he thought he made a saccade, he pressed a button that indicated the direction of the saccade. If the subject's response was incorrect, an auditory signal informed him of the correct response. Analogue and digital correlates of horizontal eye position and the subject's response were recorded for all trials. Saccades tend to have a component on both horizontal and vertical meridians, so it is reasonable to ask the subject whether the spontaneous saccade was more left or right, and to ignore the vertical component. This simplifies his decisions as well as the instrumentation.

Results

Spontaneous saccades occurred very rarely. GH attempted to hold her eye in place with slow control for 607 7-sec trials; she made only 195 spontaneous saccades during 4249 sec of recording. RS attempted to hold his eye in place with slow control for 834 7-sec trials and only made 224 saccades during 5838 sec of recording.

Spontaneous saccades were not only infrequent, they were also large. On the average, twice as big as small voluntary saccades observed in the first experiment and twice as big as fixation saccades studied elsewhere. GH's average spontaneous saccade was 11·4′ arc (S.D. = 6·4) and RS's was 10·6 (S.D. = 10·3). These results are summarized in Table 2.

GH's visual error at spontaneous saccade-onset was very large (15·7′ arc) and always to the right. Her saccades, almost always to the left, reduced visual error markedly (they undershot by 4·6′ arc on the average). This result suggests that the direction and size of spontaneous saccades depend on visual errors as CORNSWEET (1956) proposed. But, for RS, only the *direction* of spontaneous saccades supports Cornsweet's model. Their size does not support his model. RS was almost on target at saccade–onset and his spontaneous saccades introduced a large error (he overshot by 7·3′ arc, on the average). This subject's data, however, do support Cornsweet's suggestion that direction and size of saccades are controlled by different mechanisms.

TABLE 2. ALGEBRAIC MEAN SIZE (′ arc) OF SPONTANEOUS SACCADES AND VISUAL ERRORS AT SACCADE ONSET FOR SUBJECTS GH AND RS

Saccade Direction	Size	Visual error[1]
GH		
Right (6)	3·2 (2·6)	12·5 (3·0)
Left (188)	11·7 (6·3)	−15·8 (8·9)
RS		
Right (157)	13·2 (11·1)	−0·3 (4·6)
Left (67)	4·5 (4·1)	−2·7 (4·0)

[1] Minus signs mean that the visual error was opposite in direction to the direction of the spontaneous saccade. No sign means that the visual error was in the same direction as the saccade.

Why do such spontaneous saccades occur? They are not simply reflex responses to the size of the visual error. An analysis was made to determine whether they were triggered by changes in drift velocity. A comparison was made between the velocity of a random sample of 167 msec drifts on trials when no spontaneous saccade was made with similar samples of drifts beginning 333 msec before the onset of spontaneous saccades and ending 167 msec before the saccade on the assumption that spontaneous saccades, like fixation saccades, are signalled about 150 msec before they occur (NACHMIAS, 1959). For subject GH, drift velocity was higher at the time spontaneous saccades were signalled (mean drift velocity = 5·3′ arc/sec, S.D. = 3·7, $n = 194$) than her random sample drift velocity (mean drift velocity

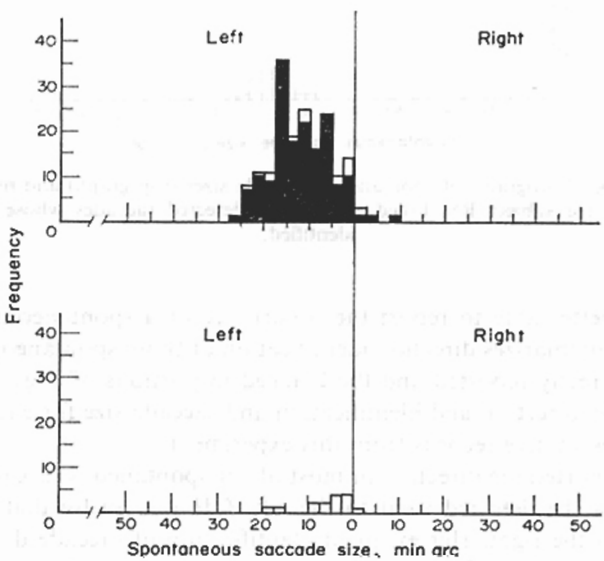


FIG. 5. Frequency histograms of spontaneous saccade sizes of detected saccades (top graph) and missed saccades (bottom graph) for subject GH. Filled areas show detected saccades whose direction was identified.

= 3·9′ arc/sec, S.D. = 2·6, n = 276). However, RS's drift velocity was lower when spontaneous saccades were signalled (mean drift velocity = 3·8′ arc/sec, S.D. = 2·9, n = 222) than his random sample drift velocity (mean drift velocity = 5·4, S.D. = 5·4, n = 276). Because the changes in drift velocity when spontaneous saccades were signalled were different for each subject, we conclude that spontaneous saccades are probably not triggered by changes in drift velocity.

Subjects were aware that spontaneous saccades had occurred. GH made 195 spontaneous saccades in 607 trials; she detected 179 of them (92 per cent). RS made 224 spontaneous saccades in 834 trials; he detected 199 (88 per cent). Both subjects seldom reported that they had made a saccade when they had not (false alarms for RS were 2 and 5 per cent for GH). Figures 5 and 6 show frequency distributions of the sizes and directions of spontaneous saccades that were detected and missed.

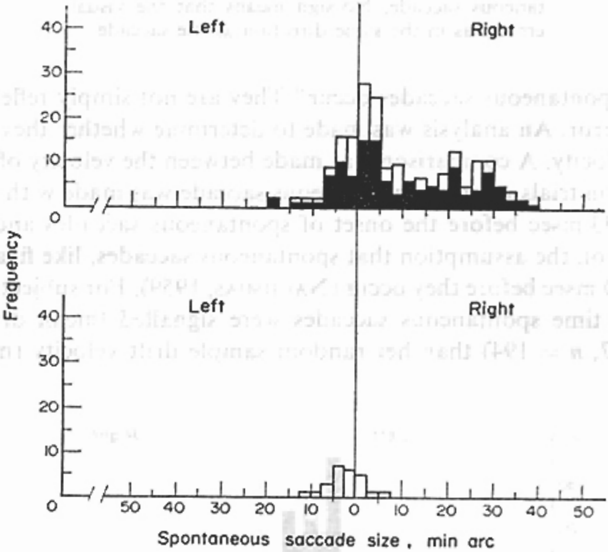


FIG. 6. Frequency histograms of spontaneous saccade sizes (top graph) and missed saccades (bottom graph) for subject RS. Filled areas show detected saccades whose direction was identified.

Subjects were better able to report the occurrence of a spontaneous saccade than its direction. Table 3 summarizes direction identification of those spontaneous saccades whose occurrence was correctly reported and the blacked in portions of Figs. 5 and 6 show the relationship between direction and identification and saccade size for each subject. Figures 7 and 8 show representative records from this experiment.

GH correctly reported the direction of most of her spontaneous saccades. However, 175 of the 180 saccades she detected went to the left. GH was aware that she had a strong tendency to drift to the right. Her excellent identification of saccade direction can not be taken very seriously, therefore, because of her characteristic drift pattern and her knowledge of it. RS, on the other hand, was often mistaken about the direction of his spontaneous saccades even though he almost always knew the saccade had occurred. Unlike GH, RS's

TABLE 3. THE NUMBER (n) OF CORRECT AND WRONG DIRECTION IDENTIFICATION OF DETECTED SPONTANEOUS SACCADES FOR SUBJECTS GH AND RS

	n	%
GH		
Saccades to the right		
Correct	1	1
Wrong	4	2
Saccades to the left		
Correct	161	89
Wrong	14	7
Total saccades		
Correct	162	90
Wrong	18	10
RS		
Saccades to the right		
Correct	92	46
Wrong	58	29
Saccades to the left		
Correct	29	15
Wrong	20	10
Total saccades		
Correct	121	61
Wrong	78	39

Direction identifications are also expressed as the percentage (%) of the total number of detected saccades.

drifts, when he suppressed saccades, were not always in one direction and his spontaneous saccades occurred with reasonable frequency in both directions.

This experiment suggests that if spontaneous saccades occur in the fixation pattern, they are very rare and rather large. Moreover, a subject can easily be aware of having made a spontaneous saccade, but not necessarily know its direction.

Experiment 4. The ability to identify the occurrence and direction of small target movements is superior to the ability to identify the occurrence and direction of target image displacements produced by spontaneous saccadic eye movements

If the subject's ability to detect the occurrence and direction of saccades results from the sudden shift of the target image on the retina that occurs when the saccade takes place, then his ability to detect saccades should be similar to his size threshold for target step displacements. This was found *not* to be the case in the next experiment in which the subject's ability to detect small target steps was measured under the same conditions as the previous experiment.

The subject was instructed to suppress saccades while looking at a stationary target (eye position was recorded to guarantee that he did so). He started the 7-sec trial when he was ready. If he saw the target move, he pressed a button indicating whether the target moved to the right or to the left. If he did not see the target move, he pressed another button at the end of the trial. If the subject's response was incorrect, an auditory signal informed him of the correct response. The experiment was run in randomized blocks. Each block included target step displacements of 7·0, 3·5 and 1·75′ arc to the left and to the right as well as one catch trial during which the target did not move at all. The time in the trial that the target displacement occurred varied between 1 and 6·75 sec after the trial started. Times were chosen from the previous experiment so that target displacements were introduced at the same times spontaneous saccades had occurred for each subject. Two hundred and seven trials were obtained for RS and 97 for GH. Three trials were discarded, two for GH because a saccade occurred before the target moved and one for RS because of an experimenter error.

Results

Subjects were able to reliably report displacements produced by target steps that were much smaller than the displacements produced by spontaneous saccades they failed to detect. RS always detected 7 and 3·5′ arc steps and only missed 36 per cent of the 1·75′ arc steps. He made no false alarms (said the target moved on catch trials). GH also made no false alarms and always detected 7′ arc steps. She did almost as well with 3·5′ arc steps (96 per cent identifications) and missed only 33 per cent of the smallest steps. Moreover, there was no direction idiosyncracy in either subject's ability to detect target displacements and they were never mistaken about the direction of the step if they saw the target move. Performance in this experiment was very different from performance in the experiment on the detection of spontaneous saccades where subjects failed to detect 10 per cent of spontaneous saccades that were, on the average, much larger than the target steps introduced in the present experiment. The identification of the direction of the target displacements was also much poorer when the displacement was produced by a spontaneous saccade than when it was produced by a small change in the position of the target.

These results show that the failure to detect spontaneous saccades probably did not occur because the retinal displacements produced by such saccades were too small. It is possible that subjects missed 10 per cent of their spontaneous saccades because of the known threshold elevation that occurs during small saccades (DITCHBURN, 1955; BEELER, 1967) or because of the shift in directional local signs known to occur before and during saccades (MATIN, 1972). Either, or both, of these phenomena could obscure visual cues that the subject needed in order to know that a spontaneous saccade had occurred. Or, perhaps, the subjects failed to detect some of their spontaneous saccades because the velocity of the retinal image displacement during a saccade is much lower than the velocity of the target steps employed.

SUMMARY

(1) Subjects can make voluntary saccades as small as fixation saccades if the target is visible. But, only if it remains visible. Saccades are larger in the dark. These saccades create, as well as reduce, visual errors. (2) Subjects do make spontaneous saccades. Spontaneous saccades, as defined in the present experiments, occur very rarely. They are large relative to small voluntary and typical fixation saccades, and tend to move the eye opposite to its drift direction. (3) Subjects are usually aware of having made a spontaneous saccade. But, they are better able to detect target steps and identify their direction than they are able to detect and identify the direction of their spontaneous saccades.

These results are compatible with our belief that the tiny saccades used during maintained fixation serve visual search.

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Abstract—(1) Subjects can make voluntary saccades as small as fixation saccades if the target is visible (mean size < 5·7′ arc, S.D. < 3·0). These saccades were made away from the preferred fixation position showing that a visual error signal is not necessary, but a visible target is because voluntary saccades were 3–4 times as large when made after the target was removed from view. (2) Subjects do make some spontaneous saccades, but very rarely throughout 7 sec trials when explicitly instructed to suppress them (1 every 25 sec). Such saccades were large relative to voluntary and typical fixation saccades (mean size > 10·0′ arc). (3) Subjects were usually aware of making spontaneous saccades (90 per cent detections), but were better able to detect and identify the direction of target steps than their own spontaneous saccades. These results are compatible with a visual search interpretation of the saccadic component of the maintained fixation pattern.

Résumé—(1) Des sujets peuvent exécuter des saccades volontaires aussi petites que les saccades de fixation si la cible est visible (moyenne < 5,7′ d'arc, écart-type < 3,0). Ces saccades se font en s'écartant de la position de fixation préférée, ce qui montre qu'un signal d'erreur visuelle n'est pas nécessaire, tandis qu'une cible visible l'est car les saccades volontaires sont 3–4 fois plus amples quand on retire la cible de la vue. (2) Les sujets font quelques saccades spontanées, mais rarement pendant des essais de 7 sec si on leur demande explicitement de s'en abstenir (1 toutes les 25 sec). De telles saccades sont grandes vis-à-vis des saccades volontaires ou de fixation typique (moyenne > 10,0′ d'arc). (3) Les sujets sont habituellement conscients de faire des saccades spontanées (90 pour cent de détection), mais sont plus capables de détecter et d'identifier la direction d'échelons de la cible que pour leurs propres saccades spontanées. Ces résultats sont compatibles avec une interprétation par recherche visuelle de la composante saccadée dans une fixation maintenue.

Zusammenfassung—1. Versuchspersonen können willkürliche Sakkaden durchführen, die so klein wie Sakkaden bei der Fixation sind, wenn das Sehobjekt sichtbar ist (mittlere Grösse < 5,7 min, S.D. < 3,0). Diese Sakkaden wurden weg von der bevorzugten Lage des Fixationspunktes gemacht. Sie zeigen, dass ein visuelles Fehlersignal nicht notwendig ist, dass aber ein Sehobjekt sichtbar ist, weil willkürliche Sakkaden 3 bis 4 mal grösser sind, wenn sie dann durchgeführt werden, wenn das Sehobjekt ausserhalb des Gesichtsfeldes gebracht wurde.

2. Versuchspersonen machen einige spontane Sakkaden, jedoch sehr selten während 7-sek.-Versuche, wenn sie ausdrücklich angewiesen wurden, diese zu unterdrücken (1 alle 25 sek.). Derartige Sakkaden waren gross, relativ zu den willkürlichen und typischen Fixations-Sakkaden (mittlere Grösse > 10,0 min).

3. Versuchspersonen sind sich im allgemeinen dessen bewusst, dass sie spontane Sakkaden durchführen (90 Prozent Erkennungsrate). Sie sind jedoch besser in der Lage, die Richtung von Verschiebungen des Sehobjektes zu erkennen und zu identifizieren als die ihrer eigenen spontanen Sakkaden. Diese Ergebnisse stehen im Einklang mit der Hypothese eines visuellen Abtastvorganges bezügl. der sakkadischen Komponente der Augenbewegungen während der Fixation.

Резюме—(1) Испытуемые могут выполнять произвольные саккадические движения глаз малой амплитуды, если объект виден (средняя амплитуда менее 5,7 угл.мин., $\sigma < 3,0$). Саккады выполнялись в направлении, противоположном естественному направлению на объект фиксации; отсюда следует, что зрительный сигнал рассогласования не является необходимым; однако, наличие видимого объекта необходимо, м.к. амплитуда произвольных саккад возрастала в 3–4 раза, если при выполнении скачка объект уже не был виден. (2) Наблюдатели очень редко (1 за 25 секунд) совершают спонтанные саккады на протяжении 7-секундных опытов, хотя инструкция требует подавления саккад. Амплитуды этих саккад бльше произвольных и типичных непроизвольных скачков (в среднем более 10 угл.мин.). (3) Испытуемые обычно сознавали, что их глаза совершают скачки (обнаружение—в 90% случаев), но лучше замечали смещение объекта, чем собственные спонтанные саккады. Эти результаты согласуются с представлением о том, что саккадический компонент служит зрительному поиску при задаче устойчивой фиксации.