PATTERNING OF EYE MOVEMENTS
IN THE CHAMELEON

by

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I dedicate this dissertation to the memory of my grandfather, Karl W. Onthank. Together with his wife, he fostered the love of Nature in his children and grandchildren.

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INTRODUCTION

According to the scheme of G. L. Walls (1942), the eye movements of all vertebrates are coordinated when they are compensatory for general shifts in the visual reference frame; but when the movements are apparently voluntary, they are "independent" in all vertebrates *except* the mammals. According to Walls, the eye movements of all mammals are always coordinated and are, therefore, by definition, "conjugate." Whenever one eye moves, the other moves at the same time and through the same angle. Porpoises, however, have been found to move their eyes "independently" (Lilly, 1962). "Independent" eye movements are such that the eyes *need not* move as though both eyes were one; the left and right eyes may move at different times, through different angles. The Old World chameleons, Family Chameleonidae, present a classically observed case of independent eye movements (e. g., Aristotle in *Historia Animalium*). These lizards have highly mobile and protuberant eyes, so their saccades (jump-like displacements of the eyes) are especially noticeable.

Tauber and Atkin (1967) suggest that in the chameleon, *Chameleo melleri,* each half of the animal's visuomotor system functions independently. Holden (1966) hypothesized that for chameleons and other animals with independent eye movements a "single channel" limit in the brain entails alternation of input processing from one eye to the other. Assuming that visual sensory processing is reflected in the pattern of saccades of left and right eyes, left eye saccades should correlate with right eye saccades if the movements of both eyes are contingent upon completion of processing through such a "single channel."

At least two questions are raised: (1) in what ways are saccades of left and right eyes not truly statistically independent, and (2) do such correlations as exist provide insight into the visuo-motor system(s) of such animals? A description of the individual saccadic behavior of each eye is a necessary antecedent to a description of their bilateral relationship. Furthermore, I want to compare the behavior of each independently-moved eye with the behavior of a conjugately-moved pair of eyes. I have been unable to find quantitative descriptions of long-term saccadic behavior except of human eyes, in terms of order-independent measures and very special visual tasks and displays (e. g., reading, Carmichael and Dearborn, 1947; simulated radar watching, White, 1960; helicopter piloting, Troy, Chen, and Stern, 1972; viewing of two dimensional pictures, Yarbus, 1967; Jeannerod, Gerin, and Pernier, 1968; Noton and Stark, 1971). So a third question arises: Can a detailed statistical description of saccadic behavior, taken from a variety of situations over long periods of time, be informative about visuomotor processing?

In the light of the above questions, I felt that saccadic patterning in African chameleons would be most interesting to observe and describe. Many other animals share with chameleons the ability to move their eyes independently. But chameleons are particularly suitable for study. Their eye movements are easy to observe and seem about as frequent as our own. In most circumstances, practically all their eye movements are saccadic. Observations of chameleon eye movements have already shown that the oculomotor independence persists during sleep (Tauber, Roffwarg, and Weitzman, 1966, for *C. jacksoni* and *C. melleri*) and also during optokinetic nystagmus (Tauber and Atkin, 1967, for *C. melleri*), contradicting the thesis of Walls (1942) that all compensatory eye movements in vertebrates are coordinated.

Using techniques of time series analysis (Cox and Lewis, 1966), in conjunction with more or less direct observations, I attempted to analyze chameleons' eye movement patterns. Where possible, I have compared the results of these chameleon studies to results from studies of the eye movements of other species. But a non-primate literature of saccadic eye movements is essentially nonexistent. I hope this study helps provide a start in that direction.

MATERIALS AND METHODS

Chameleons, C. dilepis, C. jacksoni, and C. hohnelii, were the subjects of these studies. Individuals of all three species were ordered from Arizona reptiles, Inc., Tempe, Arizona, and delivered to me at the University of Oregon, Eugene, Oregon, after a transit time of about twenty-four hours. They were immediately placed in their home cage and retained there without experimental interference until their health seemed stable. Water was provided in a perpetual drip, and crickets, which constituted the chameleons' staple diet, were introduced to the cage in slight excess of the rate they were consumed. The chameleons, which are diurnal animals, were kept on a roughly twelve hour light-dark cycle with dawn at 10 am; temperature was usually held at about 22°C ±3. Several animals, received as adults, lived under this regimen for as long as one year.

The majority of my data were taken from C. dilepis individuals, both male and female. Widely-distributed in southern Africa, these chameleons are hardy and fairly large (adults are 6+ inches in body length) and were easier subjects to experiment with than were the hardy but small C. hohnelii (adults are about 4 inches in body length).

C. hohnelii are viviparous and, during this study, I was fortunate to witness a live birth. I raised the young animals on *Drosophila*, and considerable data were collected from one young lizard at the age of one month. Also, data from one adult male *C. jacksoni* (5 inches body length) are reported in this paper. Table 1 gives further information describing the experiments and the individual chameleons which participated in them.

Usually, I could not determine the age of the animals nor could I determine their state of health. Superficially, no animal appeared ill during the several weeks before and after an experiment in which it had participated. Most animals, however, died after several months in the laboratory. Chameleons are notoriously hard to keep and their approximately two-year life span is thought to be the shortest of all lizards (Pope, 1955). Bustard (1963), however, suggests that the short life-span observed in confinement is due to inadequate care.

Chameleon Oculomotor Behavior

Saccadic eye movements are rapid, step-like displacements of the line of sight. The timing, sizes and directional properties of chameleon saccades are the subjects of this thesis. It is therefore important to distinguish between saccades and other sorts of oculomotor behavior.

Table 1: Sources and analyses of chameleon saccade data. This table presents a summary of the methods and materials used directly in the quantification of descriptions in the thesis. Qualitative remarks were made on the basis of these data and of observations of other animals.

TABLE 1

Experiment	Species member	Saccade-recording method	Record	Analysis (saccade recognition and characterization)	Total saccades recorded	Record duration	Comments
D1	*C. dilepis*--1A	Movies of S on wheel	16 mm film of Ss' eyes	Frame analyses of projected 16 mm film	248	3 min	Constrained to move on a wooden wheel.
D2	*C. dilepis*--2B	Movies of Ss in mirror trough			489	5 min	No external motion; bright illumination.
D3	*C. dilepis*--3B				470	5 min	
H3.02	*C. hohnelii*--2	Horizontal EOGs	Kodak KIND-1732 35 mm paper strip--film exposed EOGs on a CRT.	Manual inspection of EOGs on strip-film.	783	20 min	1-month old baby; free to move about. External motion was visible
H3.03	*C. hohnelii*--2				984	20 min	
H3.04	*C. hohnelii*--2				1332	20 min	
H3.05	*C. hohnelii*--2				1123	20 min	
H3.06	*C. hohnelii*--2				746	20 min	
H3.07	*C. hohnelii*--2				693	20 min	often "asleep"
H3.08	*C. hohnelii*--2				855	20 min	Right eye covered
H3.09	*C. hohnelii*--2				882	20 min	Both eyes covered
H3.10	*C. hohnelii*--2				440	20 min	
1	*C. dilepis*--1C	Horizontal EOGs	FM-tape reels (2400' at 1 7/8 ips= 4 1/2 hr).	Automatic "recognition" and computer analyses; also manual examination of strip-films of playback of taped EOGs.	10872	275 min	No external motion; partial restrain in all cases below (Figure 1f).
2	*C. dilepis*--2C				15970	275 min	
3	*C. dilepis*--3C				13368	275 min	
4	*C. dilepis*--4C				17423	275 min	
5	*C. jacksoni*--2				11297	275 min	
6	*C. dilepis*--6C				6616	275 min	
7	*C. dilepis*--4C				9259	275 min	Occlusion (see Figure 8)
8	*C. dilepis*--2C				8948	275 min	Rx-time test; occlusion
9	*C. dilepis*--1C				8058	275 min	Rx-time test; occlusion
10	*C. dilepis*--4C				11651	275 min	S in stroboscopic light

Human eye movements, except very small movements of fixation, are segregated into two general classes: (1) smooth movements of tracking and compensation with maximum velocity of thirty to forty degrees per second, and (2) saccadic movements with velocities up to eight hundred degrees per second (Dodge, 1903; Rashbass, 1961; Alpern, 1962). The distinction appears to extend to other vertebrates (e. g., goldfish, Hermann and Constantine, 1971; pigeon, Nye, 1969; rabbit, Collewijn, 1969; monkey, Robinson and Fuchs, 1969).

Chameleon optokinetic compensatory eye movements have already been studied (Tauber and Atkin, 1967). During my studies, vestibularly induced movements were occasionally generated by chameleons suspended from branches and from the wires used for saccade recording (Figure 4e). Yet, I rarely observed smooth eye movements which I could attribute to optokinetic or vestibular stimulation (fewer than 1% of all observed eye movements were not saccades), and smooth movements are easily distinguished from saccades by virtue of their kinetics. I never observed smooth, target-tracking eye movements, even in contexts I expected to be conducive to their generation, as during stalking of moving prey insects (Figure 5).

The most commonly observed chameleon eye movements other than saccades were "shut eye rolls" (Figure 4f-g). Associated with blinking, such movements involve smooth, slow rotations and retractions of the eyes under the lids, after the lids have closed. They are easily distinguishable from the much more rapid and step-like saccades.

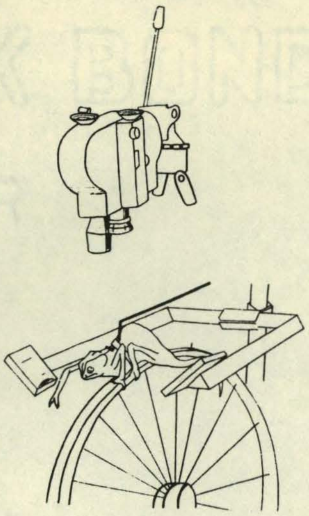
Saccade Detection and Measurement

Movie Films

Sixteen millimeter movies of partially restricted chameleons were taken at 32 fps with a Bolex camera and at 50 fps with a HYCAM rotating prism camera (Redlake, Inc., Anaheim, California). Mirrors kept the pupils of their eyes within view at all times (Figure 1a-b). The special anatomy of the chameleon eye facilitates movement detection by the observer. The fused eyelids, which closely invest the eye, move with it and often have graticule-like pigmentation patterns.

The movies were projected for frame by frame analysis. Saccades were easily recognized by their kinetics, usually occupying less than 150 msec. Saccades smaller than about five degrees were not reliably observed and their frequency of occurrence remains unknown (see Discussion). The frame numbers of the onsets of saccadic movements and the durations and terminal positions of the saccades were entered into notebooks; some of this information was later punched into IBM cards for computer processing.

Figure 1: The various means of chameleon saccade recording. (a)-(b), two methods used to restrain animals whose eye movements were filmed using mirrors, M; in (b), the chameleon (not shown) was trapped at the bottom of the slippery glass trough of mirrors. (c)-(f), methods of acquisition of horizontal EOGs, taken with two pairs of horizontal electrodes, E, connected to twisted, shielded, wires, T, connected, in turn to AC-coupled preamplifiers, A, all inside a large, 3' x 3', electrically shielded cubicle, Cu. Chameleons, S, were fully restrained in (c), not restrained in (d), and partially restrained in (e). The majority of data came from the situation depicted in (e) and (f), wherein an animal could walk and turn around, but could not grasp his electrode leads; small, 1/2" diameter floats, F, were suspended from the wrists by strings passing between the dowels, D, upon which the animal walked; vertical travel of the wrists was thus restricted; the electrode leads were strung over a glass rod, G, and counterweighted, W, to take up slack.



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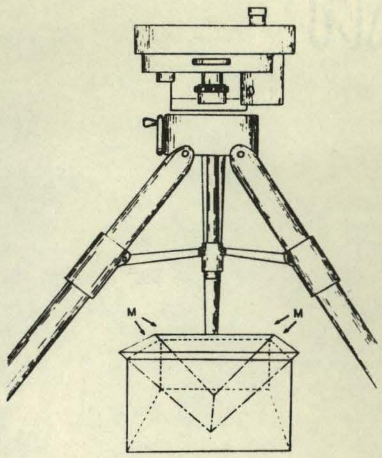

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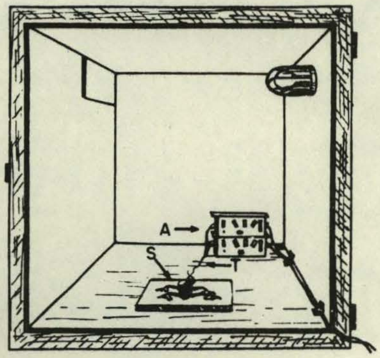

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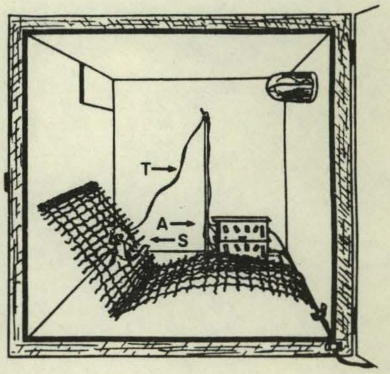

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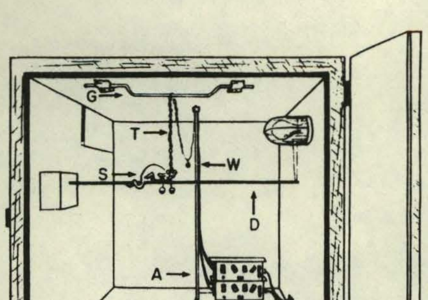

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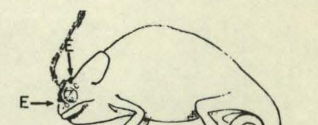


(f)

EOG Recording

An electrical potential difference exists between the fundus and cornea of the vertebrate eye. Vertebrate eyes are therefore electrical dipoles (for further information see: Granit, 1947; Brindley, 1960). When the eyes move, the electrical fields about them change; one monitors this change by recording the voltage between two or more electrodes positioned about the eye on the surface of the skin. The record is called an electrooculogram or EOG. Note that if the corneo-fundal potential changes, the EOG (recording a potential difference depending on eye position) will vary and one may falsely conclude that the eye has moved (Kris, 1958). If the recording-electrodes are placed opposite each other, on the orbital skin of the eye, the eye will generate a potential difference between them which is monotonically related to the eye's position along the line drawn between the two electrodes (Bicas, 1972).

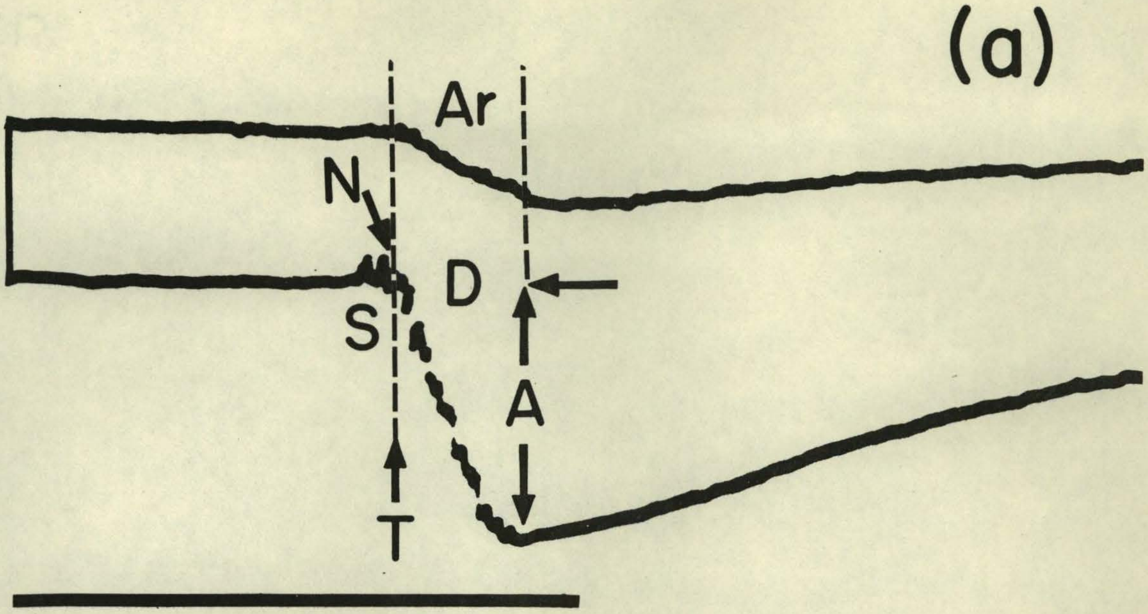
A pair of Ag-AgCl electrodes (1 mm diameter disks) was placed on the slightly abraided orbital skin of each eye; the electrodes rested opposite each other in a horizontal line, one nasal and the other temporal (Figure 1f). The potential recorded between them is the horizontal EOG of the eye. Good skin contact was maintained with the use of electrode paste (EKG Sol, Burton, Parsons and Co., Washington, D. C.).

Two pairs of insulated electrode leads (lightweight, shielded twisted-pairs used for hearing aids) were affixed to the top of the chameleon head with low-melting-point wax. This procedure was performed while the chameleon was under light Metofane (methoxyflurane) anesthesia; recovery seemed rapid and complete (in less than fifteen minutes, behavior appeared normal).

Each of the two pairs of electrode leads entered an AC-coupled preamplifier (Grass Model P15) and the differential voltage between the leads was usually amplified 1000-fold. The input potential differences were generally in the range 0.1 to 0.6 millivolts (c.f., 0.2 to 0.8 mV for human EOG; Fenn and Hursh, 1937). Each amplifier's output signal was either filmed (Tektronix type RM-565 oscilloscope and Grass Linograph camera) or tape recorded (Ampex SP-300 at 1 7/8 ips in the FM-mode).

Fortuitously, in addition to recording the voltage transients due to eye movements, the system also records summed extra-ocular muscle spike activity. A burst of such activity invariably precedes the slower voltage changes due to eye movements and facilitates visual identification of saccade occurrence in the EOG (Figure 3a). The EOG-system was insensitive to effects beyond those mentioned above. They contained little noise due to mechanical factors. Unrestrained chameleons sometimes slipped and fell from their perches, suddenly imposing

Figure 2: The saccadic EOG deflection, definitions and descriptions. The "typical" horizontal EOG after AC-coupled amplification (taken from a pair of electrodes placed horizontally opposite each other across the eye) is shown in (a). Just prior to the EOG deflection, a group of summed muscle spikes invariably occurs, S, with polarity opposite that of the EOG deflection, thus creating a "notch" in the record, N. I define the time of saccade occurrence, T, to correspond to the start of the EOG deflection just following the notch. The amplitude of the deflection, A, is the level of maximum excursion. The duration of the saccade, D, is the time to A measured from T. As shown in (b), the triggering of the analog circuit used for saccade EOG "recognition" is contingent on the maintenance of a minimum voltage slope, Sm, for a minimum duration, Md. The analog circuit output is shown below the parent EOG trace. Typical artifact, Ar, of the movement of an eye appears at the contralateral electrode pair, demagnified, in synchrony, and in the same direction. The top trace of each pair represents the right eye; an upward deflection represents an eye movement in the anterior (nasal) direction, a downward deflection, a movement in the posterior (temporal) direction. Calibration: horizontal bars, 250 msec; vertical bars, 25 mV.


(a)
Ar
N
D
S
A
T

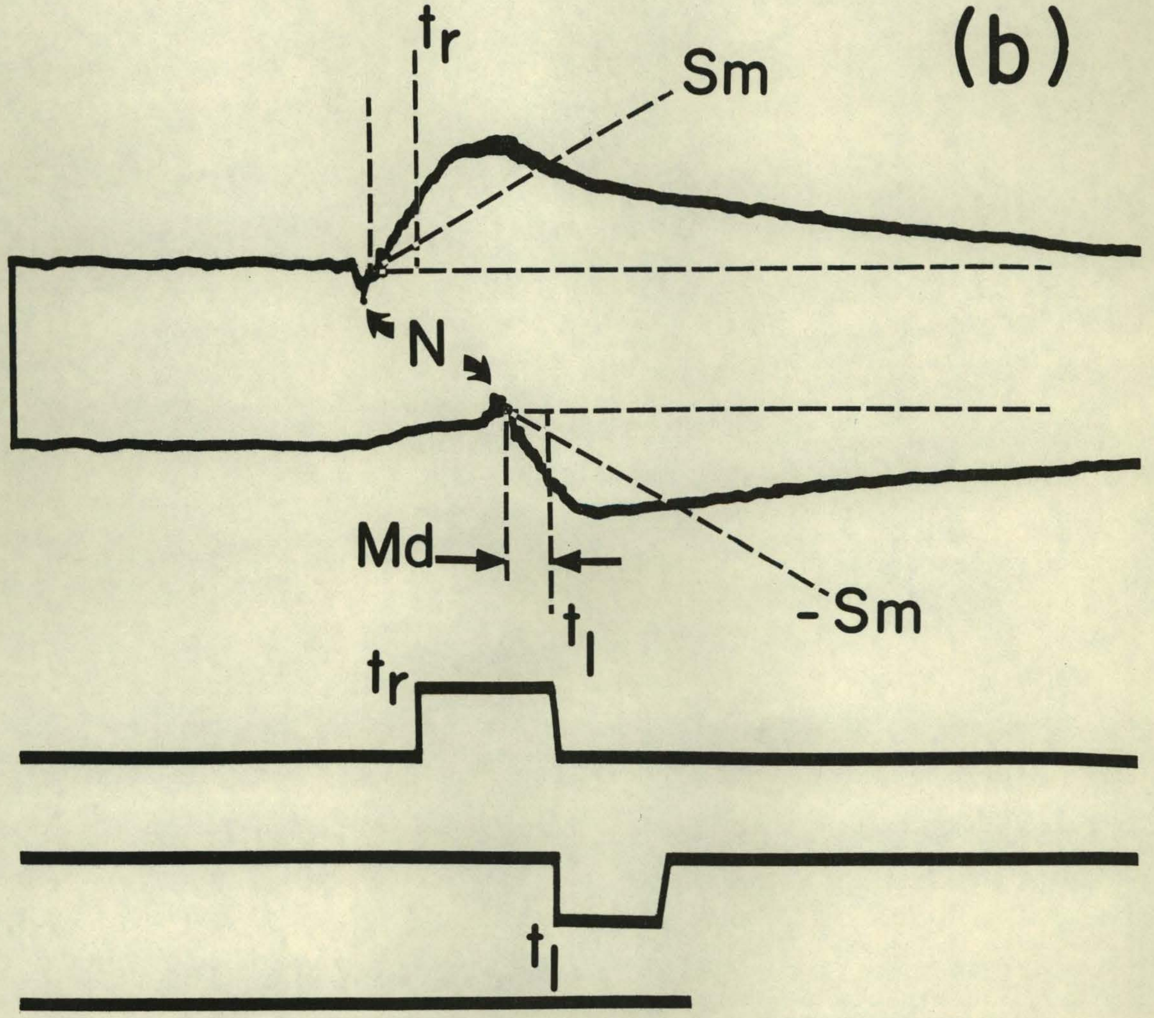
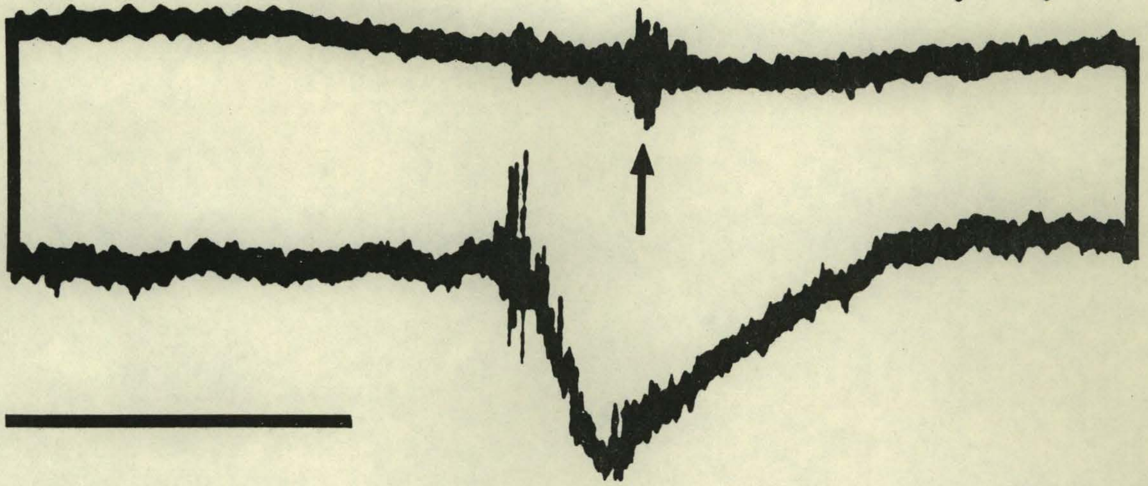

(b)
t_r
Sm
N
Md
$-$Sm
t_l
t_r
t_l

Figure 3: Unusual extra-ocular muscle behavior. The bottom trace of (a) shows a typical group of summed extra-ocular muscle spikes preceding the saccadic voltage swing; the top trace, however, shows such a group of spikes but no horizontal movement. Often, as shown in (b), several groups of spikes appear associated with a single EOG deflection. The top trace of each pair represents the right eye; an upward deflection indicates an eye movement in the anterior (nasal) direction, a downward deflection, a movement in the posterior (temporal) direction. Calibration: horizontal bars, 200 msec; vertical bars, 0.1 mV.

(a)



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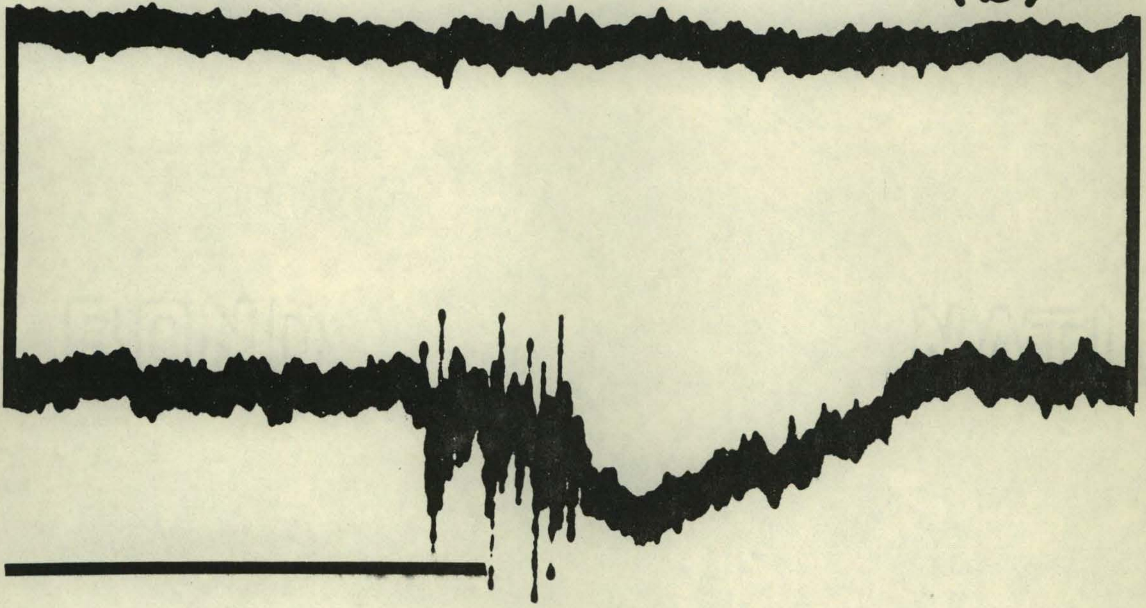
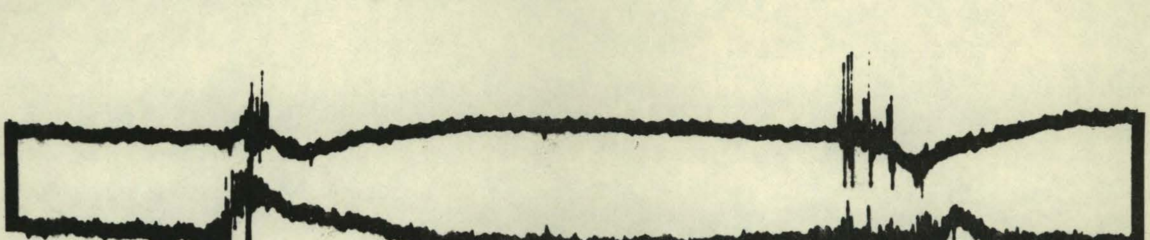


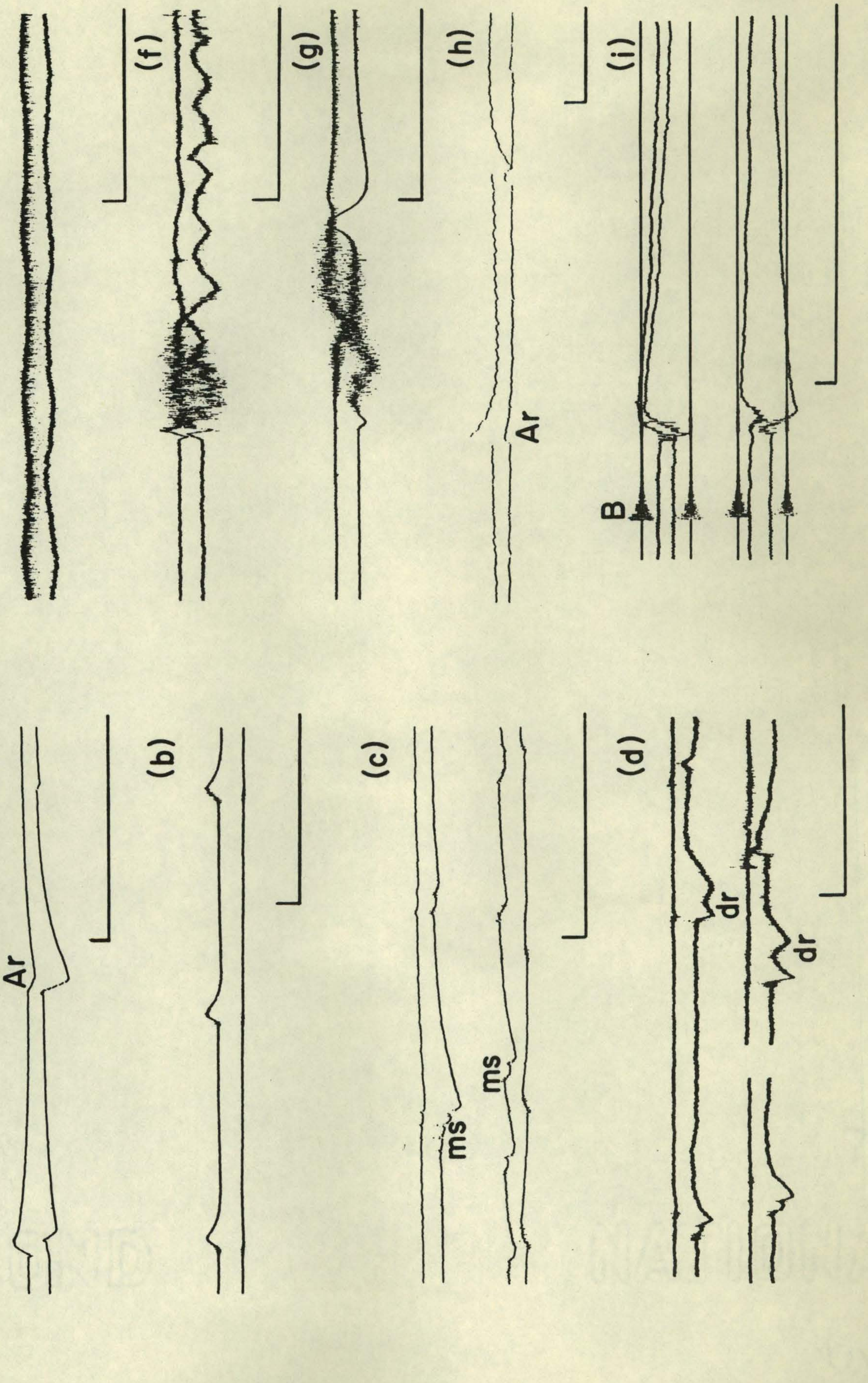


their entire body weight and momentum upon slack recording leads; even under these conditions, visual observation indicated that no EOG transients other than those typical of eye movements and summed muscle spikes occurred.

Absolute eye-position information might have been acquired if more than two electrodes had been used to record the potentials about each eye. But a total of four electrodes on a chameleon seemed to be the largest number conducive to its freedom of movement and unobstructed vision. Absolute position information is confounded because the electrical fields of the two eyes interact, as will be discussed shortly. Thus the position of one eye affects the potential difference between the contralateral electrode pair. Contralateral eye position does not, however, affect the change in potential difference due to the motion of an eye. Therefore, I rejected DC-coupled amplification of the potential difference in favor of AC-coupled amplification with a large RC time constant, usually 3.4 seconds so as to preserve the fast kinetics of saccades in their corresponding EOG deflections.

As mentioned above, a change in corneo-fundal potential can effect a change in EOG and thereby mimic an eye movement. It will also change the relationship between the amplitude of an EOG deflection and the size of the associated eye movement. The EOGs from a chameleon in flickering light (Figure 4h) suggest that the change was not

Figure 4: EOG signatures of various eye movement types. (a)-(b), "typical" saccadic EOGs taken from (a) a *C. dilepis,* and (b), a *C. hohnelii*; artifact = Ar. (c), the "multiple saccades," ms, of a *C. jacksoni*. (d),EOGs from a *C. hohnelii* with eyes occluded by small patches of opaque tape; the eyes remained mobile, but unusually many multiple saccades, ms, were seen, as well as peculiar "drifts," dr, rather than normal saccade terminations. (e), vestibularly induced EOGs of a *C. hohnelii* with occluded eyes. (f)-(g), extreme and normal cases, respectively, of "shut eye rolls," the eyes are shut, retracted, and rolled about, either singly or together. (h), the effect of stroboscopic illumination (8 flashes/sec) upon the EOG of a *C. dilepis*. (i), outer traces show sound bursts, B, due to the blow of a hammer on the table on which chameleon EOGs were taken (two inner traces); the times from the start of the sound to the saccades of both eyes were accumulated as "reaction times." The top trace of each pair represents the right eye; an upward deflection of either trace represents an eye movement in the anterior (nasal) direction, a downward deflection, a movement in the posterior (temporal) direction. Calibration: horizontal bars, 1 sec; vertical bars, 0.1 mV for (b), (d), (e), (f), (g), (h); 0.2 mV for (i); 0.25 mV for (a), (c).


(a)
Ar
(b)
(c)
ms
ms
(d)
dr
dr
(e)
(f)
(g)
(h)
Ar
(i)
B

significant. The ratio of light flux, flash to darkness, was many times greater than for any contrast encountered in the other experiments, and yet the observed EOG ripple was insufficient to trigger either manual or automatic saccade EOG recording methods described below. I did find, however, that the EOG from one eye was affected by the voltage across the electrode pair associated with the other eye; any substantial voltage change in the EOG of one eye was mirrored by a simultaneous, smaller change in the contralateral EOG. I presumed that this was due to volume conduction between left and right electrode pairs for the following reasons beyond simultaneity: (1) the electrodes, leads, and other circuitry were independently and jointly tested and showed no interactions remotely large enough to account for the observed "cross-talk" between left and right horizontal EOGs; (2) the cross-talk gain was about 0.25, a figure for which volume-conduction could suffice, since the electrodes of a pair were placed about 1.0 cm apart, whereas the electrode pairs, one on each side of the head, were only about 1.5 cm apart (C. dilepis adult); (3) the cross-talk was invariably the expected polarity given the symmetrical placement of the left and right electrode pairs. As determined from the EOGs, the cross-talk caused a real saccade to appear to be accompanied by a smaller and invariably converging saccade of the other eye. Accurate measurements of the times of saccade occurrences are of more importance in this study than are accurate measures of saccade size; saccade sizes have been tentatively estimated via theoretical consideration of their relation to EOG deflection amplitudes (see Discussion).

Manual EOG Measurement

Films of EOG records were manually examined. Detection of saccadic EOG deflections is unambiguous due to the typical saccade dynamics and the invariable presence in the record of summed muscle spikes ahead of and during saccades. Deflections of an EOG due to cross-talk from the contralateral eye were easily ruled out. The left and right EOG records were filmed and examined in parallel. An EOG deflection from a saccade, if an artifact of volume conduction, will be a simultaneous, deamplified version of the generating saccade seen in the EOG from the symmetrically-placed, contralateral pair of electrode leads (Figure 2a). The time of a saccade's occurrence was defined as the start of the major EOG swing, not the start of the preceding muscle spikes (Figure 2a). The occurrence times, amplitudes, and directions of the horizontal, saccadic EOG deflections were transcribed into notebooks and later punched into IBM cards for computer processing.

Automatic EOG Measurement

The AC-recorded EOG deflection of a saccade has a characteristic waveform (Figure 2a). I designed an analog circuit to "recognize" such deflections (Appendix A1.1). To qualify as the EOG deflection of a saccade, the slope (volts per unit time) of the deflection must exceed a set value for a minimum duration, usually about 2 mV/sec for at least 10 msec (Figure 2b), corresponding to about 300^{o}/sec of horizontal motion. These two criteria were designed into a circuit; the circuit will not pass slow voltage swings (shut eye rolls) or high frequency spikes (muscle spikes). In response to a saccadic EOG deflection, the recognition circuit puts out a fixed-amplitude, rectangular pulse in the same direction, positive or negative, as the EOG deflection (Figure 2b).

Saccades have high initial accelerations so that recognition, as defined by the above rules, occurs at a fixed time lag (10 msec ± 10 after saccadic onset) no matter what the EOG deflection amplitude. Previously reported EOG recognition circuits have used RC-filters (Bourne, Hudak, and Duke, 1972; Gaillard and Tissot, 1973), presumably with more variable recognition lags after different sized saccade occurrences (i.e., the response of an RC-filter varies continuously with input slope). Furthermore, my selection procedure is consistent with the known kinetic behavior of voluntary saccades of humans (Robinson, 1964) for which there are relatively fixed velocity to duration to amplitude relationships. Both velocity and duration can each define the other two parameters and so the velocity-duration criteria of the analog circuit place powerful natural restrictions on which waveforms are recognized as saccadic EOG deflections.

Two recognition circuits were built, one for each eye. During simultaneous input of left and right horizontal EOGs, the circuits interacted to eliminate artifactual saccadic EOG deflections by a crossed subtraction procedure. Since the circuitry can recognize saccadic EOG deflections in real time, one could trigger experimental operations contingent upon saccade occurrences. But my use of the recognition circuitry was confined to analysis of pre-recorded EOGs. This way, I was able to vary the threshholds of the recognition circuits to optimize their performance. The outputs of the recognition circuits were recorded in parallel with the parent EOG signals. Concurrent with the EOG signals, a 100 Hz signal, a voice track, and a miscellaneous track were also recorded; all seven channels of the tape were used. The magnetic tape recordings were occasionally displayed on a CRT and filmed. They provide for extremely flexible storage of large amounts of eye-movement data.

These tape recordings were input to a Varian 620/i computer through a special asynchronous data register built for this purpose

(Appendix A1. 2). The small computer simultaneously generated IBM-compatible tape files, which are the sources from which the major quantitative analyses have been performed by the University of Oregon's IBM 360/50 computer. The small computer acts as a real-time multiple event sorter, timer, and encoder with storage on nine-track digital tape. The program eliminates artifacts left over from the analog recognition circuitry (Appendix A2. 1). More information (e. g., voice-identified on-going behavior) was manually toggled into the asynchronous data register concurrently with input of the tape-recorded EOG recognizer outputs. The Varian computer sampled, processed and reset the sixteen bit asynchronous data register and wrote the digital tape, all at a rate better than 2 kHz. The IBM 360/50, using my assembly language program (Appendix A2. 2), sorted the data from the above digital tapes and created tape files of catalogued data and results of partial analyses. The IBM system, under control of my Fortran IV programs (Appendix A2. 3) printed statistics and plotted many of the distributions used to illustrate this thesis (Houston Instruments Omnigraphic incremental plotter).

Comparison of Methods

The results of the three detection and measurement methods, movie analysis, manual and automatic EOG analyses, are comparable

(Figure 6), but the methods have not been used concurrently. In all cases, saccades of angular extent of less than about five degrees of horizontal motion are detected with decreasing reliability (in the case of EOG records, this value was subjectively estimated by simultaneous observation of the animal and his EOGs, displayed on an oscilloscope screen; in movies, most movements were visible which were more than 1/4 the pupil diameter, about 20° in size). The extent to which smaller saccades are produced by chameleons is not known. Microsaccades, comparable to those of human fixation, could occur. This study of the ordering of chameleon saccades does not include all saccades, even in the horizontal plane.

Behavior Transcription

The overt behavior of chameleons was recorded concurrently with their saccadic activity. Early data were hand-recorded while later data were also voice-recorded (together with the EOG) on magnetic tape. These later data were subsequently coded and stored on digital tape (using the asynchronous data register mentioned above). Most of the coding refers to locomotory activity (Table A2). These data have not been fully analyzed and are not presented in this thesis. Their relation to saccadic behavior will be treated in the future.

Experimental Sessions

General

I restricted the study to chameleon eye movements of an apparently voluntary, non-reflexive nature. To this end, motion external to the chameleons during experiments was minimized. Unfettered chameleons occasionally suspended themselves by their electrode leads, a circumstance leading to pendular motion and compensatory smooth movements. On the other hand, the more restrained chameleons volunteered fewer saccades (they shut their eyes). Figure 1e-f shows the compromise which allowed free movement and normal body position, but prohibited the animals from reaching their electrode leads. The slow body movements of chameleons seem unaccompanied by compensatory eye movements (Figure 5). Therefore most recorded saccades were unrelated to target tracking or to compensation.

Before saccade recording, recognition and analysis were automated, I occasionally excited the experimental chameleons by gently touching them, or more commonly, by pulling a string tied to the animals' tails. These steps were taken because manual analysis of film or EOG records of very sparsely occurring saccades was inefficient, expensive and frustrating. In later experiments, little or no interference with the animals ever took place; this was due to the automatic processing

Figure 5: Chameleon prey-tracking behavior. Tracings from a 16 mm film taken at 32 frames/sec of a C. dilepis attempting to "track" a cricket stuck to a piece of tape which was swung on the end of a fishing line from the end of a pole. The hatched object in the foreground is the out-of-focus cricket and tape. I eventually ceased swinging the cricket and the chameleon then struck and captured the cricket with his tongue. Note the absence of oculomotor tracking. Frame numbers are shown relative to the first in the sequence.

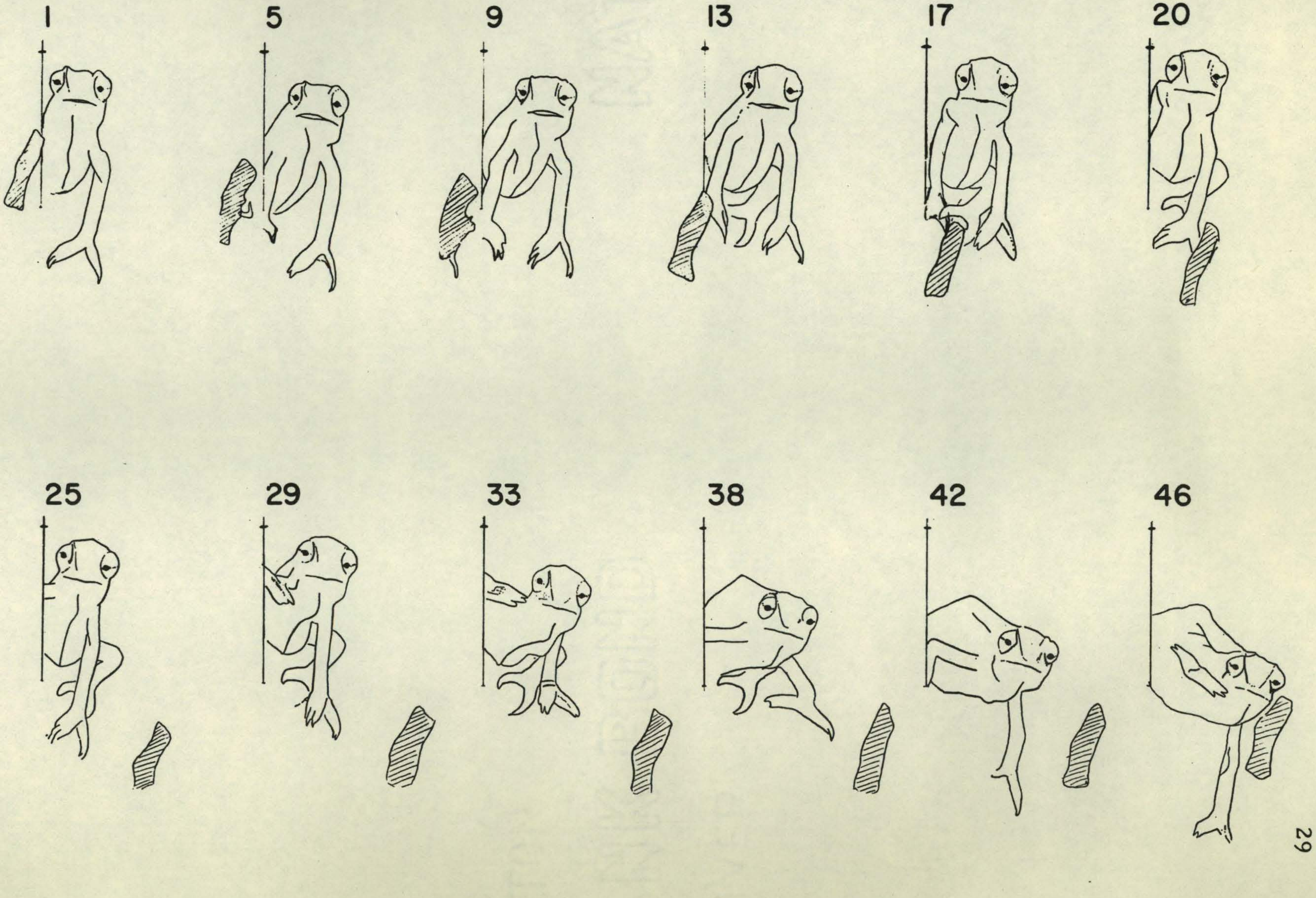
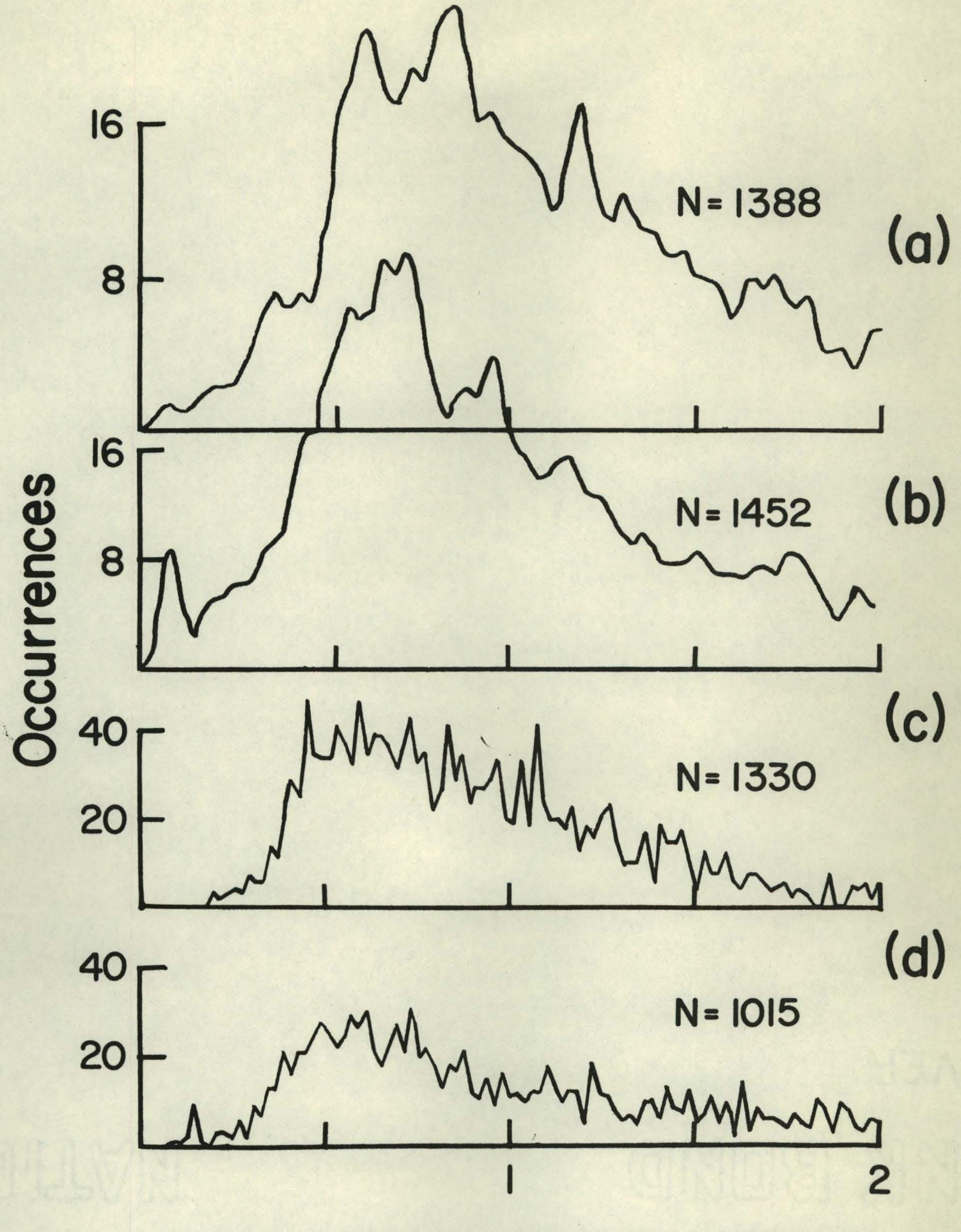

1
5
9
13
17
20
25
29
33
38
42
46

Figure 6: Inter-saccade intervals by the several methods. (a) shows automatically analyzed data from the right eye of a *C. dilepis.* (b) shows automatically analyzed data from the left eye of a *C. jacksoni.* A *C. hohnelii*'s EOGs were manually analyzed to produce (c). 16 mm movies of a *C. dilepis,* held in a trough of mirrors, produced (d). Both (c) and (d) show intervals accumulated from both left and right saccade sequences (i. e., left-left intervals, and right-right intervals). All plots are redrawn from frequency-polygons (20 msec bin-width); (a) and (b) were previously smoothed by weighting adjacent bin counts in the ratios, 1:4:6:4:1.


16
8
N= 1388
(a)
16
8
N= 1452
(b)
Occurrences
(c)
40
20
N= 1330
(d)
40
20
N= 1015
1
2
Inter-saccade interval (sec)

later available and the extremely long recording capability of the magnetic tape reels.

Other aspects of the animals' environments during saccade recording were not tightly controlled. All experiments were performed at room temperature (about 22°C ±3). Noise was generally kept to a low level, although there is evidence that chameleons' hearing of airborne sounds is very poor (Wever, 1968, 1969 a-b, for C. hohnelii, C. jacksoni, C. senegalensis, and C. quilensis). Later I obtained EOGs from animals in a sound-dampened, electrically shielded cage (Lehigh Valley Electronics, Inc., Fogelsville, Pennsylvania). Finally, none of the methods of data collection required any surgical or other injury to the chameleons. The waxed-on electrodes were simply peeled off the chameleons' heads at the ends of experiments.

Brief Descriptions

The earliest of the experimental setups is shown in Figure 1a. An adult C. dilepis was held so that it could walk on the rim of a wooden bicycle wheel but could not physically displace itself. A pair of mirrors reflected the images of its eyes to a downward pointing Bolex camera operated at 32 fps. Later, I constructed a trough of mirrors in which a chameleon could walk but from which it could not escape (Figure 1b).

A downward-pointing, rotating-prism camera recorded images of both eyes' pupils at 50 fps. Individuals of two species, C. dilepis and C. hohnelii, were filmed in this way without other interference.

Using an Offner Dynagraph chart recorder, EOGs were first obtained from two C. dilepis. The animals were fully restrained within an electrically shielded cage (Figure 1c), and occasionally had to be stimulated to "wake up" and produce more saccades. The longest spans of manually examined data (EOG) came from ten separate recording sessions during three different days with a freely moving C. hohnelii, only one month old (Figure 1d). The EOG was strip-filmed (Grass Linograph camera) at the rate of 5 cm/sec, thus giving twenty minutes of record per 200-foot roll of film (Kodak KIND 1732). More than 10,000 saccades were measured from these sessions. The most numerically fruitful method of saccade EOG analysis was the automated method described above. More than 100,000 saccades were recorded from one C. jacksoni and several C. dilepis. The animals were sometimes unrestrained, sometimes partially restrained. Some experiments lasted almost five hours (a time equivalent to one 2400-foot reel of magnetic tape recorded at 1 7/8 ips).

Recordings were taken from four C. dilepis whose eyes were occluded with small rectangles of opaque black tape (4 mm^2) placed over the palpebral fissures of one or both eyes. The occluded eyes retained their full mobility. One animal's saccades were recorded at night in flashing light; these strobe-light data have not yet been analyzed in detail.

Statistical Procedures

The Renewal Hypothesis

Serial relationships in chameleon saccadic behavior are examined below against the hypothesis that the saccades were generated by a "renewal" process, that is, a process which produces intervals between successive saccades of an eye independently of past production. A renewal process is a type of "stationary" process, a process whose first and second order statistics are independent of the point at which observation starts. Tests for renewal are usually performed after tests for stationarity. This is because failure of the renewal hypothesis may simply mean that the process is non-stationary.

The renewal hypothesis is not here presented as a serious contention, but rather as a backdrop against which to examine serial relationships. Saccadic behavior was often non-stationary over some time spans and therefore non-renewal. But the serial relationships discussed in this thesis persisted in non-stationary cases as well as in those which appeared stationary. No formal tests for stationarity were performed, although I acquired subjective impressions by segmenting the data and comparing the statistics and distributions of the segments (Perkel and Gerstein, 1967a).

Successive Differences and the Joint Interval Histogram

During an experimental session, each eye defines a sequence of times of its saccades. A left saccade sequence and a right saccade sequence are concurrently generated. These time sequences are transformed into other sequences by the method of successive differencing (Anderson, 1971). To do this, one replaces every term in the original sequence with the difference between that term and its successor in the sequence. All terms but one (the last) of the original sequence are replaced by the terms of the new sequence. The first-differences of a time sequence are the intervals between successive times. Their frequency distribution, as estimated by defining bin sizes and accumulating the number of terms in the first-difference sequence which lie within appropriate bins, is the "interval histogram." In addition to times and intervals, sequences of second- and third-differences were calculated and their frequency distributions derived.

Bin-widths were usually set to twenty milliseconds. At 50 fps, the maximum time resolution of movies is 20 msec. Also, the best time resolution of the EOG analyses, whether manual or automatic, was 10 msec. Regularities in chameleon saccade timing seem to occur close to these resolution limits (e.g., a 60 msec periodicity). The bin-width was therefore small. By accumulating saccades over time spans sufficiently long to put at least an average count of four per 20 msec bin, distributions not only had reproducible means, standard errors, medians, etc., but also had subjectively reproducible shapes. For the statistical tests described below, each bin was widened sufficiently to contain an "expected" count of five or more (see below).

The joint-interval histogram is a two-dimensional interval histogram of the interval pairs between three successive saccade times. The duration of the first interval of the pair is the coordinate in one dimension, the duration of the second interval is the coordinate in the second dimension, and the coordinate pair lies within a two-dimensional bin. A renewal process generates independent successive intervals (by definition). If the intervals of such a process have discrete durations, Billingsly (1961) has shown that N x N joint-interval histogram converges to the equivalent contingency table. In other words, the expected count, E, in a bin is calculated as the product of the two marginal distributions evaluated at the bin's two respective coordinates. The sum of the fractions, $(O-E)^2/E$, where O is the observed count in a bin, is accumulated over the entire histogram and is written X^2 (Sokal and Rohlf, 1969). This X^2 variate distributes as χ^2 with $(N-1)^2$ degrees of freedom. Thus, a quantitative measure of first-order serial correlation can be derived from the histogram (Cox and Lewis, 1966), although the histogram is likely to be more informative by its symmetry and structure than by this single quantitative test for renewal (Rodieck, Kiang, and Gerstein, 1962).

The second-difference frequency distribution is a condensation of the joint-interval histogram. The frequency of second-differences of a particular size can be calculated by summing the joint-interval histogram along a line which is (1) parallel to the diagonal through the origin and (2) intersects the margin at the appropriate difference. The expected frequency of second-differences of a particular size, assuming independence of intervals, is calculated as though the joint-interval histogram were a contingency table. The expected count for each bin along the appropriate line parallel to the diagonal of the joint-interval histogram is calculated and then the expected counts are summed along that line. An X^2, equal to the summed fractions, $(O-E)^2/E$, is calculated. If the intervals are independent, X^2 is presumed to have a χ^2 distribution with 2N-1 degrees of freedom (number of bins less one).

Since one may ask whether the second-difference sequence reflects a renewal process, the same test is applied to the third-difference distribution, using the second-differences as the marginal distributions from which the expected third-difference distributions are calculated. I found graphic portrayal of the contribution to an X^2 value from each bin more informative, however, than calculation of the probability that the X^2 arose from a renewal process. The fractions, $(O-E)^3/E\,|O-E|$, were plotted (e. g., Figure 13) in parallel with the observed distributions and carry the sign of the deviation of observed from expected bin count.

Cross Interval Distributions

One can examine the relationship between concurrent left and right saccade sequences in the following way: identify a saccade; then measure the time interval forward to the next, or backward to the previous contralateral saccade(s). If only the nearest contralateral saccade is measured, the frequency distribution of the intervals is termed the first-order forward (or backward) cross-interval histogram. Under the assumption that two saccade sequences are stationary, the hypothesis os their independence is tested. If two sequences are independent, the events of one sequence may serve as random origins for measurement of the other sequence. Using one unilateral saccade sequence to generate origins, the interval durations from these origins to the next contralateral saccade (or previous) have a predictable frequency distribution derived from the interval distribution of the contralateral sequence via the equivalent "survivor function." A function of the waiting-interval, _i_ (the interval of time between the occurrence of an event and its subsequent occurrence, namely the inter-saccade interval in this context), the survivor function describes the probability after a saccade of having to wait longer than _i_ until the next saccade of the same eye. Under the assumption of no relation between sequences, the frequency distribution of first-order cross-interval durations (normalized so that the total frequency equals one) is the product of the contralateral survivor function with the inverse of the contralateral mean interval (Perkel and Gerstein, 1967b).

RESULTS

Introduction

The results presented below may be split into two classes, order-independent results, and order-dependent results. The former are similar to certain results from the observation and theory of neural spike trains (Stein, 1965). The model against which the latter class of results is examined below is the renewal process. This process produces events such that the successive intervals between events are unrelated. If the saccade generation process is a renewal process, then the former class of results completely determines the latter class (Cox and Lewis, 1966). The results are presented in the following order:

The timing of unilateral saccadic occurrences is described, showing (1) order-independent results first, and (2) order-dependent results second. (3) Some timing relations between concurrent left and right saccade sequences are uncovered and timing patterns of bilateral saccade production are described.

The next section concerns horizontal sizes of saccades and starts with (4) the relationship between the amplitude of an EOG deflection due to a saccade and the deflection duration. Then follow (5) order-independent and (6) order-dependent descriptions of the horizontal sizes of saccades. My treatment of this facet of saccadic behavior is less complete and quantitative than the treatment of timing, partly because saccade size measurements are hard to make, and partly because I have only recently begun to analyze these data.

Finally, (7) the results of a simple experiment are described, namely occlusion(s) of one or both eyes of an animal.

Saccade Timing

An Overview

The horizontal EOG records have been photographed at different film speeds (Figure 7). The most time-compressed of the photographic records show that saccades often occur in "bursts," groups of about 50 saccades occurring over the period of a few minutes. The presence of the bursts indicates that inter-saccade intervals are probably positively correlated. Also note that larger EOG deflections occur in the bursts than elsewhere and that both left and right eyes participate in a burst of saccadic movements. Figure 8 shows cumulative number of saccades as a function of time, another view of the way in which saccadic behavior unfolded during sessions of long duration. In several cases,

Figure 7: EOGs, photographed at various rates and for various durations. Successive magnifications of the time axis, photographed from a single stretch of EOGs, are shown. Note the bursts of saccades, B. The top trace of each pair represents the right eye; an upward deflection of either trace represents an eye movement in the anterior (nasal) direction, a downward deflection, a movement in the posterior (temporal) direction.

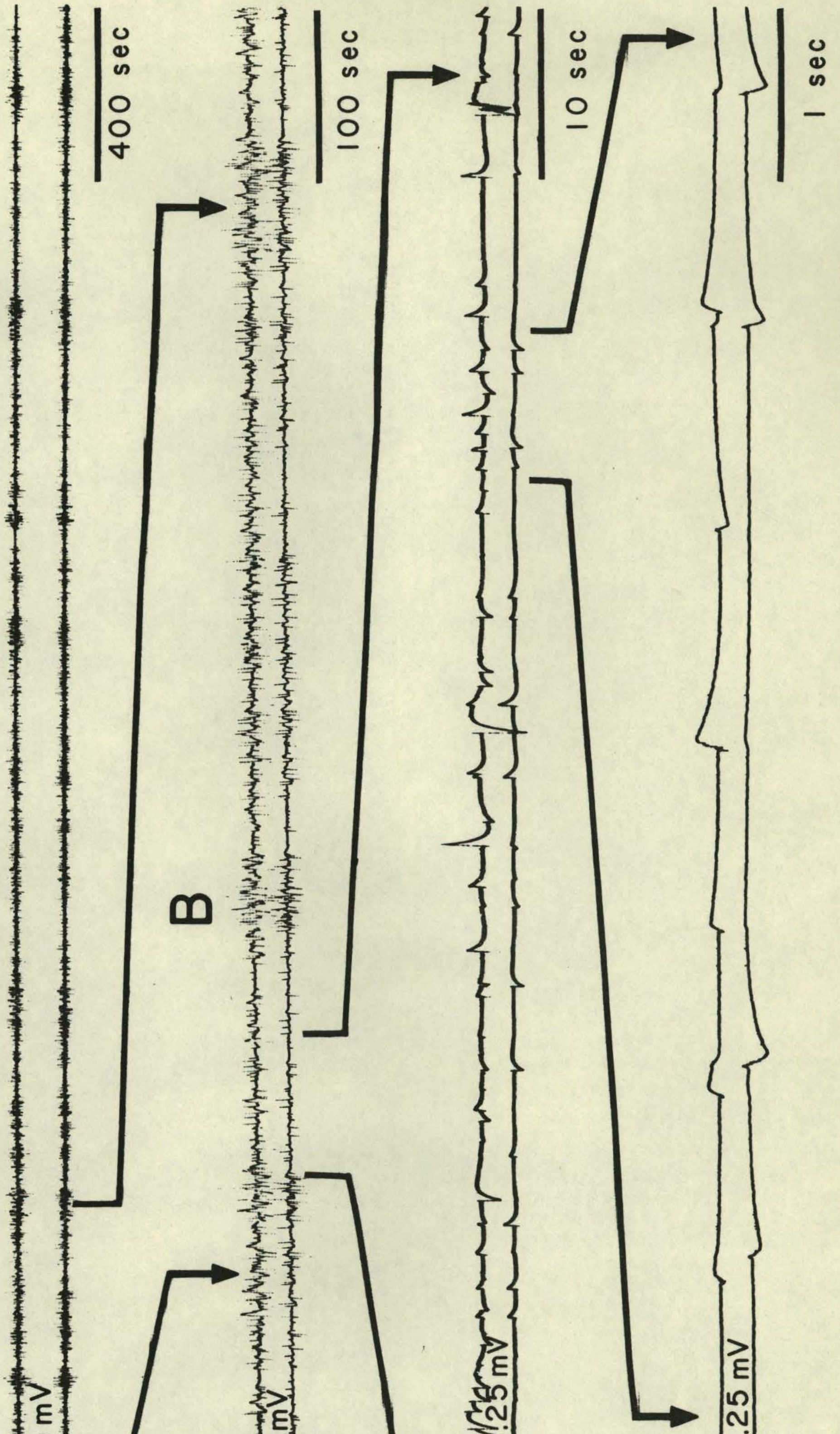
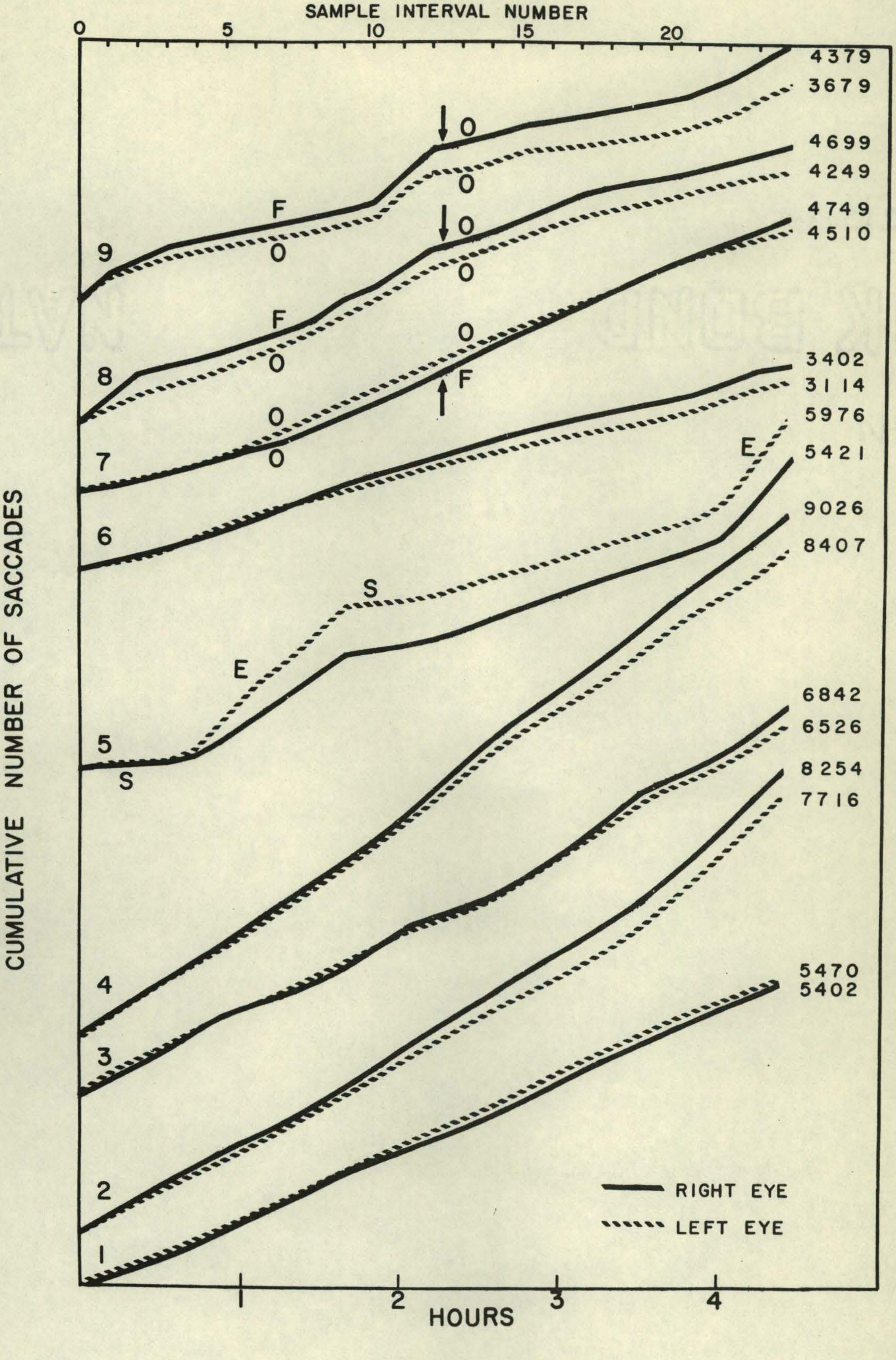

.50 mV
B
400 sec
.50 mV
B
100 sec
.25 mV
10 sec
.25 mV
1 sec

Figure 8: Saccadic accumulation over time. Saccade occurrences were inferred from horizontal EOG deflections "recognized" by analog circuitry used in analyses of EOGs from nine experiments (4 1/2 hr each). The final number of saccades is shown on the right margin of the graph; all origins on the left margin are at zero. Experiments 1-4 and 6-9 used *C. dilepis* individuals; experiment 5 used a *C. jacksoni* whose behavior was unusually variable; E = excited, S = sleeping. Experiments 6-9 involved occluding the animals' eyes with small bits of opaque tape which nevertheless allowed complete eye mobility; O = occluded eye, F = un-occluded eye. Note the similarity of the saccade production behavior of the left and right eyes, even with one or both eyes occluded. For each plot, the accumulated number of saccades was calculated at the end of each of 25 continguous intervals of equal duration, about 11 min, each.


SAMPLE INTERVAL NUMBER
0
5
10
15
20
CUMULATIVE NUMBER OF SACCADES
HOURS
1
2
3
4
9
8
7
6
5
4
3
2
1
F
O
O
F
O
O
O
O
O
O
F
S
E
S
E
S
4379
3679
4699
4249
4749
4510
3402
3114
5976
5421
9026
8407
6842
6526
8254
7716
5470
5402
RIGHT EYE
LEFT EYE

the gross rate of saccade production was constant for hours. Both eyes produced saccades at similar rates, even if one eye was occluded.

The intervals between successive saccades of an eye were collected and distributed according to frequency. The interval histograms have high positive skewness and exponential tails (Figure 9). If the frequency of occurrence of an interval defines its probability (independent of previous interval lengths), the probability per-unit-time of a next saccade becomes constant at large intervals (i. e., duration >1.5 sec).

A methodological note is apropos here. In most cases, interval histograms were accumulated for intervals no more than five seconds long. Such histograms therefore selectively characterize bursts. Computational simplicity dictated these truncations and, since they affect statistical interpretation, care has been exercised to bias statistical treatment in favor of the null hypothesis (that intervals are independently and identically distributed). Even though rare, intervals less than about 70 msec long have also been deleted from consideration and so are not seen in the interval histograms. Such intervals were due to electronic noise or to the "multiple saccades" described below.

Most of the interval distributions show a small number of short intervals of duration less than 150 msec. I call such pairs of saccadic EOG deflections "multiple saccades" (Figure 4c-d). They are always

Figure 9: Exponential tails on chameleon inter-saccade interval distributions. In (a), left eye data from a C. dilepis experiment were plotted with linear ordinate scaling (#4 of Figure 8; 4 1/2 hr). In (b), the same data were plotted with logarithmic ordinate scaling. Note the linearity of the "tail" of the latter plot. Both curves are frequency-polygons (50 msec bin-width), smoothed by weighting adjacent bin counts in the ratios, 1:2:1; for the semilog plot, the smoothing was done after log-transformation.

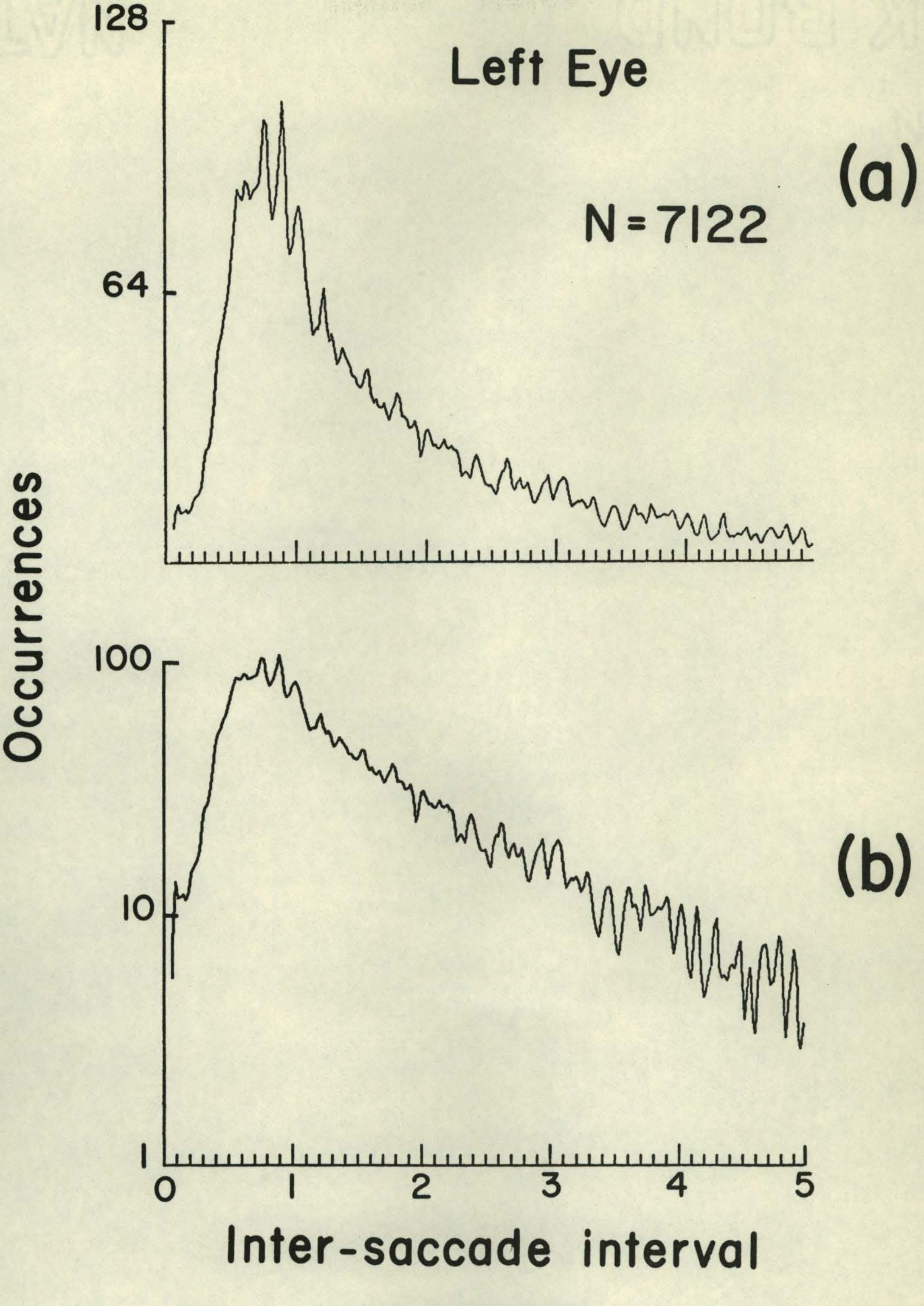
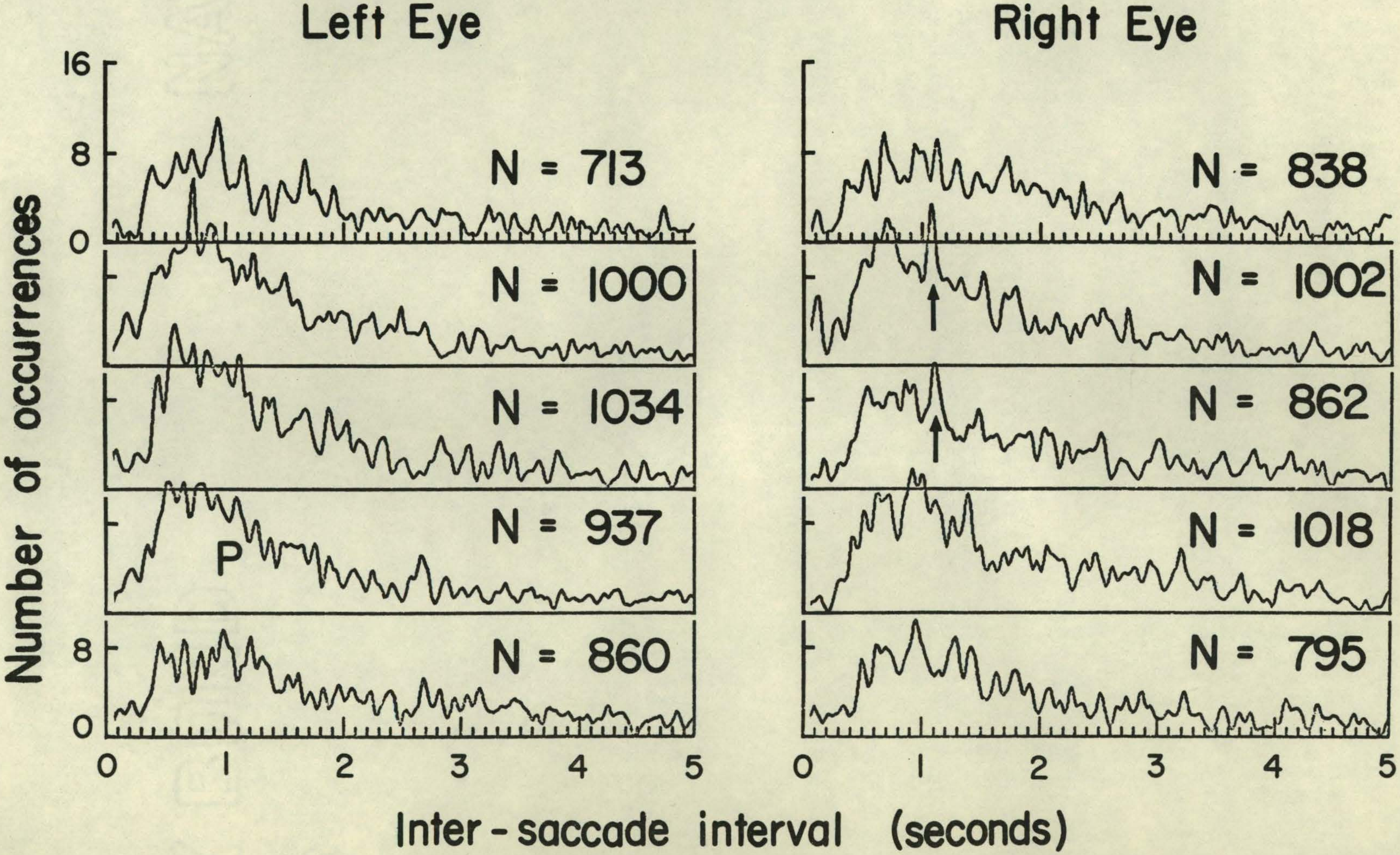

Left Eye
(a)
N = 7122
128
64
Occurrences
100
10
1
(b)
0
1
2
3
4
5
Inter-saccade interval
(seconds)

Figure 10: The structure and similarity of successive interval distributions. Inter-saccade interval distributions were formed from the data of consecutive and contiguous segments of an experiment (#1 of Figure 8). The curves associated with the first to last segments are placed on the page from bottom to top, respectively. The first four segments represent 1 hr of data, each, and the data are plotted for concurrent segments of the left and right saccade sequences. Note the evidences of structure in these curves (arrows) and of periodicity (p), as well as their similarity, one hour to the next. The curves are frequency-polygons (20 msec bins), smoothed by weighting adjacent bin counts in the ratios, 1:4:6:4:1.


Left Eye
Right Eye
16
8
0
8
0
N = 713
N = 1000
N = 1034
N = 937
N = 860
P
N = 838
N = 1002
N = 862
N = 1018
N = 795
0
1
2
3
4
5
0
1
2
3
4
5
Number of occurrences
Inter - saccade interval (seconds)

observed to be in the same direction. Multiple saccades are rare and not to be confused with bursts of saccades during which the vast majority of inter-saccade intervals exceed 200 msec in duration. They were especially common in the two types of experiments which tended to deprive the animals of fixation points, (1) the experiments in which the eye(s) were occluded, and (2) the experiment with a flashing environment. Finally, the single C. jacksoni which I observed made many more multiple saccades than either of the other two species of chameleons.

Many of the interval histograms show an almost complete lack of intervals shorter than about 200 msec (no multiple saccades). Histograms, accumulated from successive partitions of experiments during which the saccade frequency monotonically increased, show a dead time in the saccade generating system with few successive saccades closer than 200 msec apart, even though the mean, median, and modes of the distributions press close to this lower limit (Figure 11). It is possible that the 200 msec delay corresponds to a "reaction time."

During recording sessions when the animals were dozing with eyes still and closed, a sharp blow to their cage often resulted in a response saccade(s) after a delay of about 200 msec (Figures 4i and 12b).

Figure 11: Inter-saccade intervals and the "dead time." The distributions were taken from consecutive and contiguous segments of an experiment (#2 of Figure 8). The curves associated with the first to last segments are placed on the page from bottom to top, respectively; each of the six segments represents 45 min of data, and the data are plotted for concurrent segments of the left and right saccade sequences. Note that this *C. dilepis* slowly increased his rate of saccade production by both eyes during the course of the experiment. Yet, very short inter-saccade intervals (< 200 msec) do not appear to become relatively more frequent than longer intervals. A "dead time," about 200 msec long, is suggested by the intercepts of the dotted lines in the curves for the right eye (the dotted lines were fitted by eye). The curves are frequency-polygons (20 msec bins), smoothed by weighting adjacent bin counts in the ratios, 1:4:6:4:1.

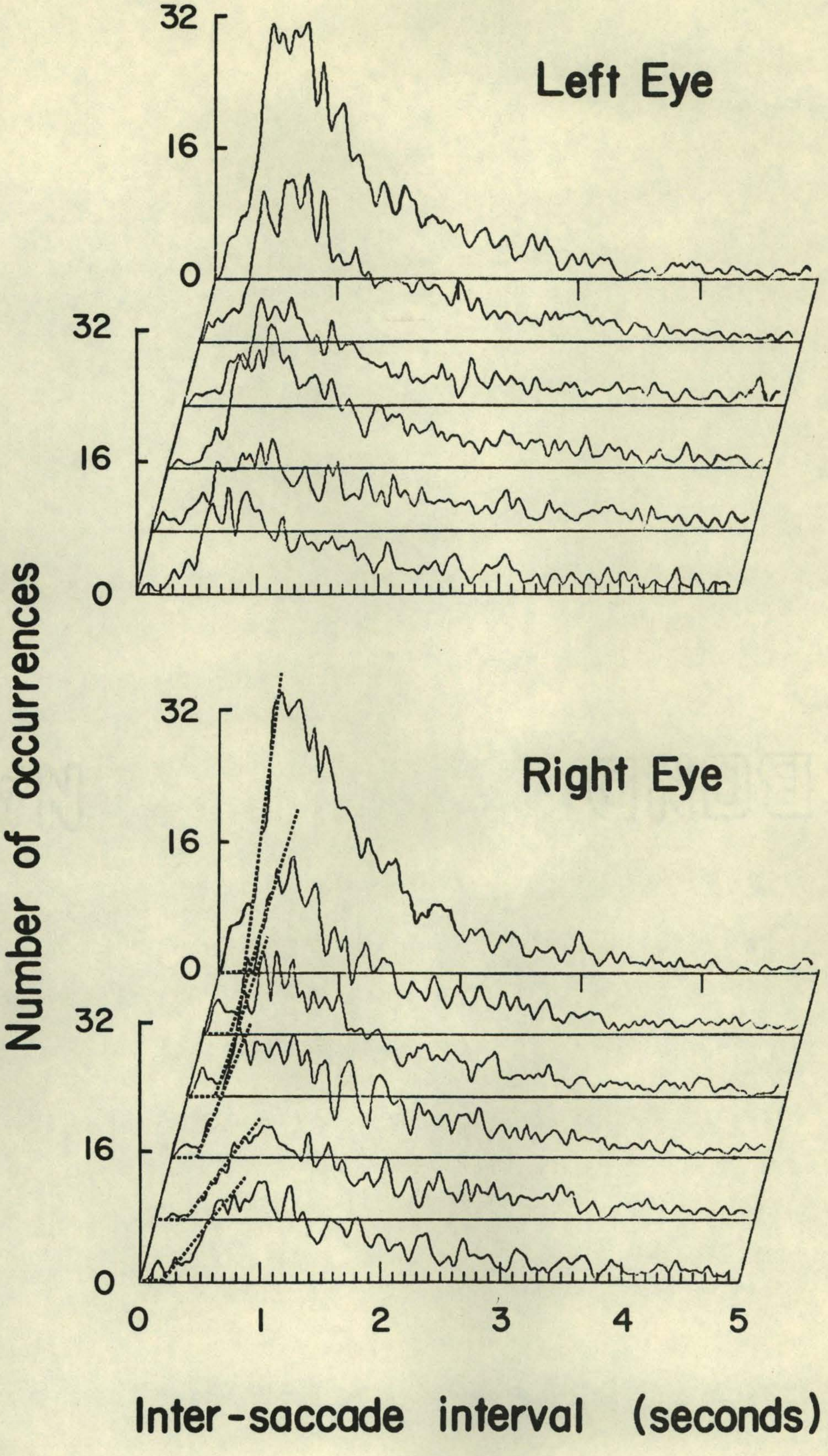
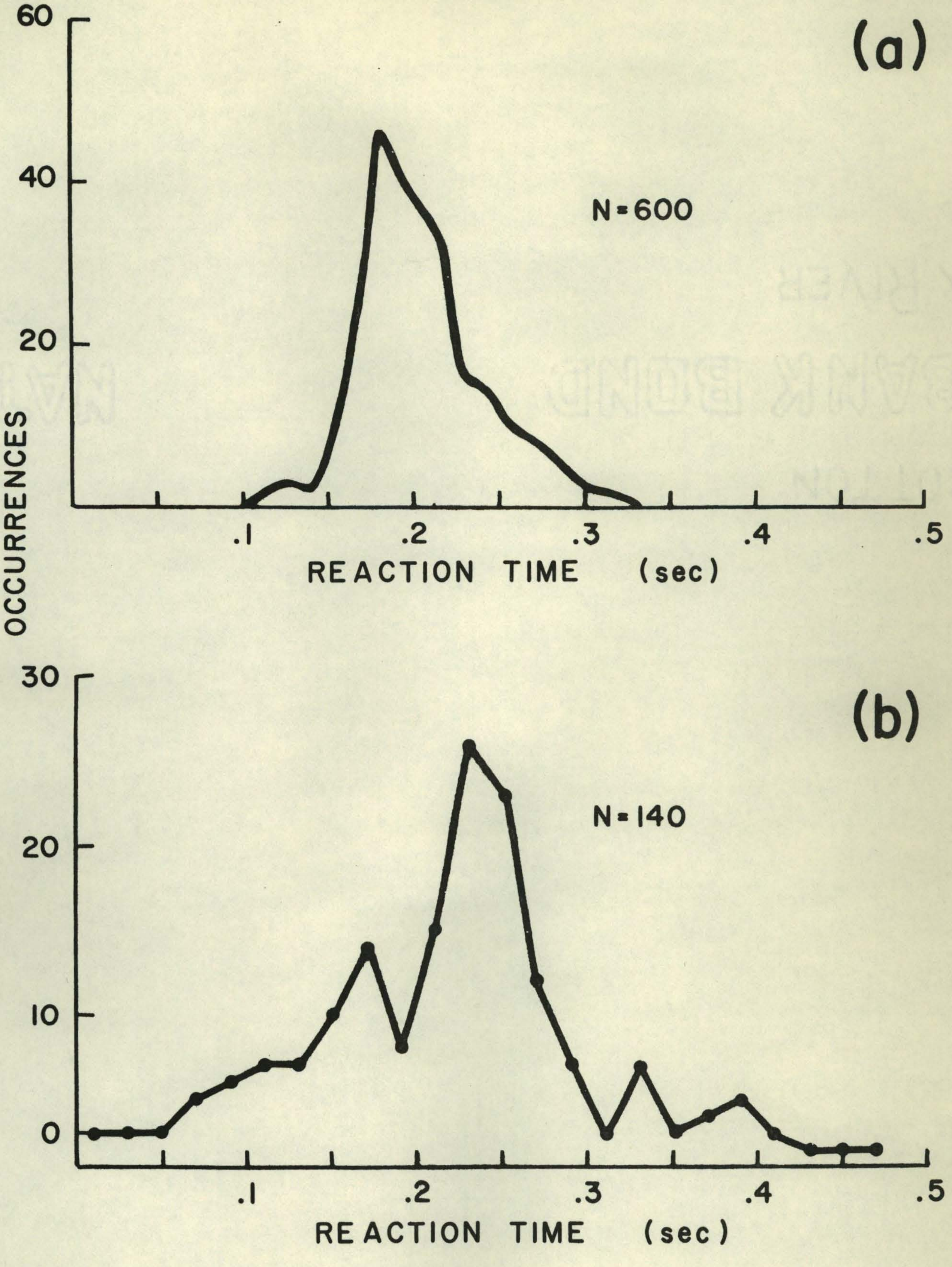

32
16
0
Left Eye
32
16
0
32
16
0
Right Eye
32
16
0
Number of occurrences
0
1
2
3
4
5
Inter-saccade interval (seconds)

Figure 12: Reaction times of *H. sapiens* and *C. dilepis*. (a), the times required for a human subject to refixate a spot moved in steps across the face of a television screen (redrawn from Latour and Bouman, in *Sensory Communication*, W. A. Rosenblith, Ed., 1961). (b), the times to eye saccades of a *C. dilepis* after a hammer-blow to the table upon which the cubicle containing the animal rested; prior to every hammer blow, saccades had been infrequent; the accumulated "reaction times" were the times to *all* saccades (of either eye) subsequent to the hammer blows.


60
40
20
(a)
N=600
.1
.2
.3
.4
.5
REACTION TIME (sec)
OCCURRENCES
30
20
10
0
(b)
N=140
.1
.2
.3
.4
.5
REACTION TIME (sec)

Serial Dependencies in Unilateral Saccade Timing

As mentioned above, if chameleons created independent inter-saccade intervals, then the interval histogram would fully describe saccade production. Each second- and third-difference, however, must depend on the occurrences of three and four successive saccades, respectively (recall that a second-difference is the difference between two successive inter-saccade intervals, and a third-difference is the difference between two successive second-differences). Sequences of second- and third-differences are examined below to see if they conform to the results expected if successive inter-saccade intervals were independent. A more commonly used test of renewal is later presented, a test dependent on the joint-interval histogram. I demonstrate that serial, unilateral inter-saccade intervals are not independent.

Typical second- and third-difference frequency distributions are shown in Figure 13. The second-differences are symmetric about zero. Therefore, no monotonic trends appear over the time spans from which the data were drawn. On the other hand, the third-differences have positive modes, medians, and means, indicating that successive second-differences tend to increase (Table 2).

Under the assumption that the first-difference frequency distributions were created by a renewal process, the expected second- and

Figure 13: 2nd- and 3rd-difference frequency distributions. Data were taken from the left eye of a C. dilepis for 4 1/2 hr (#2 of Figure 8). The lower pair of distributions of (a) and (b) are the 2nd- and 3rd-difference distributions respectively; the upper pair of distributions of (a) and (b) are measures of the deviations from the corresponding, hypothetically "expected,"* 2nd- and 3rd-difference distributions. The significances of the deviations were tested by summing the absolute values of the ordinates to X^2s, and locating the X^2s in χ^2 with 500 degrees of freedom (the histograms have 500 bins, each 20 msec wide); $p < .005$ that each observed 2nd- and 3rd-difference distribution was to be "expected."

---

*"Expected" frequencies of 2nd-differences were calculated from the observed frequencies of 1st-differences (inter-saccade intervals) under the assumption that successive 1st-differences were uncorrelated; "expected" frequencies of 3rd-differences were calculated from the observed frequencies of 2nd-differences, assuming that successive 2nd-differences were uncorrelated.

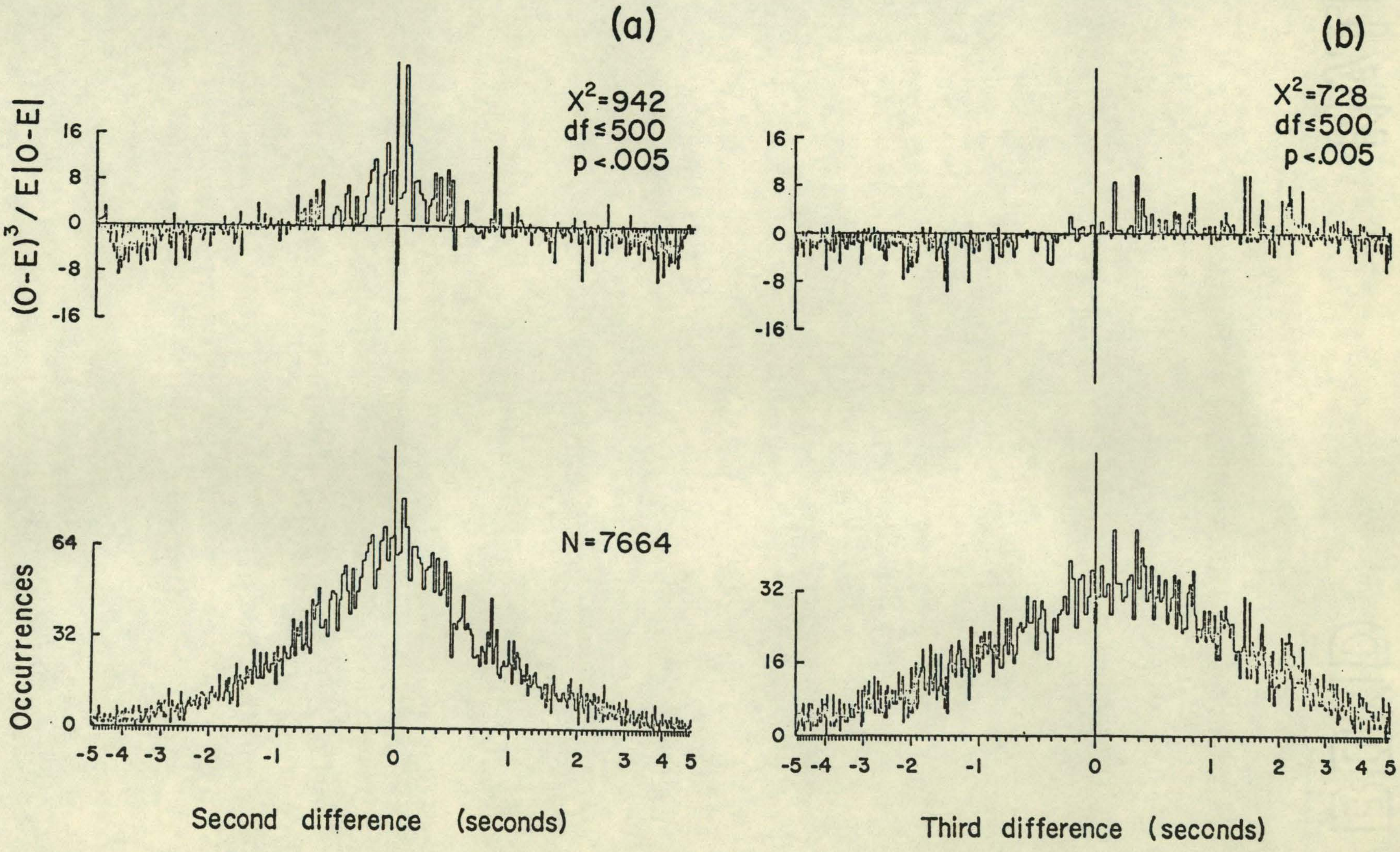

(a)
(b)
(O-E)^3 / E|O-E|
16
8
0
-8
-16
X²=942
df≤500
p<.005
X²=728
df≤500
p<.005
Occurrences
64
32
0
N=7664
32
16
0
-5 -4 -3 -2 -1 0 1 2 3 4 5
Second difference (seconds)
-5 -4 -3 -2 -1 0 1 2 3 4 5
Third difference (seconds)

Table 2: Saccade timing statistics. The time differences between successive saccades of an eye are the inter-saccade intervals, or 1st-differences. The differences of successive 1st-differences are the 2nd-differences, etc. Experiment results for 1st-, 2nd- and 3rd-differences are shown, placed in the appropriate row for the experiment and for whether left or right eye was the generator of the summarized data. Cross-interval measures are placed in the rows, R or L, to which the intervals are measured (e. g., measures on intervals, backwards from saccades of the left eye to the previous right eye saccade were placed in an R-row). The S of experiment 5 was a C. jacksoni; other Ss were C. dilepis (see Table 1). The experiments were 4 1/2 hr long. Experiments 7-9 involved eye-occlusion (see Figure 8) and the visual environment of experiment 10 was strobe-lighted.

TABLE 2

Experiment Number	Eye	Total No. Saccades	First-differences (Inter-saccade intervals) (sec)			Second-differences (sec)			Third-differences (sec)			First-order backward cross-intervals (sec)		
			Median	Mean	S. D.	Median	Mean	S. D.	Median	Mean	S. D.	Median	Mean	S. D.
1	R	5402	1.86	1.88	1.22	-.04	-.012	1.91	.38	.33	2.25	1.40	1.49	1.29
	L	5470	1.72	1.76	1.22	-.02	.010	1.91	.36	.36	2.15	1.40	1.45	1.30
2	R	8254	1.30	1.57	1.08	0	.016	1.55	.26	.22	1.99	0.94	1.22	1.13
	L	7716	1.36	1.61	1.12	-.02	.016	1.61	.28	.25	2.03	1.00	1.27	1.18
3	R	6842	1.42	1.60	1.14	+.02	.010	1.64	.28	.25	2.03	0.98	1.22	1.17
	L	6526	1.32	1.51	1.16	0	.024	1.70	.28	.30	2.04	1.04	1.30	1.25
4	R	9026	1.32	1.54	0.98	0	.016	1.41	.22	.21	1.90	0.90	1.14	1.06
	L	8407	1.44	1.62	1.01	-.02	.010	1.47	.24	.22	1.94	0.94	1.17	1.09
5	R	5321	1.04	1.29	1.04	0	.022	1.45	.14	.12	1.78	0.64	0.90	0.94
	L	5976	0.76	0.95	0.87	0	0	1.20	.14	.12	1.44	0.68	0.92	1.07
6	R	3402	1.90	1.78	1.20	0	.046	1.89	.38	.35	2.16	1.48	1.32	1.22
	L	3214	1.82	1.67	1.19	-.02	.016	1.82	.26	.24	2.16	1.84	1.37	1.27
7	R	4749	1.40	1.48	1.23	0	.012	1.74	.28	.31	2.08	0.96	1.10	1.19
	L	4510	1.50	1.45	1.34	0	.008	1.90	.34	.34	2.23	1.30	1.34	1.32
8	R	4699	1.14	1.32	1.12	0	-.004	1.64	.26	.28	1.97	0.98	1.18	1.20
	L	4249	1.22	1.33	1.25	0	-.038	1.79	.30	.30	2.186	1.30	1.31	1.23
9	R	4379	1.12	1.30	1.07	0	.030	1.56	.28	.28	1.92	0.76	1.00	1.09
	L	3679	1.20	1.33	1.17	0	.022	1.71	.34	.26	2.16	1.08	1.18	1.17
10	R	5398	1.44	1.58	1.13	0	.012	1.68	.28	.22	2.17	1.00	1.20	1.18
	L	6253	1.20	1.41	1.17	-.02	.014	1.61	.28	.27	2.02	0.90	1.15	1.15

third-difference distributions were calculated and compared with the actual frequency distributions. The fractions, $(O-E)^2/E$, were calculated and summed to X^2 variates which were compared with χ^2 with 500 degrees of freedom (the approximate number of 20 msec bins in the distributions). Five or more expected counts per bin are required for this test, so a sample size of at least 3000 was required. The X^2 variates were found to lie in the upper 0.5% of the χ^2 distribution (Table 3), thus showing that successive inter-saccade intervals are not independent, and that successive second-differences are not independent, either.

Plots of the contributing fractions, $(O-E)^3/E\,|O-E|$, are shown in Figure 13. They indicate that the greatest contribution to the second-difference X^2 arose from an excess of second-differences distributed symmetrically about zero with a peak at zero. The third-differences show a surfeit of negative sizes and an excess of positive sizes contributing to the third-difference X^2. By the above criteria, successive intervals tended to be too nearly equal (excess small second-differences). Second-differences tended, more than chance, to be successively larger (excess positive third-differences). Too often, in other words, successive inter-saccade intervals became progressively larger or progressively smaller.

Table 3: X^2 deviations from renewal and left-right independence. Assuming that left and right unilateral saccade sequences came from a renewal process, left and right "expected" 2nd- and 3rd-difference frequency distributions, f(E)s, were calculated from the observed 1st- and 2nd-difference distributions, f(O)s. X^2s were formed by summing the fractions, $(O - E)^2/E = X^2$. Assuming that left and right sequences were stationary, expected cross-interval distributions were calculated and compared with the observed distributions to form, as above, X^2 variates. The X^2s are tested against X^2s with 500 df for 2nd- and 3rd-differences, and 250 df for 1st-order cross-intervals' X^2s (df = # bins in distributions). The critical value for $p = .0005$ for 2nd- and 3rd-difference distribution X^2s is about 600, and about 330 for the cross-interval X^2s. "*" indicates $p \ll .0005$. These data came from the 10 automatically processed 4 1/2 hr experiments of Figure 8. The S of experiment 5 was a *C. jacksoni*; all other Ss were *C. dilepis.* Experiments 7-9 involved eye-occlusion, and experiment 10 was lighted stroboscopically.

TABLE 3

		Second-difference		Third-difference		1st-order cross-interval	
Experiment	Eye	X^2 (df=500)	$\overline{(O-E)^2/E}$ (sec)	X^2 (df=500)	$\overline{(O-E)^2/E}$ (sec)	X^2 (df=250)	$\overline{(O-E)^2/E}$ (sec)
1	R	1111*	-0.09	690*	0.47	783*	1.08
	L	1228*	-0.07	813*	0.42	459*	1.29
2	R	942*	0.10	728*	0.13	539*	1.30
	L	1035*	-0.06	663*	0.20	446*	1.69
3	R	1024*	0.06	693*	0.36	1075*	0.76
	L	1051*	-0.11	827*	0.41	924*	0.93
4	R	756*	0.09	632*	0.04	1118*	0.56
	L	881*	0.18	628*	0.06	572*	0.92
5	R	944*	-0.01	651*	0.09	3200*	0.47
	L	994*	0.05	729*	0.05	4121*	0.54
6	R	1000*	-0.04	724*	0.20	1132*	6.74
	L	1016*	-0.04	650*	0.28	1050*	7.66
7	R	1447*	-0.01	798*	0.28	2213*	0.44
	L	1378*	-0.02	792*	0.21	2946*	0.35
8	R	1010*	0.00	729*	0.06	2207*	0.62
	L	1052*	0.01	719*	0.27	2225*	0.48
9	R	922*	-0.01	664*	0.18	3430*	0.52
	L	856*	-0.09	549	0.13	3288*	0.30
10	R	1009*	0.13	655*	-0.13	1871*	0.52
	L	1147*	0.05	772*	-0.25	2064*	0.48

Figure 14 shows the observed and expected joint-interval histograms calculated for the inter-saccade intervals of a young C. hohnelii. Again, the fractions, $(O-E)^2/E$, are summed to an X^2 variate, ($X^2 = 893$). Placement of the X^2 variate in a χ^2 distribution with $(N-1)^2$ degrees of freedom (df = 361) shows that X^2 lies in the upper 0.5% of this χ^2 distribution. Thus the renewal hypothesis that successive intervals were independent is rejected again ($p < .005$). The positive contributions to X^2 come from the diagonal of the joint-interval histogram. But the excessive tendency to equality disappears for the longer intervals, 1.5 sec or more in duration.

When mean saccade frequency rises, inter-saccade intervals, less than 1.5 sec long, become relatively more frequent (Figure 11). One may expect the X^2 variates, calculated as above, to lie on increasingly remote positions of the associated χ^2 distributions. There is weak evidence that this prediction holds. Due to the small sample sizes, however, the degrees of freedom of the test χ^2 distributions were approximated (df $\geq$ # saccades/5). Regression lines of X^2 against saccade number (Figure 15) deviate from the family of curves describing constant fractions of χ^2 distributions of varying degrees of freedom (i.e., a curve for $p = 0.5$, a curve for $p = 0.05$, etc.). Figure 15 seems to suggest that the increase of saccadic frequency (measured on 20 min data

Figure 14: Joint-interval histograms, observed and "expected." These data were taken from a young (1 month old) *C. hohnelii*. For each observed saccade of an eye, the following two successive inter-saccade intervals added 1 to a bin (width = 100 msec x 100 msec) in the joint-interval histogram, (a). Both left and right saccade sequences contributed to this histogram. Not shown, are the marginal sums of the columns and rows, giving the frequency distributions of the 1st- and 2nd intervals, respectively. The product of the distributions is proportional to the "expected" joint-interval histogram, (b), given independence of successive interval durations. Each value, $(O-E)^2/E$, where O is the observed count in a bin in (a), and E is the expected count in the same bin in (b), is represented in (c) by the nearest integral number of dots, placed in the same bin. Only values where the observed count exceeded the expected count are shown in (c). The density of dots gives an indication of how the deviations from expected bin counts distribute. The sum of all fractions, $(O-E)^2/E = X^2 = 893$, is greater than 99.5% of the corresponding χ^2 distribution (df = 19^2), and the hypothesis that successive, inter-saccade intervals were statistically independent fails for these data.

Second interval (x 50^{-1} sec)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	1	0	1	4	5	9	9	2	14	2	4	3	4	5	2	7	2			
95	1	1	1	2	5	8	4	6	8	8	3	6	5	4	2	0	3			
90	2	1	1	2	7	6	15	12	12	9	5	9	7	8	5	5	3			
85	5	0	2	4	7	11	5	16	13	9	4	7	6	3	8	3	8			
80	1	0	5	4	9	17	20	13	12	10	3	8	15	9	3	7	5	4	4	3
75	2	2	4	7	15	13	17	17	18	17	11	10	11	8	10	8	5	1	5	4
70	3	2	6	2	14	28	17	25	19	16	11	23	17	13	9	7	0	5	4	2
65	3	4	4	7	20	24	25	22	24	23	16	22	12	12	9	7	6	6	2	4
60	3	2	4	15	24	36	39	30	32	19	27	25	18	20	10	11	12	8	2	8
55	5	1	9	17	22	43	49	40	38	21	20	23	15	18	10	11	10	11	4	10
50	3	1	6	15	37	39	39	34	34	21	37	22	13	14	15	14	10	5	4	4
45	8	6	11	25	44	48	52	47	45	52	46	28	12	19	15	16	14	16	5	5
40	3	6	8	25	48	62	66	47	51	46	28	21	29	21	17	16	12	7	7	3
35	2	5	14	33	71	74	71	58	50	32	47	41	21	30	13	14	12	8	8	6
30	6	5	10	29	79	68	68	63	58	34	44	25	29	15	20	15	13	11	6	8
25	1	15	15	45	66	68	62	45	36	35	30	17	16	11	15	12	6	13	3	2
20	4	10	19	25	27	57	30	22	19	15	16	16	8	9	6	4	13	5	1	3
15	2	9	8	13	14	11	8	16	10	5	6	7	6	4	2	3	2	2	1	0
10	3	0	3	5	9	10	5	12	3	3	3	4	3	0	2	1	0	1	0	2
5	6	4	1	3	2	2	5	9	6	1	4	4	4	3	3	2	1	1	0	0

	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	2	2	3	6	10	11	11	10	9	7	8	7	7	6	4	4	4	4	2	3
95	1	2	3	6	10	11	11	9	9	7	8	7	6	6	4	4	4	4	2	3
90	2	2	4	8	14	14	14	12	12	10	11	10	9	7	6	6	5	5	3	3
85	2	2	4	8	15	16	15	13	13	10	11	10	9	8	6	6	6	5	3	4
80	2	3	5	9	17	18	18	16	14	12	13	12	11	9	7	7	7	6	4	4
75	2	3	5	10	17	19	18	16	15	12	14	12	11	9	7	7	7	6	4	4
70	3	3	6	12	21	23	22	19	18	15	17	15	13	11	9	9	8	8	5	5
65	3	4	7	14	25	26	26	23	21	17	19	17	15	13	10	10	10	9	6	6
60	4	4	8	16	29	31	30	26	25	20	22	20	18	15	12	12	11	10	7	7
55	4	5	9	18	32	34	33	29	27	22	25	22	20	17	13	13	12	11	7	8
50	4	4	7	15	26	28	28	24	22	18	20	18	16	14	11	11	10	9	6	6
45	5	5	10	19	35	37	36	32	30	24	27	24	22	19	15	14	14	12	8	9
40	5	5	10	20	35	38	37	32	30	25	27	25	22	19	15	14	14	12	8	9
35	6	6	11	23	41	43	43	37	35	29	32	28	25	22	17	17	16	14	9	10
30	6	6	12	23	41	44	43	38	35	29	32	29	26	22	17	17	16	15	9	10
25	5	6	11	21	38	41	40	35	33	27	30	27	24	21	16	16	15	14	9	9
20	3	3	6	13	23	24	24	21	19	16	18	16	14	12	10	9	9	8	5	6
15	2	2	3	6	10	11	11	9	9	7	8	7	7	6	4	4	4	4	2	3
10	1	1	2	3	6	6	6	5	5	4	4	4	4	3	2	2	2	2	1	1
5	1	1	2	3	5	6	5	5	4	4	4	4	3	3	2	2	2	2	1	1

First interval (x 50^{-1} sec)

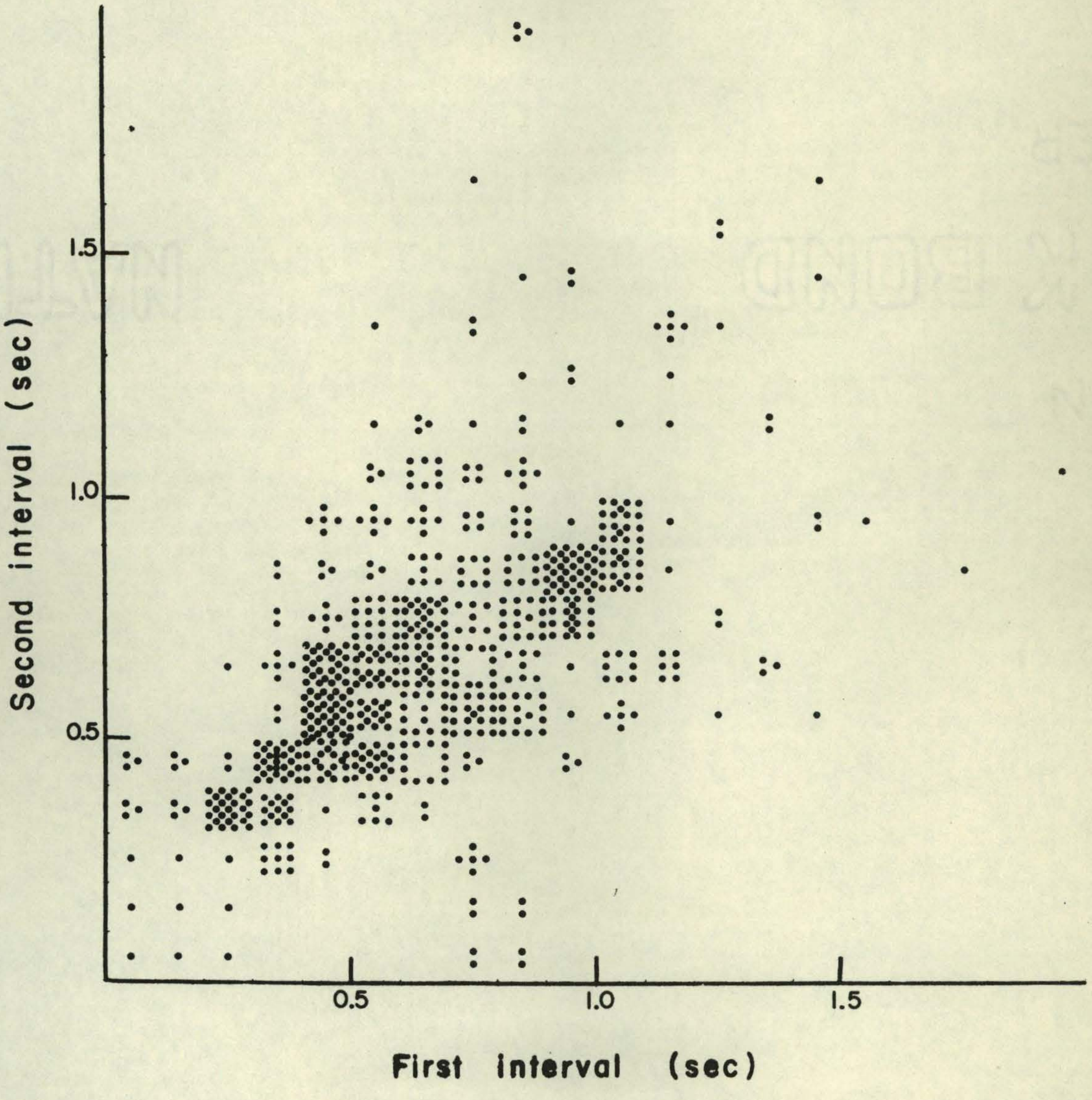
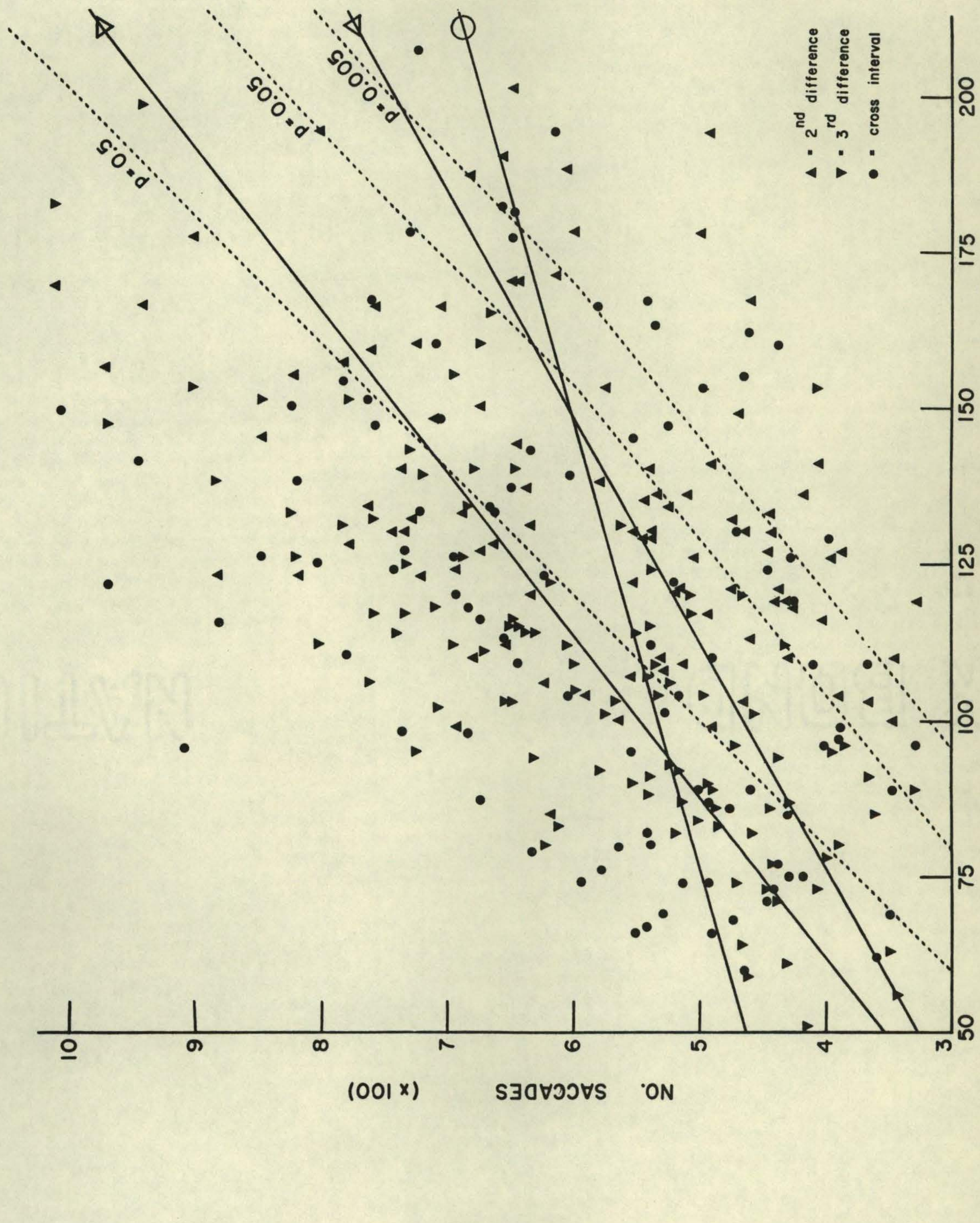


Figure 15: X^2s, as functions of saccade-count/unit-time. The dotted lines show the likelihood of an X^2 value to be larger (to the right of the lines), assuming that successive inter-saccade intervals of an eye are from a renewal process and that left and right saccade sequences are independent. These lines represent extreme requirements of the X^2 variates, however, because they are based on χ^2 distributions with df = # saccades/5. But the X^2 calculations were made with all expected bin-counts $\geq$ 5. So df is over-estimated by the calculation. The linear regression lines are drawn for 2nd-difference, 3rd-difference, and cross-interval X^2s, against the hypotheses above. They indicate an increasing deviation with increasing saccade-count/20 min. The data were taken from left eye and right eye saccade sequences of 3 C. dilepis (#1, #2, and #3 of Figure 8). (Regression slopes and their standard errors, and the product-moment correlation coefficients are: 1st-diff., slope = 2.7 ± 0.6, r = 0.5; 2nd-diff., slope = 3.9 ± 0.3, r = 0.8; cross-intervals, slope = 1.42 ± 0.5, r = 0.3.)


NO. SACCADES (x 100)
10
9
8
7
6
5
4
3
50
75
100
125
150
175
200
X²
p=0.5
p=0.05
p=0.005
▲ = 2nd difference
▼ = 3rd difference
● = cross interval

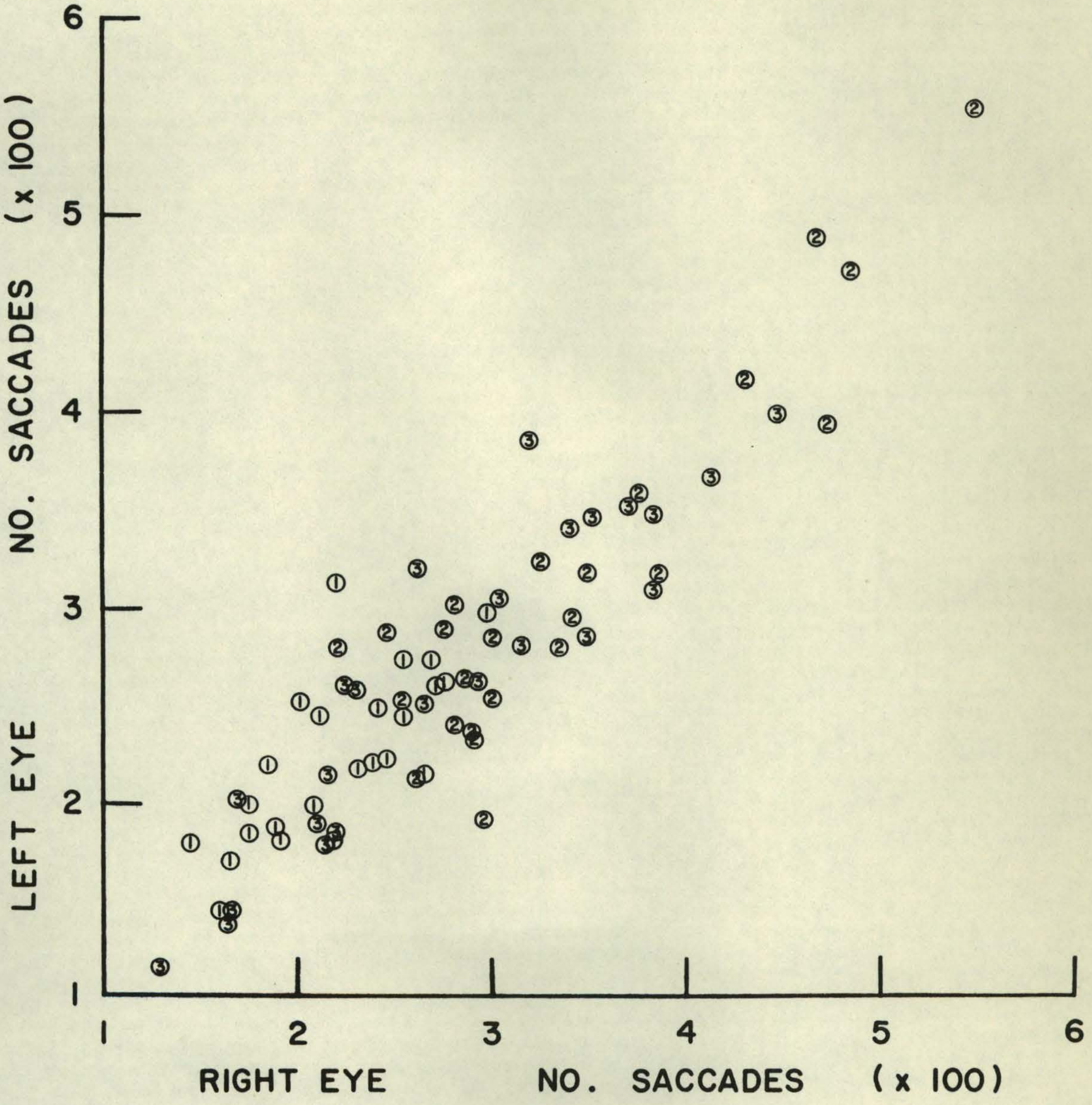
segments) increases the strength of serial dependencies among saccade occurrence times.

The non-renewal aspects of these data are not due to simple non-stationarities such as trends. Stationarity is most directly assessed by comparisons of separate analyses of the segmented data (Perkel and Gerstein, 1967a) and, by virtue of the similar shapes of distributions taken from successive segments of data (Figure 10), many saccade sequences appear stationary. The departures from renewal discussed in the thesis occur in all cases (i. e., both in cases of possible stationarity and in cases of certain non-stationarity; Table 3).

Bilateral Timing Patterns

In addition to the gross similarity between left and right sequences shown by the cumulative saccade plots (Figure 8), concurrent left and right saccade sequences are correlated over short intervals of time (e. g., ten minutes or less). The numbers of left and right saccades co-vary in time (Figure 16) as do other properties of the concurrent left and right saccade sequences. To emphasize this point, I paired illustrations taken from concurrent saccade sequences of both left and right eyes of an animal (Figures 7, 8, 10, 11, 18).

Figure 16: Numbers of saccades concurrently produced by left and right eyes of chameleons. Data were taken from three 4 1/2 hr experiments (#1, #2, and #3 of Figure 8). Each point represents 11 min of data taken from the experiments indicated by the encircled numbers. (Product-moment correlation coefficient, r = 0.91.)


LEFT EYE NO. SACCADES (x 100)
RIGHT EYE NO. SACCADES (x 100)
1
2
3
4
5
6
1
2
3
4
5
6
①
②
③

The first-order cross-interval durations provide quantitative evidence of bilaterally-coupled saccade behavior. First-order forward and backward cross-interval distributions (Figure 17, 18) exhibit a more-than-chance tendency of saccades of the left and right eyes to occur within 100 msec of one another ($p < .005$ that left and right saccade sequences are independent). A goodness-of-fit test was calculated (Sokol and Rohlf, 1969), again using the X^2 variate, summed from the fractions $(O-E)^2/E$. The expected counts in the bins are calculated as in the Methods above. The test has been performed only on backward cross-interval distributions, although the forward cross-interval distributions taken from the C. hohnelii data also show an excess of near-simultaneous left and right saccades.

Neighboring left and right saccades are also observed to be separated by interval durations which distribute as the unilateral inter-saccade interval durations. This latter phenomenon is most clear in the C. hohnelii data, but may sometimes be found in C. dilepis data by plotting, not only the cross-interval distributions, but also the fractions $(O-E)^3/E\,|O-E|$ (Figure 18b). Note that saccades of left and right eyes often lie within the unilateral dead time of one another, indicating that left and right saccades need not wait upon a single refractory process common to both visuo-motor systems.

Figure 17: Forward cross-interval distributions. The frequency distributions of the durations of intervals forward from a left-eye-saccade to the next right-eye-saccade, is shown for 20 min of data from a young C. hohnelii in (a). The distribution forward from right to left is shown for the same 20 min in (b). If left and right eye saccades were timed independently, intervals less than 0.2 sec would probably have been more rare, and intervals between 0.2 and 0.4 sec, more common. The data were manually analyzed from EOGs. The plots are frequency-polygons with 20 msec bin-widths.

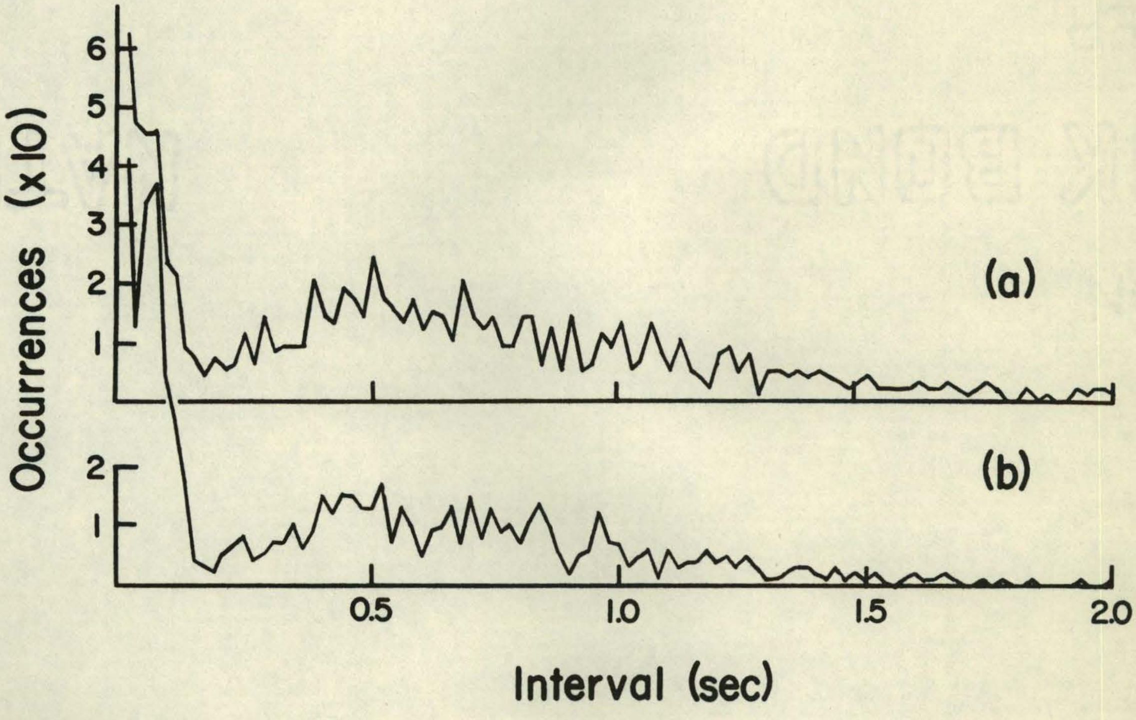
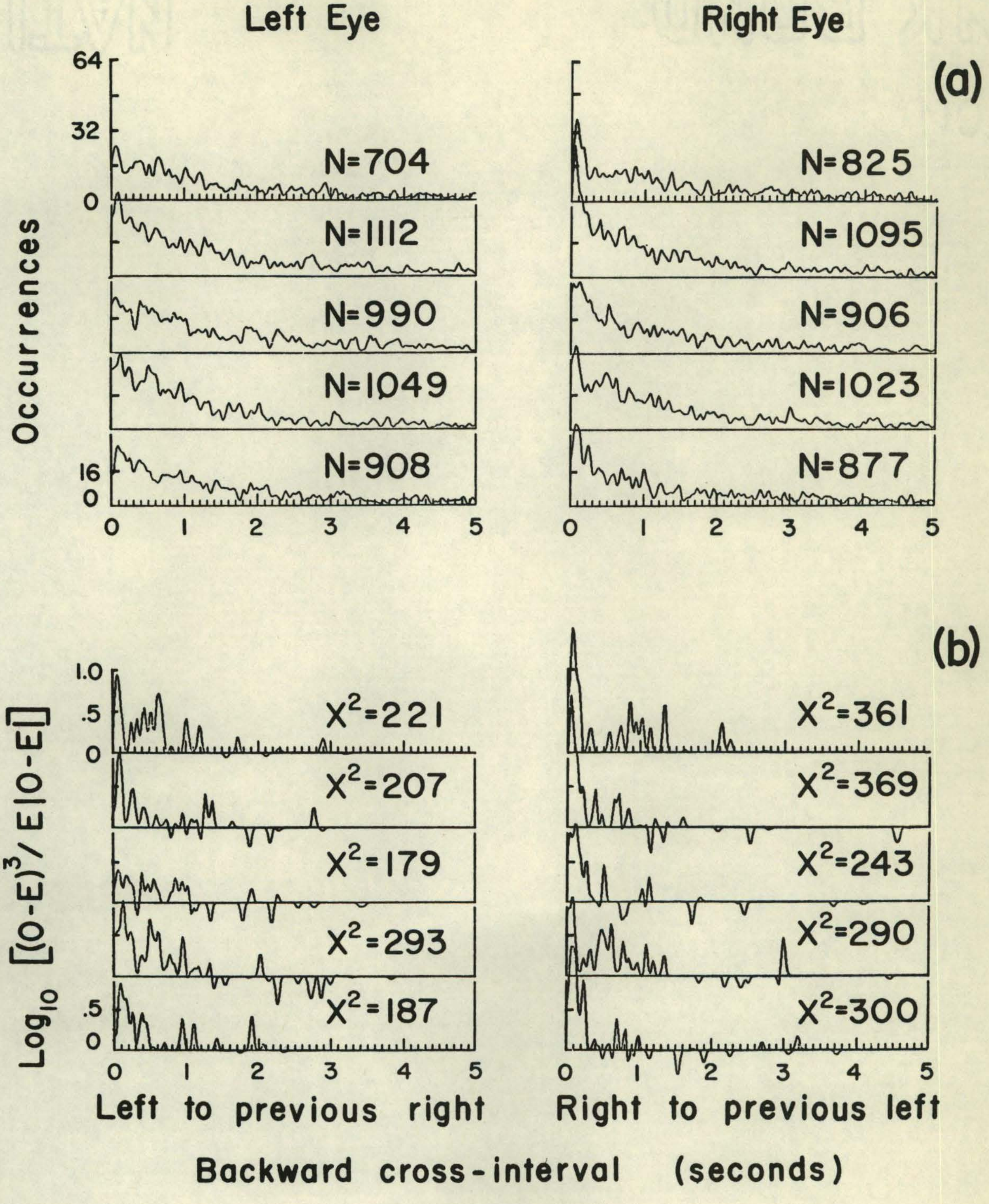

Occurrences (x10)
6
5
4
3
2
1
(a)
2
1
(b)
0.5
1.0
1.5
2.0
Interval (sec)

Figure 18: Backward, 1st-order cross-intervals. Frequency distributions of such intervals are shown in (a); the intervals are measured from contralateral eye saccades to the single, nearest, previous saccades of the ipsilateral eye. The distributions were taken from consecutive, contiguous segments of an experiment (#1 of Figure 8). The curves associated with the first to last segments are placed on the page from bottom to top, respectively. The first four segments represent 1 hr of data, each, and the data are plotted for concurrent segments of the left and right saccade sequences. A measure of the deviations of the distributions, above, from hypothetically "expected"[*] distributions is plotted in (b), below, in a 1:1 relationship with the curves of (a). The X^2s are the accumulated sums of the absolute values of the ordinates. The curves of (a) and (b) are frequency-polygons (50 msec bin-width), smoothed by weighting adjacent bin counts in the ratios, 1:4:6:4:1; in semilog plots, the smoothing was done after log-transformation.

[*] If left and right saccade sequences are stationary and independent, then the 1st-order cross-intervals, to the left eye's saccades, or to the right eye's saccades, should distribute proportionally to the survivor functions of the left eye's saccades and the right eye's saccades respectively.


Left Eye
Right Eye
(a)
64
32
0
16
0
N=704
N=1112
N=990
N=1049
N=908
N=825
N=1095
N=906
N=1023
N=877
Occurrences
0
1
2
3
4
5
(b)
1.0
.5
0
.5
0
X^2=221
X^2=207
X^2=179
X^2=293
X^2=187
X^2=361
X^2=369
X^2=243
X^2=290
X^2=300
Log10 [(O-E)^3/ E|O-E|]
Left to previous right
Right to previous left
Backward cross-interval (seconds)

The left-right dependency (as measured by the X^2 variates) increases with increasing saccade frequency (Figure 15). Just as for the individual saccade sequence results above, the relation of the X^2 variates to the corresponding χ^2 distributions seems to show increasing deviation with increasing frequency.

The quantitative examination of simple unilateral and bilateral timing relations, described above, was prompted by my early subjective observations of patterns in the bilateral timing of chameleon eye movements. To define patterns of bilateral saccadic behavior, data are presented in a different way below. The analyses of "switching" and "triads" (defined below) have not been fully computer-implemented and therefore data from the automatically analyzed sessions have not been displayed in this way. The data are from manual analyses of the young C. hohnelii EOGs.

One way of examining the possibility of a shifting left-right relationship is to look at the way in which left and right saccades are interwoven at different saccade frequencies. Therefore, "switches" were defined as pairs of consecutive saccades, one of the left eye, one of the right. It is readily seen that the left-right relationship changed (Figure 19). At the highest saccade frequencies (whether measured on one or both eyes), the eyes alternated much more than they did when the frequency of saccades dropped to lower values, where "runs" of left or right saccades tended to occur.

Figure 19: Left-right saccade "switching" as a function of saccade frequency. Successive groups of 33 adjacent saccades were accumulated, irrespective of whether the saccades were of left or right eyes. The number of "switches,"* expressed as a percentage of the maximum possible 32 switches, is plotted against the average-time/saccade in (a); the same percentage is plotted, in (b), against the average-time/left-eye-saccade. The data were taken from hand-analyzed EOGs of a young (1 month old) C. hohnelii.

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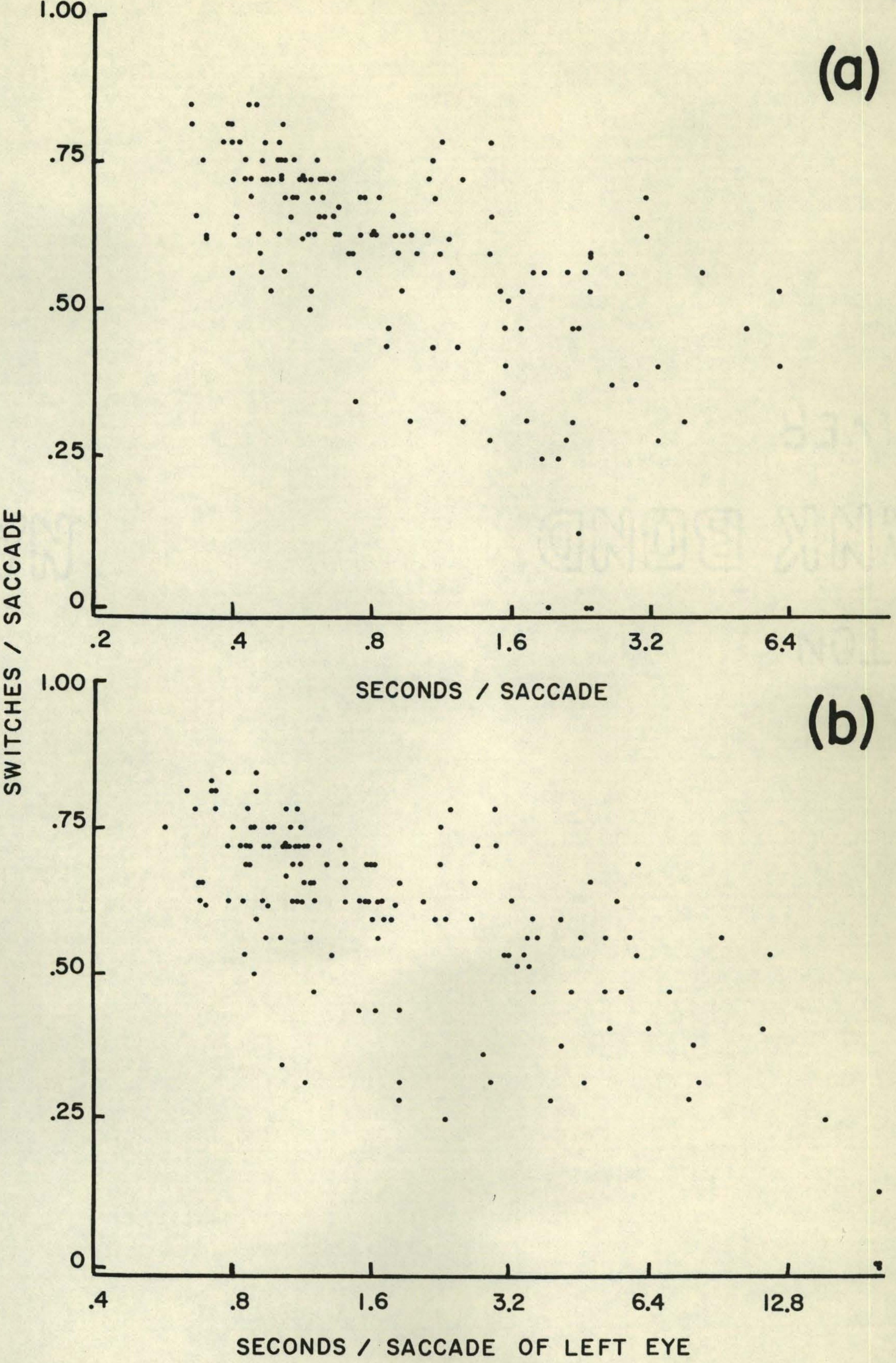
*A "switch" is defined as a pair of saccades which are of different eyes but which are nearest neighbors in time. Thus, 1 switch/saccade is the maximum possible switching rate.


(a)
SWITCHES / SACCADE
1.00
.75
.50
.25
0
.2
.4
.8
1.6
3.2
6.4
SECONDS / SACCADE
(b)
1.00
.75
.50
.25
0
.4
.8
1.6
3.2
6.4
12.8
SECONDS / SACCADE OF LEFT EYE

I have not provided an "expected" distribution of switches versus mean inter-saccade interval duration. The dead time and the non-random relationship between successive inter-saccade intervals greatly complicate this issue. For example, since both eyes of an animal show dead times of similar duration after the occurrence of a saccade and during which the occurrence of another saccade is very unlikely (about 200 msec), left-right alternation is bound to occur when inter-saccade intervals of both eyes are very short. The excessive near equality of successive short intervals further maintains the alternating state by reducing inter-saccade interval variance. I have shown that the mean frequencies of left eye and right eye saccade occurrences are positively correlated (Figure 16), which again reinforces the likelihood of left-right alternation. The frequent occurrences of near simultaneous left and right saccades help bias bilateral saccade production toward alternation.

With these considerations in mind, I think that Figure 19 shows unexpectedly long runs of saccade activity of one eye when inter-saccade intervals average one second or more. Additional circumstantial evidence of this sort of departure from a random left-right relationship is frequently found in EOGs (Figure 21). The high switching rate (nearly one per saccade) at high saccade occurrence frequencies is further explicated by the patterns of "triads" described below.

If a saccade is immediately preceded and immediately followed by saccades of the contralateral eye, this group of three is called a "triad." The interval between the first and second saccades has been plotted against the interval between the second and third saccades (Figure 20). The "triad" scattergram shows that when the first cross-interval durations are shortest (less than 100 msec), the second intervals are about one-half second in duration. In other words, at the highest rates of occurrence, left and right saccades prefer to occur about simultaneously (phase-locked at zero degrees). At slightly lower saccade rates, left and right saccades occur alternately with first and second intervals about equal in size (phase-locked at 180°). The term "rate" here refers to the inverse of the duration of the triads (only three saccades in the calculation of rate). The tendency of triad patterns to repeat themselves over and over has not been quantified, although such repetitions do occur. Figure 21 presents EOGs of the two triad patterns described above, and of "runs" of ipsilateral saccades. These EOGs demonstrate that repetition of the above patterns does occur. Figure 21 also shows a special, syncopated saccadic pattern which has been observed in moving animals. This pattern is not, however, strictly confined to periods of locomotion. The structure of chameleon saccade time sequences is certainly complex and resists simple statistical description.

Figure 20: A scattergram of "triads." If the saccade of an eye has nearest neighbors in time, before and after, which are saccades of the contralateral eye, the group of three saccades is called a "triad." The first and second inter-saccade intervals of the triads define points in this scattergram. The scattergram pattern shows that the central saccade (in time) is not randomly placed with respect to the two other saccades. Rather, it tends to be 180° out-of-phase or, alternatively, nearly in-phase. The data were taken from hand-analyzed EOGs of a young (1 month old) C. hohnelii.

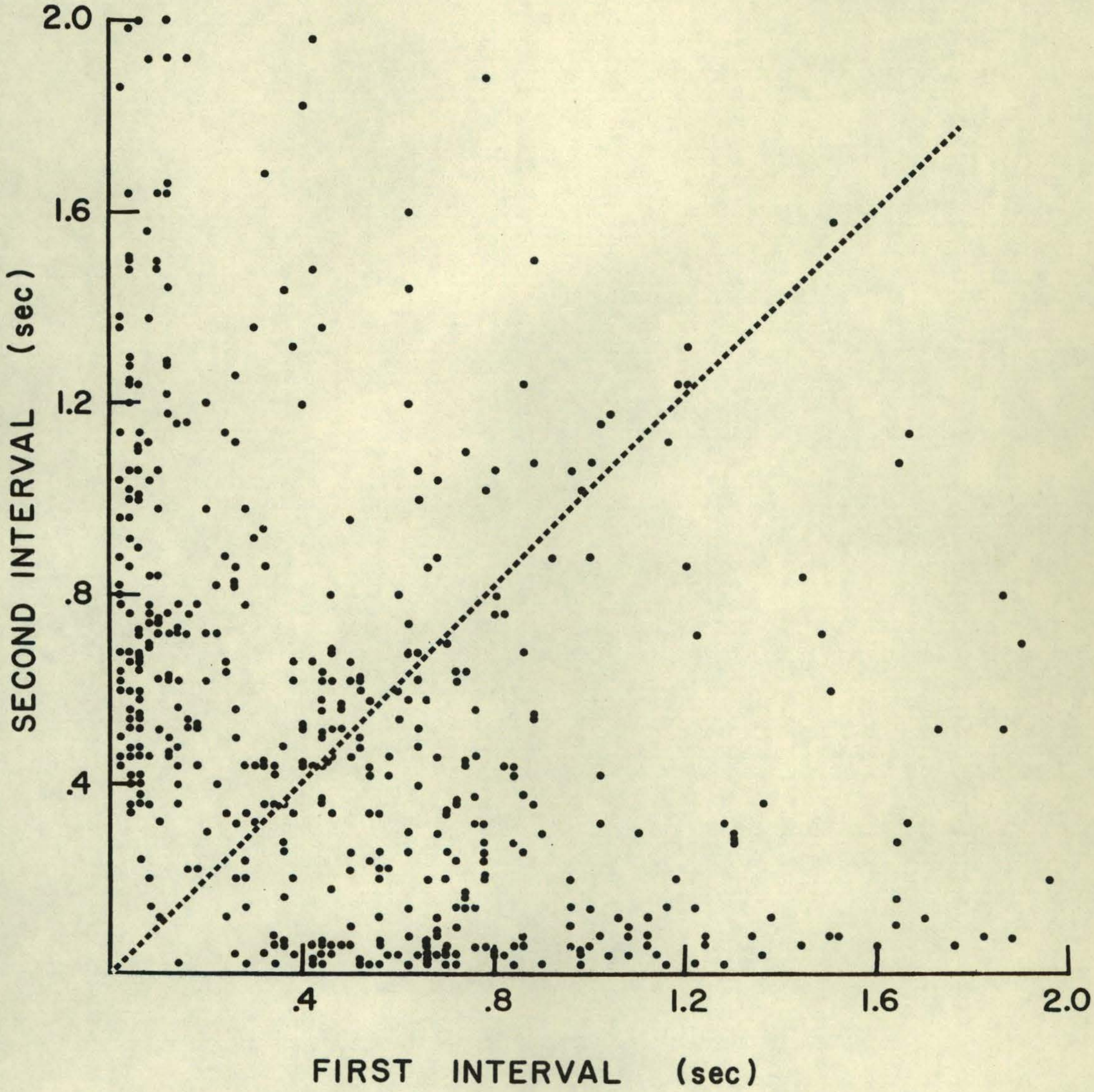
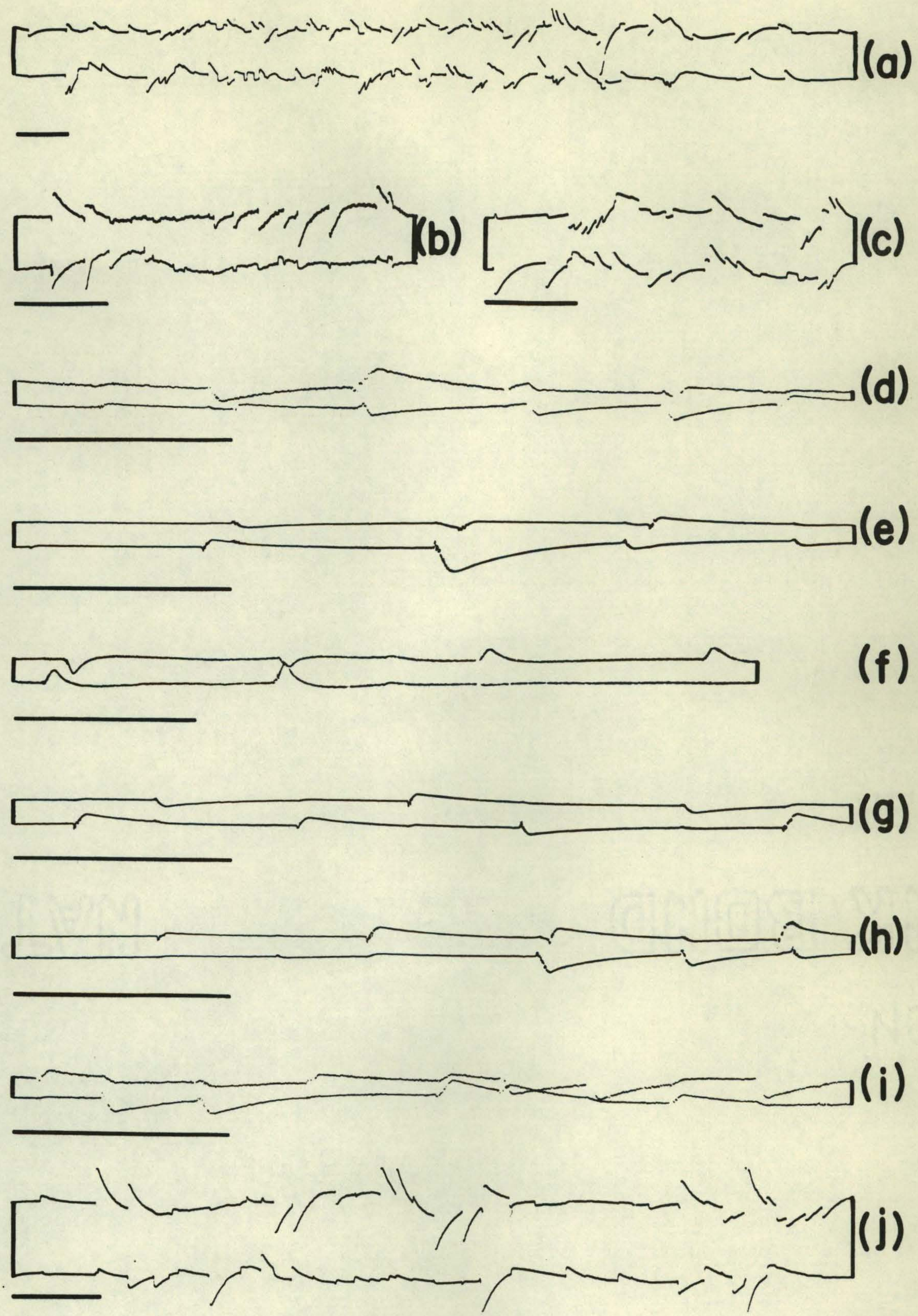

SECOND INTERVAL (sec)
2.0
1.6
1.2
.8
.4
.4
.8
1.2
1.6
2.0
FIRST INTERVAL (sec)

Figure 21: EOGs of chameleon saccade patterns. The top trace of each pair represents the right eye; an upward deflection of either trace represents an eye movement in the anterior (nasal) direction, a downward deflection, a movement in the posterior (temporal) direction. A "burst" of saccades is shown in (a). For (b) and (c), the right eye performed a "run" of saccades; note the similarities of successive EOG deflection amplitudes in the runs. Closer inspections of (a), (b), and (c) reveal coordinated EOG deflections from left and right eyes. This coordinated pattern, shown repeating in (c) and (f), was especially common at high saccade frequencies. Alternation of left and right eye saccades is illustrated by (g). (h) and (i) show combinations of the in-phase (simultaneous) and out-of-phase (alternating) left-right saccade patterns. Locomotion was often accompanied by the pattern shown in (j) for the right eye. Both eyes can participate, however. (a)-(c) and (j) were taken from the same C. dilepis, (e), (g), and (h) from another C. dilepis, (d) and (i) from a C. jacksoni, and (f) was taken from a young C. hohnelii. Calibrations: horizontal bars in (a)-(c) and (j) represent 5 sec, and all other horizontal bars are 1 sec. The vertical bar represents 1.0 mV in (a), .40 mV in (b) and (j), .75 mV in (c), .25 mV in (d) and (i), .30 mV in (e), (g), and (h), and .10 mV in (f).


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)

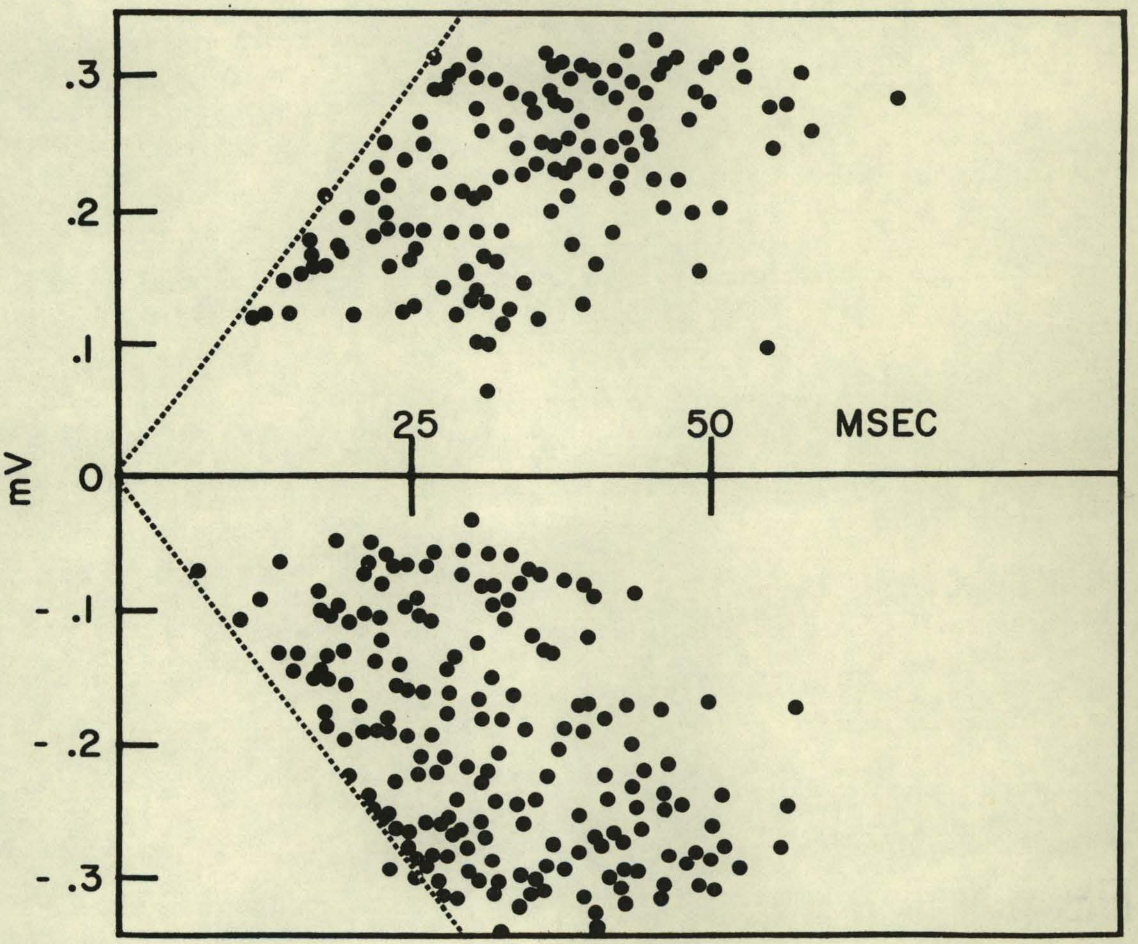
Saccade Amplitudes

I have not yet thoroughly analyzed chameleon eye movement sequences in terms of saccade amplitudes as well as saccade timing. The subject is so complementary to the discussion which will follow, however, that I present below some of the information available at this time. The reader should note that saccade amplitudes are not the primary data; rather, EOG deflection amplitudes have been measured. (EOG deflection amplitudes may be related in a fairly simple way to the associated saccade amplitudes; see Discussion.) First, the amplitude-duration relationship of saccadic EOG deflections is described. Then some frequency distributions of amplitudes of saccadic EOG deflections are presented (taken from left and right eyes of an adult *C. dilepis*). These order-independent results are followed by a short examination of unilateral serial size and direction relations and lastly, by an examination of bilateral size and direction relations.

The Saccadic EOG Deflection

The amplitudes and durations of the saccadic, horizontal EOG deflections of a *C. dilepis* were recorded (Figure 2a) and plotted as points in a scattergram (Figure 22). The point scatter is restricted to the right side of a pair of symmetrically placed lines, drawn by eye to

Figure 22: Deflection amplitude of horizontal EOG as a function of saccade duration. Dotted lines are fitted by eye and have equal and opposite slopes (about .3 mV/25 msec), estimated to correspond to about 1.2°/msec. These data were hand-analyzed from photographs of EOG deflections from a *C. dilepis* (#4 of Figure 8).


.3
.2
.1
0
- .1
- .2
- .3
mV
25
50
MSEC

approximate the margins of the scatter. The slopes of these lines appear to be closely equal and opposite. Analysis of the computer-stored deflection sizes (see below) shows that no set of consecutive EOG deflection sizes added to more than about 1.3 mV. No single EOG deflection exceeded about 0.65 mV (Figure 23). Saccadic pairs causing successive deflections of almost this size did occur. Therefore, two EOG deflections of about 0.65 mV corresponded to two roughly 90° saccades (horizontal); two such horizontal saccades cause full nasal to temporal movement of the line of sight.

Saccadic EOG Size Distributions

The same EOGs described above were input to special analog circuitry on-line to a Linc-8 computer. When signal deflections occurred, the special circuitry measured baseline to peak voltage. Such values and their occurrence times were stored by the computer. The size measurements were subsequently distributed according to frequency of occurrence. Figure 24 shows the four distributions of horizontal EOG deflection sizes, corresponding to positive and negative deflections for each eye (clockwise and counter-clockwise saccades). Three of the four frequency distributions show a roughly similar decline in frequency with increasing deflection size for saccades larger than about 10° (as estimated above). The fourth distribution of

Figure 23: Sequential deflection amplitudes of horizontal EOGs. The data presented here were provided by a C. dilepis (#4 of Figure 8) and automatically computer-analyzed. An EOG-like representation of computer-stored EOG deflections is shown in (a); note the "scanning" behavior of the individual eyes and the frequent 180° phase-lag of the left eye scan to the right eye scan. Successive deflection amplitudes, measured from (a) and its continuation, were integrated, so long as deflections were in the same direction. Each such sum is represented as a vertical line in (b), with dots representing the sizes, largest to smallest, of each of the contributing deflections. (b) shows a chronological sequence of nasal "scans" of the left eye (i. e., movements towards the anterior).

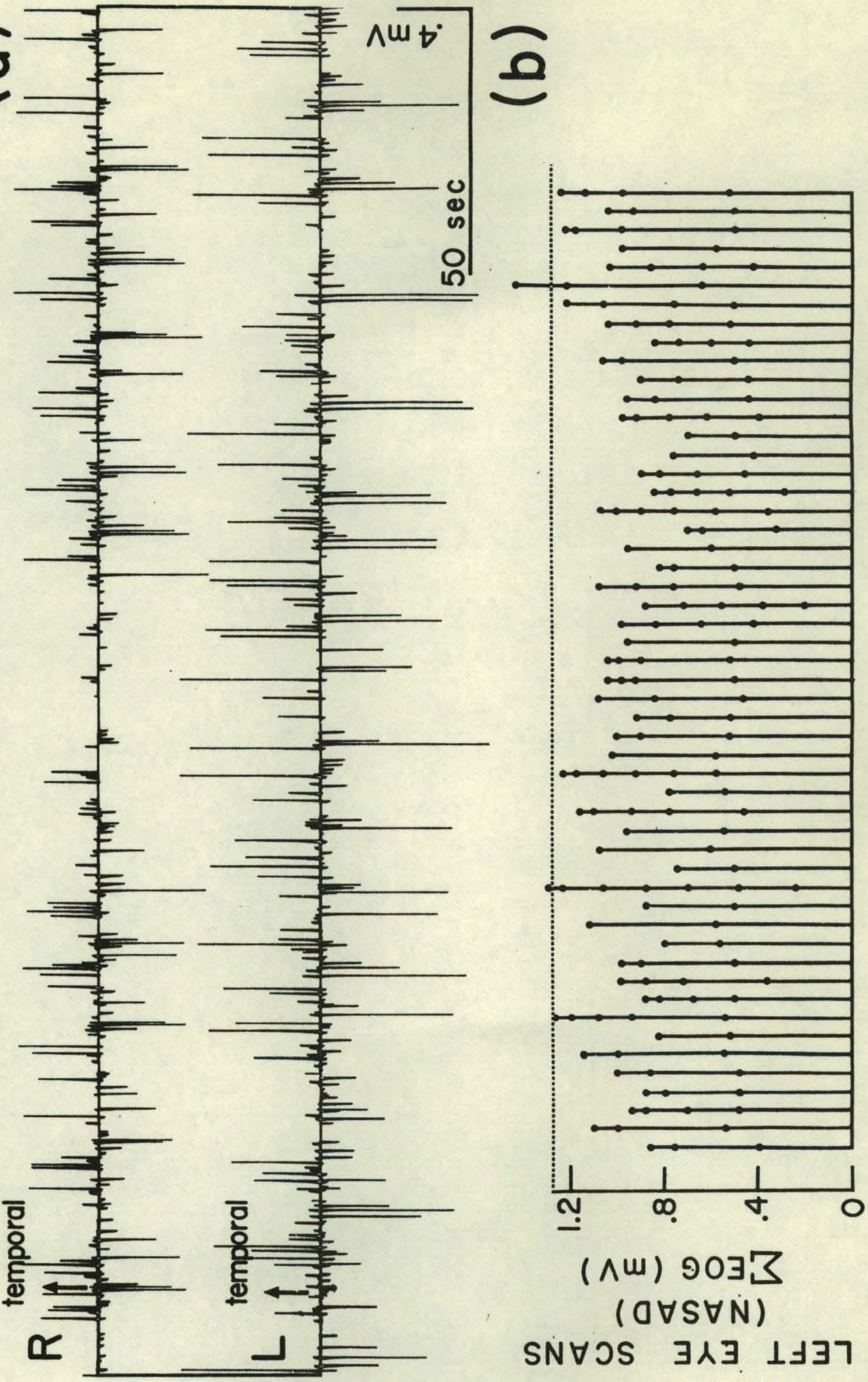
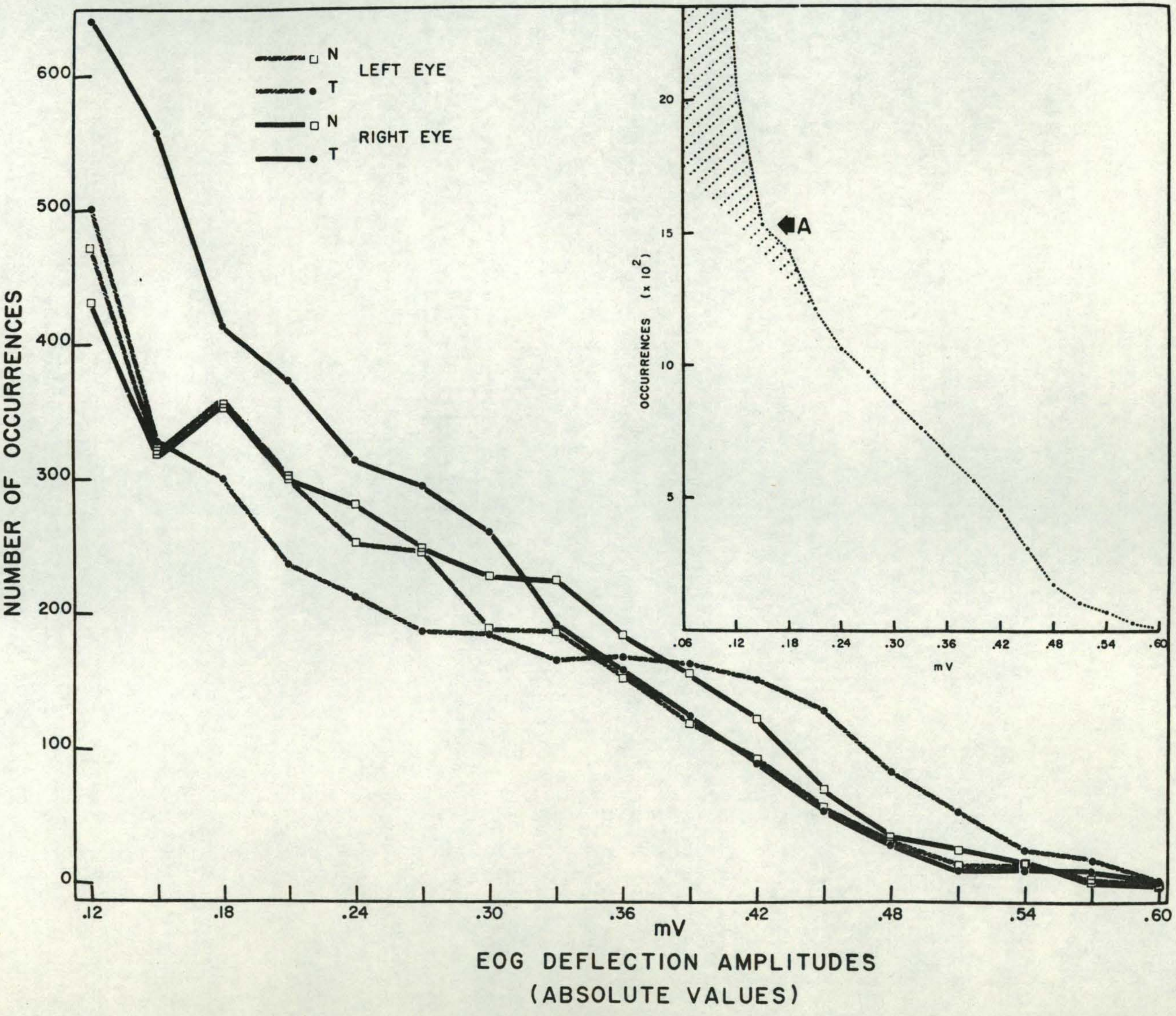

(a)
R
temporal
L
temporal
50 sec
.4 mV
(b)
LEFT EYE SCANS
(NASAD)
ΣEOG (mV)
1.2
.8
.4
0

Figure 24: Deflection amplitudes of horizontal EOGs as functions of their frequencies. The data were taken from a C. dilepis (#4 of Figure 8; 4 1/2 hr) and automatically analyzed by computer. The large graph shows the four types of deflections, of both eyes, in both nasal, N, and temporal, T, directions (anterior and posterior directions, respectively). The inset shows the sum of all four deflection types; the stippled area is felt to contain artifactual, A, computer responses to the larger EOGs to the right of the area. A 0.65 mV deflection is estimated to represent a movement of about 90° in horizontal extent.


N
T
LEFT EYE
N
T
RIGHT EYE
NUMBER OF OCCURRENCES
600
500
400
300
200
100
0
.12
.18
.24
.30
.36
.42
.48
.54
.60
mV
EOG DEFLECTION AMPLITUDES
(ABSOLUTE VALUES)
A
OCCURRENCES (x 10^2)
20
15
10
5
.06
.12
.18
.24
.30
.36
.42
.48
.54
.60
mV

temporally-directed left eye EOG sizes has about the same total measurements in the range, 10° and larger, but has more large deflections than the other three distributions.

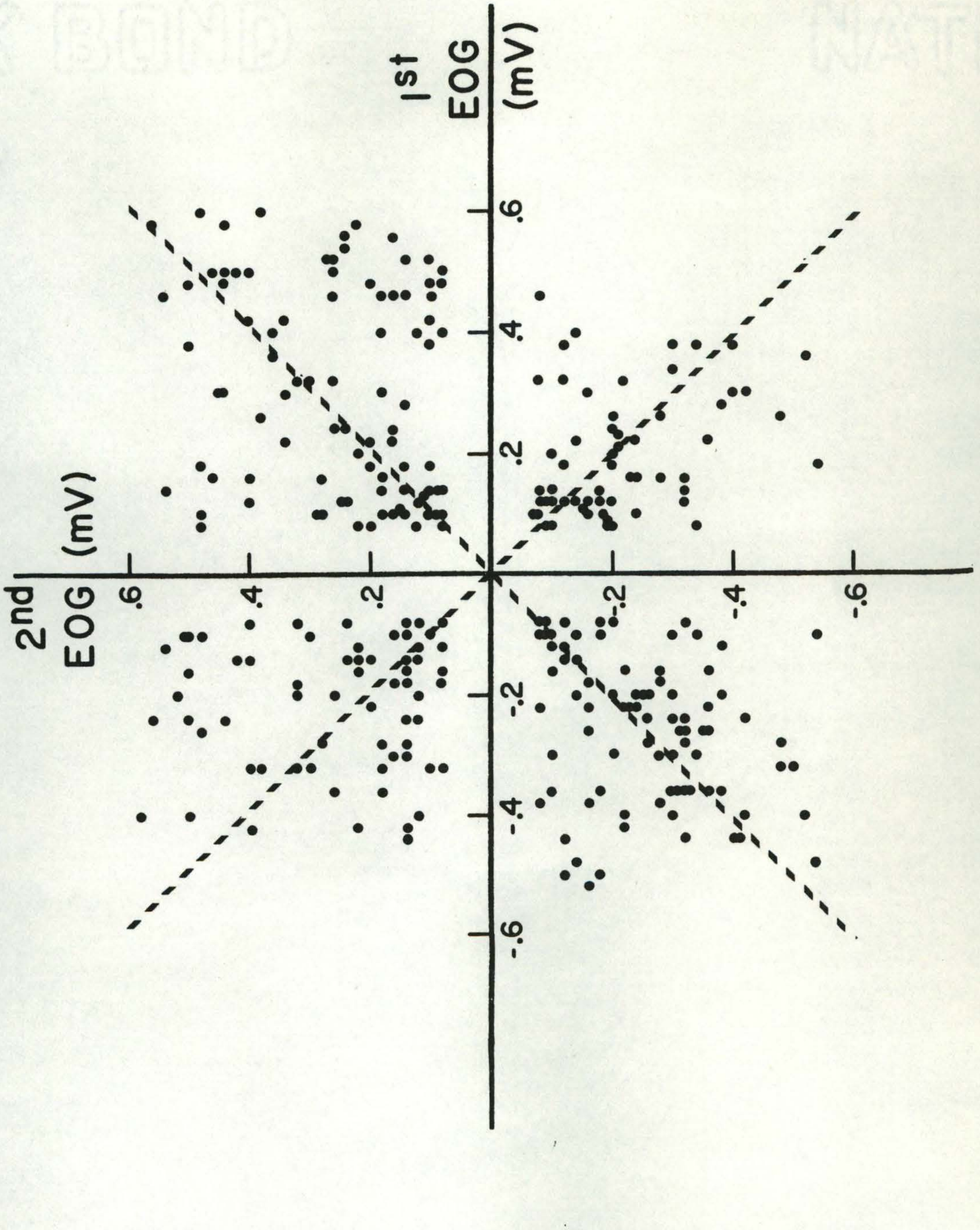
When all the Linc-8 measurements were counted, many more deflections were found to have been stored than the recognition circuitry had previously passed (i. e., 20,000 "recognized" saccades). If the roughly linear portion of the cumulative distribution is extended into the smaller EOG deflection region, the total number of measurements it would cover is about 20,000. Much of the stippled region in Figure 24 is probably artifactual. The circuitry to detect and measure EOG deflection sizes was designed for a different specialized use and so gave spurious measurements, accounted for in Appendix A1.3.

In summary of these data, the numbers of occurrences of horizontal EOG deflections of different sizes were inversely related to those sizes. Nasal and temporal deflection sizes distribute symmetrically, and horizontal EOG deflection sizes distribute similarly for left and right eyes.

Serial Size and Direction Relations

Figure 25 shows that successive EOG deflection sizes and directions, taken from the above data, were positively correlated. I have observed that the similarity between successive EOG deflection

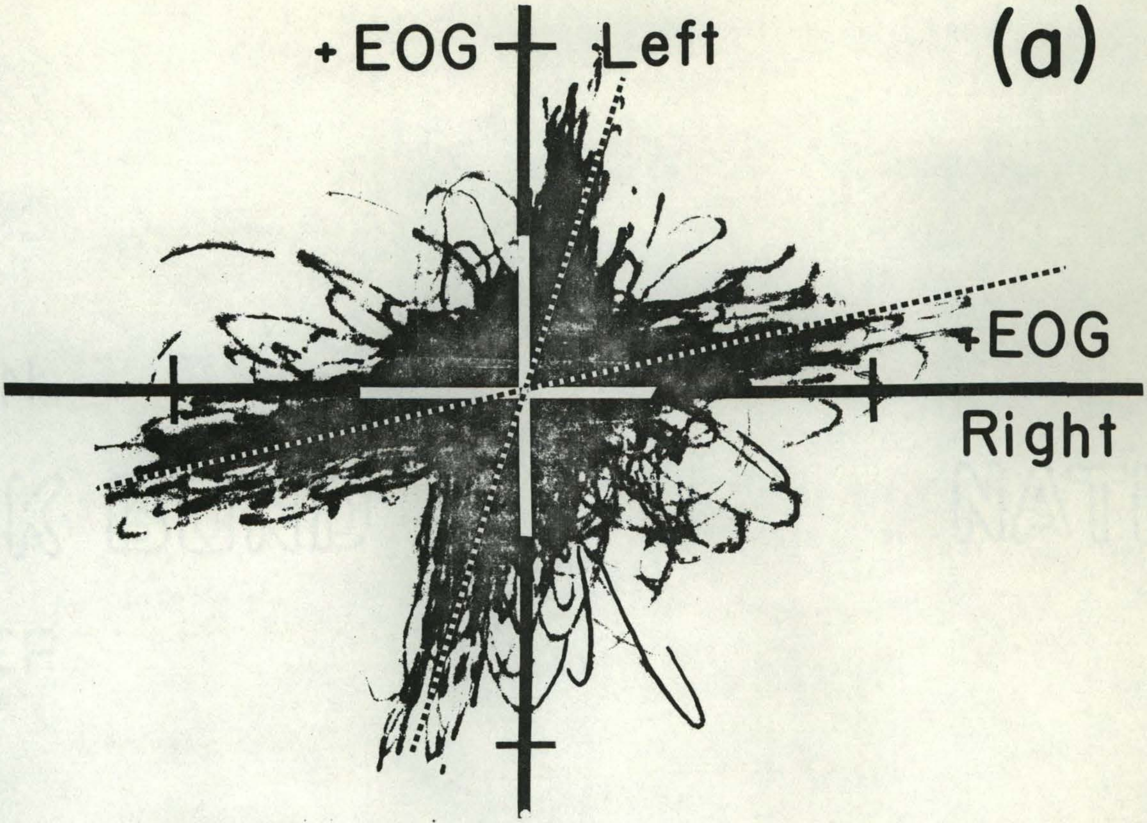
Figure 25: Sequential similarity of successive deflection amplitudes of horizontal EOGs. Each data point represents a pair of successive, non-overlapping, saccadic, EOG deflection amplitudes, taken from computer memory; a *C. dilepis* (#4 of Figure 8) provided the material for computer analysis. A 0.65 mV deflection is estimated to represent a movement of about 90° in horizontal extent.

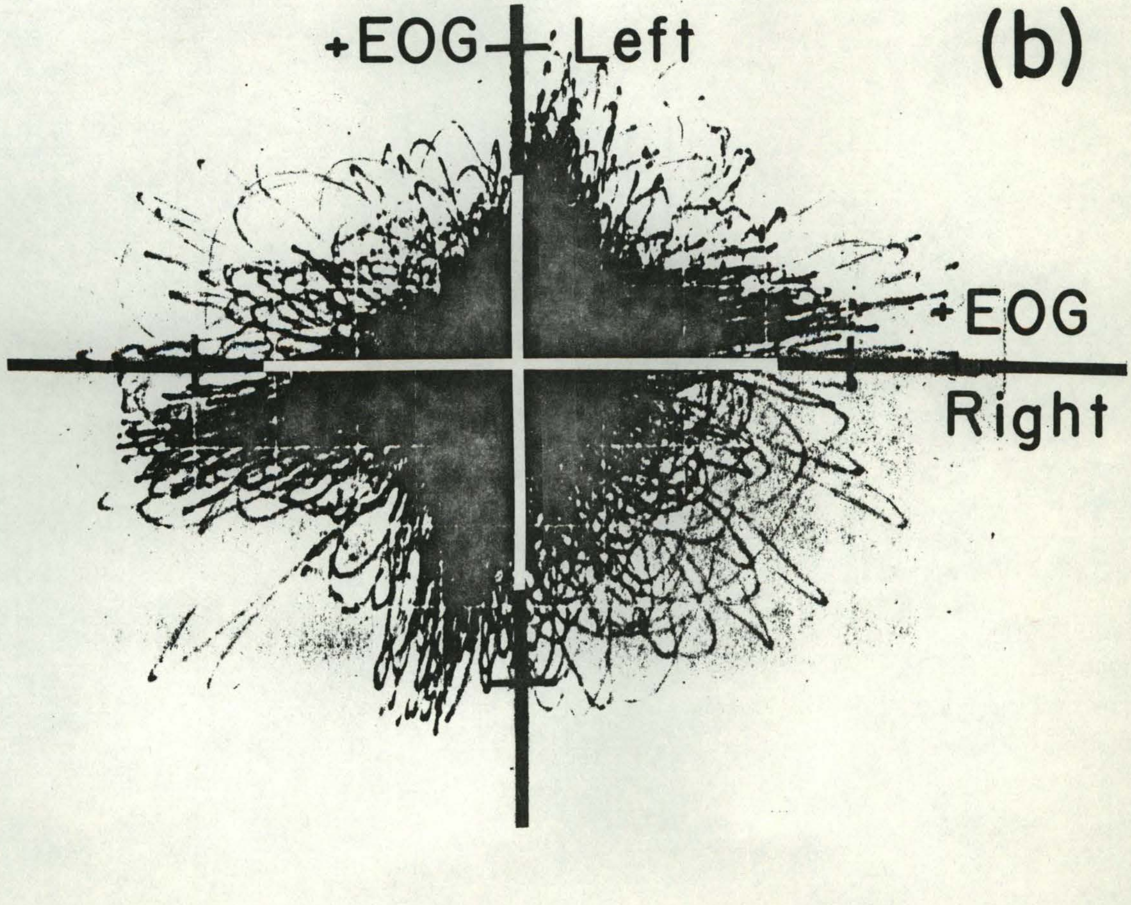

1st EOG (mV)
2nd EOG (mV)
.6
.4
.2
-.2
-.4
-.6
.6
.4
.2
-.2
-.4
-.6

amplitudes seems to be greatest at the shortest inter-saccade durations (Figure 21). Chameleons seem to scan across the range of their horizontal eye mobility (Figures 21, 23). The above observations need further corroboration in statistical terms, but special automation for chameleon EOG deflection size measurement with concurrent timing capability has not yet been built.

Figure 23 shows that while one eye of this C. dilepis was scanning in one direction, clockwise or counter-clockwise, the other eye often scanned in the same direction (with respect to external coordinates) and at about the same rate. Thus, the eyes were coordinated in an average way. (An average of x degrees per second forward in one eye was accompanied by an average of x degrees per second backward in the other eye.) Yet, the left and right saccades were infrequently simultaneous or equal in size. The coordination seemed to increase with decreasing cross-interval durations until simultaneous movements were nearly the same size and direction. (Figure 26 demonstrates this last observation, but uses the EOGs of a different C. dilepis.) Conspicuous exceptions are simultaneous eye movements snapping both eyes forward (nasad) which were commonly observed to be associated with the initiation of locomotion.

Figure 26: The relation between nearly simultaneous saccades of left and right eyes. Concurrent horizontal EOGs of left and right eyes were connected to the vertical and horizontal sweeps, respectively, of a Tektronix 565 oscilloscope. Each EOG was prefiltered by a pair of RC-networks with cutoff above at 10 Hz and cutoff below at 10 Hz (a bandpass arrangement). Positive deflections indicate eye rotations to the anterior; negative deflections indicate eye rotations to the posterior. Photographs (a) and (b) of the resulting Lissajou-type figures indicate that (1) artifact averages about 1/4 of the causative deflection, (2) simultaneous saccades of the eyes tend to be in opposite senses (i.e., both clockwise or both counter-clockwise, from above), and (3) if simultaneous left and right saccades are in the same sense, they are usually snapping forward (anterior). These data are from a C. dilepis. Tic marks are placed on the axes at ±.4 mV.


(a)
+EOG
Left
+EOG
Right


(b)
+EOG
Left
+EOG
Right

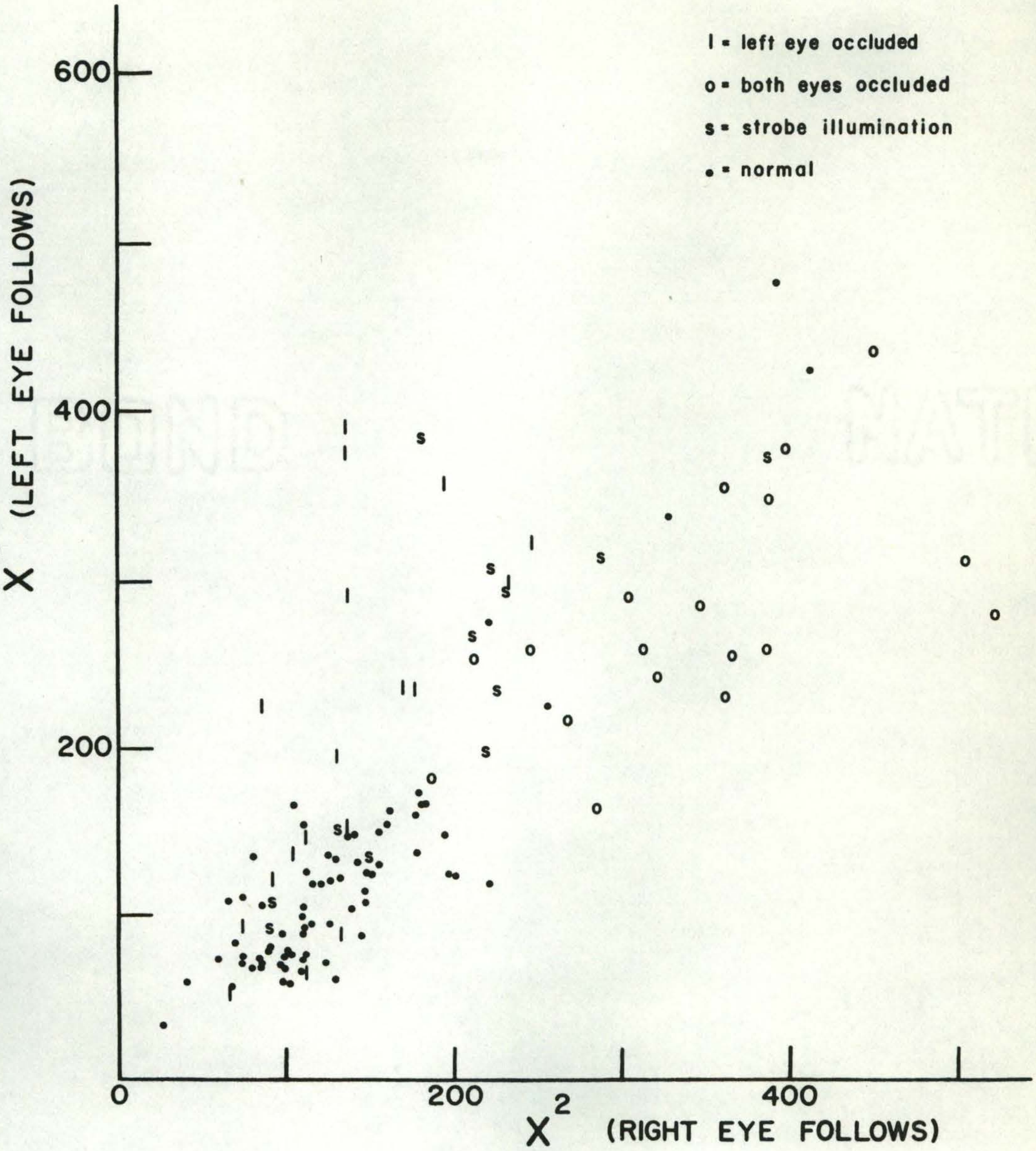
Eye Occlusion Results

To gain an impression of the degree to which the visual environment affected chameleon saccade timing, I examined saccade sequences from animals whose palpebral fissures had been entirely occluded with small pieces of opaque, black tape. In some cases, eyes were occluded thirty or so minutes prior to recording EOGs; in others, only five to ten minutes. No obvious differences were observed between records obtained after either extended or short fore-periods. I cannot determine the extent to which saccades, under these occluded conditions, were elicited by virtue of skin irritation (by the occluding tape) rather than by visual processing. To resolve this difficulty, other means of visual field alteration should be used, means which do not interact with sensory modes other than vision.

An obvious effect of this procedure was that saccades of the covered eye(s) were often abnormal. Saccade termination often was not abrupt, as usual, but slow and drifting. Multiple saccades were common (Figure 4d). The gross rate of saccade production was not much affected by occlusion (Figure 8) even when both eyes were occluded. As might be expected, cross-interval histograms indicated that the open eye "drives" the occluded eye (Figure 27). In other words, the open eye usually moves first when saccades of open and closed eyes are nearly simultaneous. When an occluded eye was uncovered, the subsequent

Figure 27: Left-right saccade timing: statistical symmetry. In this graph, each point represents data from a 22 min segment of one of three 4 1/2 hr experiments with three C. dilepis individuals (#7, #8, and #9 of Figure 8). The coordinates of each point are the X^2s, measuring deviations of left and right observed from "expected"* backward, 1st-order cross-interval distributions, taken from the same 22 min segment of data. Note the strongly asymmetric tendency of left eye saccades to follow right eye saccades when the left eye is occluded. Note, also, the large X^2 values when both eyes are occluded or stroboscopically illuminated, although symmetry is maintained.

*If right and left saccade sequences are stationary and unrelated, the "expected," 1st-order cross-interval distributions are proportional to the appropriate survivor functions.


l = left eye occluded
o = both eyes occluded
s = strobe illumination
• = normal
600
400
200
0
200
400
X^2 (LEFT EYE FOLLOWS)
X^2 (RIGHT EYE FOLLOWS)

inter-saccade interval distribution of the eye returned to normal in less than five minutes. The effect of occlusion on the interval histogram was reliably generated and was reversible (Figure 28).

The time constants of the tails of the interval histograms of occluded eyes were greater than before occlusion (Figure 29), and greater than those of the concurrent contralateral interval histogram tails (if the contralateral eyes were not covered, too). The major observed effect of occlusion on interval histograms was an increase in short interval frequency. This was due to the multiple saccades, referred to above. Semilog plots of interval histograms show inflections at roughly the same point, at intervals about one second in duration, whether the eyes were occluded or not (Figure 30).

All serial correlations, both unilateral and bilateral, previously described for animals with uncovered eyes, are also significant in animals whose eyes are occluded (Table 3). I have not examined sizes and directions of saccades of occluded eyes and their contralateral mates. Many saccades' sizes may not even be definable because of the above-mentioned drift, with which the saccades of occluded eyes often terminate.

Figure 28: The inter-saccade intervals of animals with occluded eyes. Inter-saccade interval histograms (20 msec bin-width) are shown in (a)-(c). A histogram labelled F represents an un-occluded[*] eye; otherwise, histograms represent occluded eyes. Note that eye occlusion results in markedly more very short (< 200 msec) intervals. The histograms are taken from consecutive and contiguous segments of three experiments on three C. dilepis individuals (#7, #8, and #9 of Figure 8 for (a), (b), and (c), respectively). Each segment represents 1 hr of data, and the data are plotted for concurrent segments of the left and right saccade sequences. The histograms associated with the first to last segments, in each experiment, are placed on the page from bottom to top, respectively.

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[*] Occlusion was effected by placing a very small piece of opaque tape over the chameleon's palpebral fissure; complete eye mobility was retained.

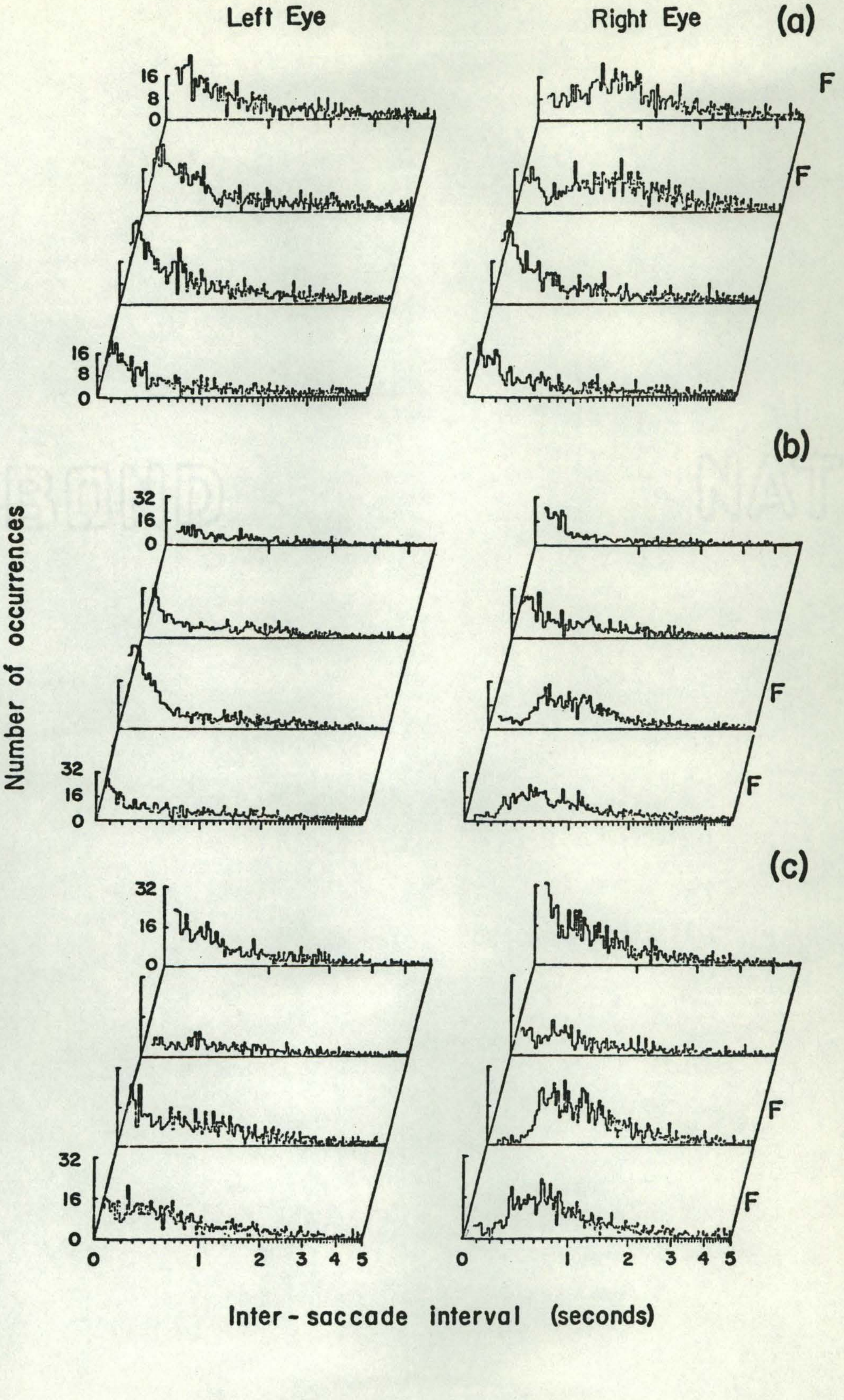
Left Eye
Right Eye
(a)
16
8
0
F
F
16
8
0
(b)
32
16
0
F
F
Number of occurrences
32
16
0
(c)
32
16
0
F
F
32
16
0
0
1
2
3
4
5
0
1
2
3
4
5
Inter - saccade interval (seconds)

Figure 29: The effects of eye occlusion on the "exponential tails" of the "expected" 1st-order cross-interval distributions. The distributions labelled F are derived from un-occluded eye saccades; otherwise, they reflect eye occlusion. The curves' ordinate scales are logarithmic; thus, the exponential tails appear linear. The effect of eye occlusion appears as a slight flattening of the tails of the curves. These distributions were derived from consecutive and contiguous segments of three experiments on three C. dilepis individuals (#7, #8, and #9 of Figure 8 for (a), (b), and (c), respectively). Each segment represents about 45 min of data, and the data are plotted for concurrent segments of the left and right saccade sequences. The curves associated with the first to last segments in each experiment, are placed on the page from bottom to top, respectively. The distributions are proportional to the associated survivor* functions which are, in turn, equivalent to inter-saccade interval distributions; they are plotted as frequency-polygons (50 msec bin-width), smoothed by weighting adjacent bin counts in the ratios, 1:2:1, after the log-transformation.

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*If left and right saccade sequences are stationary and independent, the "expected," 1st-order cross-intervals distribute proportionally to the survivor function of the same data.

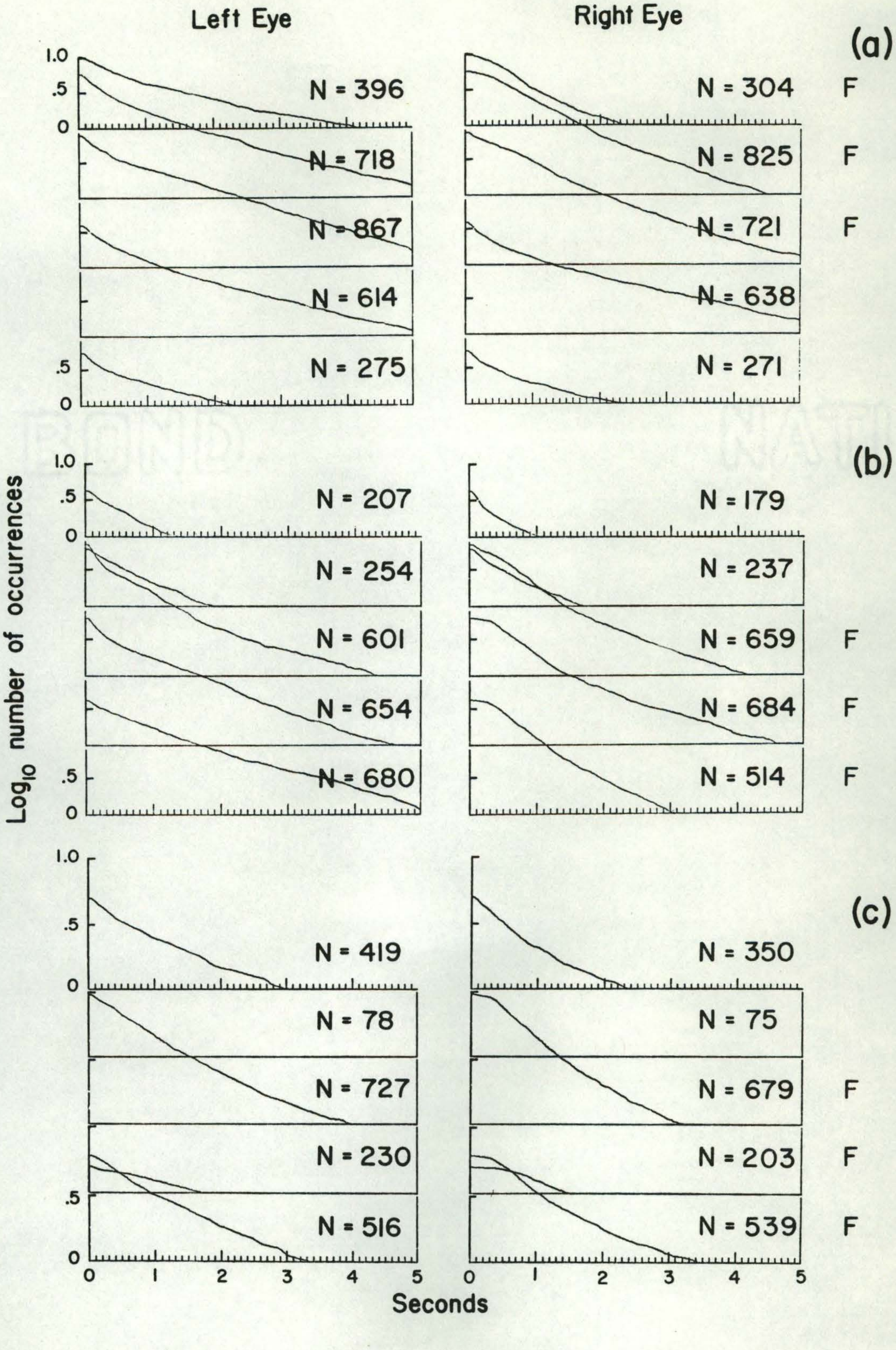
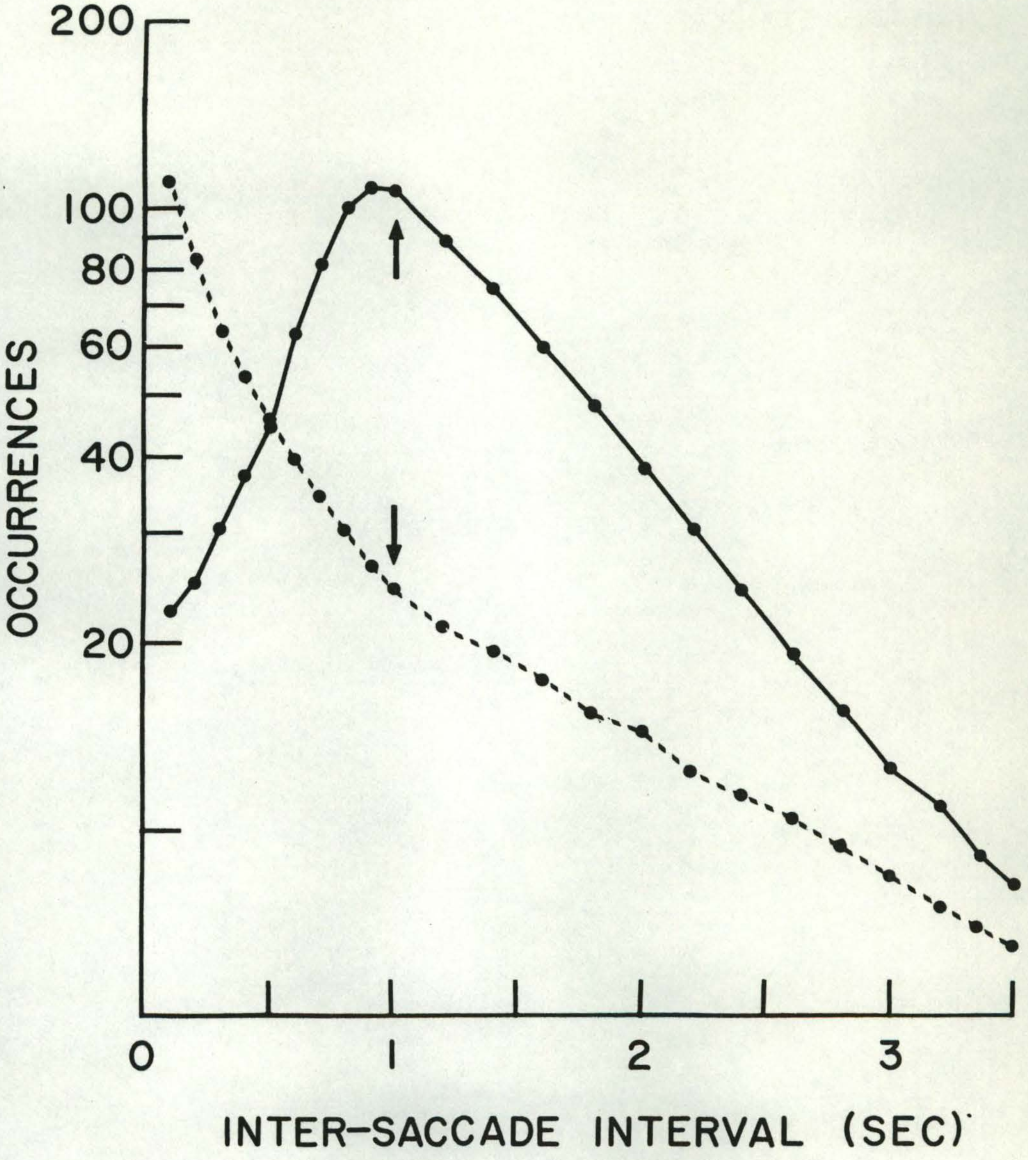

Left Eye
Right Eye
(a)
1.0
.5
0
N = 396
N = 304
F
N = 718
N = 825
F
N = 867
N = 721
F
N = 614
N = 638
.5
0
N = 275
N = 271
(b)
1.0
.5
0
N = 207
N = 179
N = 254
N = 237
N = 601
N = 659
F
N = 654
N = 684
F
.5
0
N = 680
N = 514
F
Log10 number of occurrences
(c)
1.0
.5
0
N = 419
N = 350
N = 78
N = 75
N = 727
N = 679
F
N = 230
N = 203
F
.5
0
N = 516
N = 539
F
0
1
2
3
4
5
0
1
2
3
4
5
Seconds

Figure 30: Semilog plots of the smoothed, inter-saccade interval histograms of occluded and free eyes. Note the similar inflection points of both curves at about 1 sec. The solid curve corresponds to the free eye. The curves were hand-drawn. The data were taken from the same *C. dilepis* in two experiments (#4, and #7 of Figure 8), and both curves represent the left eye.


200
100
80
60
40
20
OCCURRENCES
0
1
2
3
INTER-SACCADE INTERVAL (SEC)

Summary of Results

A renewal process, creating independent, successive, inter-saccade intervals and sizes, is an inadequate model of chameleon saccade generation. Against the predictions of such a model, successive unilateral inter-saccade intervals were too nearly equal in duration. Successive EOG deflection amplitudes were positively correlated. The third-difference distributions show that second-difference sequences were non-renewal; successive terms increased in value much more than by chance. In other words, saccade occurrence rate has monotone trends (accelerations and decelerations). The joint-interval histogram, calculated from the C. hohnelii data, confirms that similar successive inter-saccade intervals were too frequent for renewal but restricts the phenomenon to intervals shorter than about 1.5 seconds in duration.

The hypothesis that concurrent unilateral saccade sequences are not related is probably false. In particular, left and right saccades occur within 100 msec of one another far more than by chance. In many cases, a very clear excess of cross-intervals greater than 100 msec in duration also occurred where cross-interval durations distributed as did unilateral inter-saccade interval durations. The excess came most strongly from a young C. hohnelii. These relations are in addition to the positive correlations of various parameters of concurrent left and right saccade sequences observed over intervals as short as ten minutes in duration.

There was apparent increase in the non-random and non-renewal character of chameleon saccade sequences (seen by the non-constant position of the derived X^2 variates in their associated χ^2 distributions) with change in the mean saccade rate (calculated over 20-minute intervals). Such relationships as have been observed seem to be enhanced by increase in the saccade occurrence rate.

The above results imply bilateral saccade patterning in time. Such patterning is demonstrable in the horizontal EOGs (Figure 21) and is further demonstrated in the switching and triad data from the C. hohnelii. The EOG records indicate that bilateral patterning extends to sizes and directions of saccades. If saccades of left and right eyes are nearly simultaneous, they tend to be equal in amplitude and opposite in direction. Chameleons often scan with their eyes (many successive movements in the same direction), and a qualitative observation from EOGs is that when one eye scans forward, the other usually scans rearward.

To this point, order-dependent results have been summarized. The order-independent results are those often associated with renewal processes. The inter-saccade interval histograms of unilateral saccade sequences show exponential tails; they also show a dead time (after the occurrence of a saccade during which a second occurrence is very unlikely). EOG deflection sizes, although examined in only one C. dilepis, show symmetrical frequency distributions, for right eye saccade versus left, and forward saccade versus rearward.

Finally, the timing of chameleon saccades was observed in three C. dilepis and the C. hohnelii with one or both eyes occluded with a bit of opaque tape. The results indicate that, although multiple saccades distorted the inter-saccade interval distributions of occluded eyes (many short intervals), the serial properties of unilateral sequences and the bilateral relationships remained roughly as described above. Major differences are that the free eye usually precedes the occluded eye in nearly simultaneous saccades of both eyes (symmetrical when both eyes covered) and the tendency to simultaneity of left and right saccades is much enhanced by occlusion of one or both eyes. Regretably, the sizes and directions of saccades from animals with occluded eyes were not examined. Such examination may be especially difficult due to the frequent inability to chameleons to properly terminate saccades of their occluded eye(s).

DISCUSSION

Introduction

At the beginning of this thesis, three questions were posed of chameleon saccades: (1) in what ways are saccades of left and right eyes not truly statistically independent, (2) do such correlations as exist provide insight into the visuo-motor system(s) of such animals, and (3) can a general but detailed description of saccadic behavior, taken from a variety of situations over long periods of time, be informative about visuo-motor processing? I shall argue in this discussion that questions (2) and (3), above, can be answered in the affirmative using descriptions of unilateral saccade sequences and descriptions of the mutual relationships of such sequences, taken concurrently from left and right eyes. Such descriptions were, in fact, necessary for response to the first question stated above and are detailed in the preceding results section.

The discussion is divided into four more major parts: (1) a discussion of the chameleon saccade, its amplitudes and durations; (2) a discussion of saccade timing; (3) the presentation of hypotheses of chameleon saccade production; (4) final remarks.

The Chameleon Saccade

This section concerns the relationship of EOG deflection amplitudes to their associated sizes. The primary data are EOG amplitudes; yet the saccades themselves are of primary interest. A theory is proposed which allows interpretation of several important results couched in terms of EOG amplitudes but hopefully translatable into terms of saccade amplitudes. First, however, I shall present some findings which may have counterparts in other vertebrates. The last remarks deal with the possibility of saccades smaller than those observed during this study.

Muscle Spikes and Multiple Saccades

The reader may recall that groups of summed muscle spikes are invariably present in the chameleon horizontal EOG records, just prior to the slower voltage deflections corresponding to saccades. The following was observed: (a) extra-ocular muscle spikes often appear to be patterned in time; (b) occasionally, an apparently pre-saccadic spike group occurs without an ensuing horizontal saccade. The first observation suggests that extra-ocular muscle contractions may be discontinuous *during* saccades. The second observation raises the possibility that extra-ocular muscles can be directed to change their tensions without moving the otherwise unrestrained eye since entirely vertical saccades were extremely rare, if not impossible (in humans, the eyes move in a screw-like fashion; Alpern, 1962). EOGs, representative of the above observations, are presented in Figure 3. I am unaware of other such reports in the literature of saccades.

Multiple saccades were defined as saccades of an eye which occur within 150 msec of one another. They may reflect a process in control of the in-flight saccade kinetics, rather than a process which determines whether a saccade will occur or not. Such a duality is reported for human saccade production in absence of fixation points (Becker, and Fuchs, 1969), and may also appear in monkeys (Barmack, 1970). Reasons for believing so are that (1), as in the two studies just mentioned, chameleon multiple saccades are invariably in the same direction, and (2) the absence of fixation points for chameleon eyes (presumed for occluded eyes, and for vision under the strobe-light) greatly enhances the relative number of multiple saccades from the affected eye(s).

The Saccade and its EOG Deflection

Indirect estimates of eye movement parameters such as their magnitudes, directions, and durations can be made, using EOG records as source data. The eyes' horizontal position determined the EOG signal amplitudes in these experiments. Two electrodes were placed in a horizontal line about each eye, one temporal and one nasal. No attempt was made to get absolute position information from the EOG records (as movements of one eye affected the EOG of the contralateral eye, a phenomenon due to volume conduction). Saccades of the same size, but with different initial and terminal fixation points, have different horizontal EOG deflection amplitudes. The interpretation of the horizontal EOG amplitude is therefore necessarily approximate and somewhat indirect.

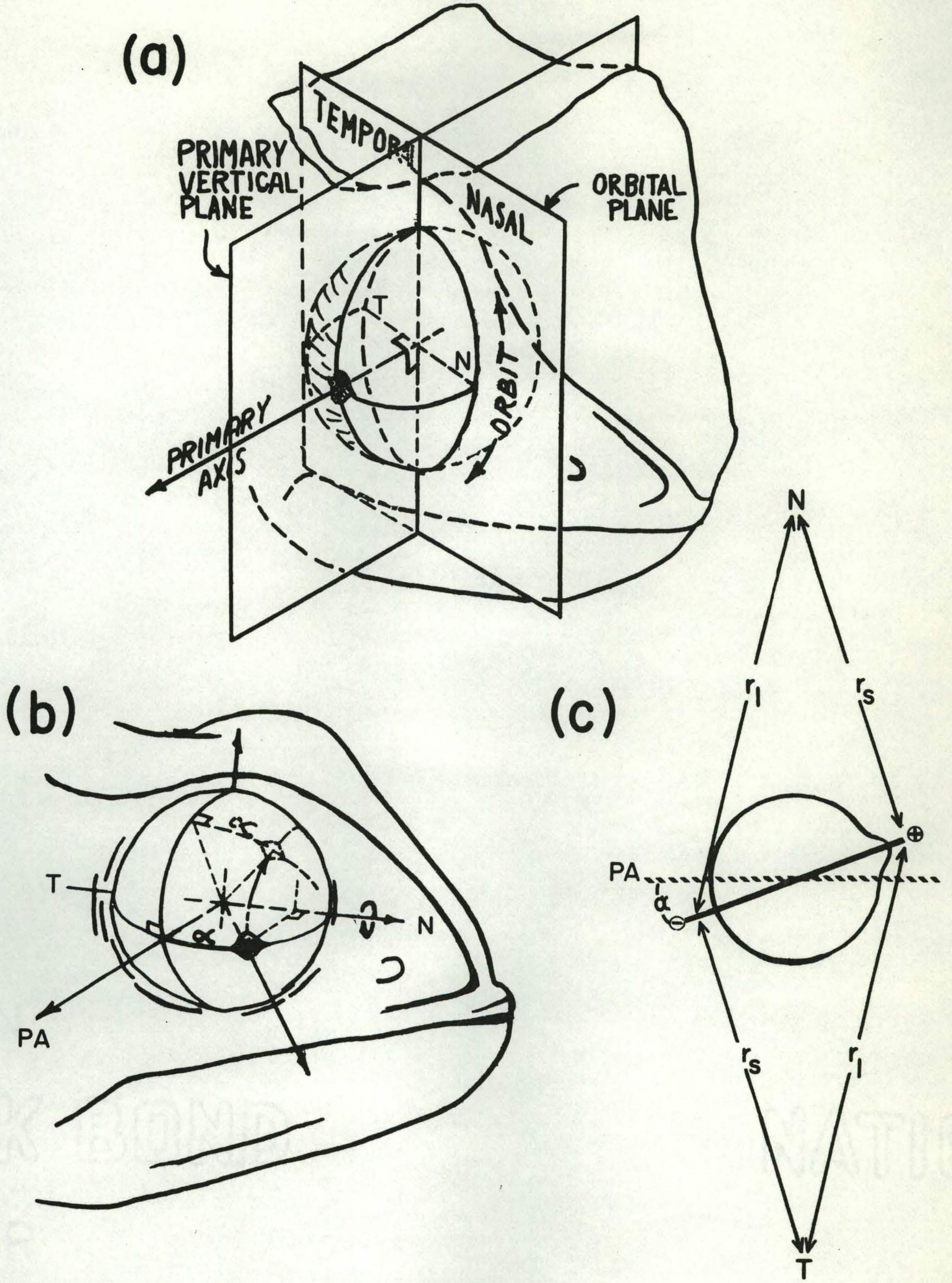
A theory for the horizontal EOG. Suppose the eye is a sphere and the outer edge of the orbit of the eye is a circle. Call the line passing through the center of the sphere and perpendicular to the plane of the orbital rim, the "primary axis." A vertical plane, passing through the primary axis, the "primary vertical plane," divides the orbit into a nasal half and a temporal half (Figure 31a). With this geometry in mind, the ensuing discussion may be more easily understood.

When one simultaneously observes an eye and its associated EOG, saccades with initial and final fixation points near the periphery of the eye's mobility range are not seen as easily in the horizontal EOG as the same amplitude saccades near the primary axis. For a fixed amount of angular rotation of the eye about an axis in the primary vertical plane, variously-sized horizontal EOG deflections may result depending on the initial and terminal positions. For humans, the relationship

Figure 31: The geometry of horizontal EOG recording from the chameleon. (a) is intended to clarify the definition of (1) the "temporal-nasal" plane passing tangent to the outer edge of the bony orbit of the eye, (2) the "primary axis," a centered perpendicular to the above plane, and (3), the "primary vertical plane," the plane passing vertically through the primary axis. The primary axis approximates the rest position of the line of sight. The "horizontal component" of the eye's position, α , is shown in (b); α is invariant with respect to rotations of the eye about a horizontal line in the temporal-nasal plane. Using (c), the variation of voltage between nasal and temporal electrodes, at N and T, is approximated:

$V_{N-T} = k \sin \alpha$ (Fenn and Hursh, 1937).

The "horizontal EOG" is the record of this voltage and was made with AC-coupled circuitry in the studies reported here.


(a)
TEMPORAL
PRIMARY VERTICAL PLANE
NASAL
ORBITAL PLANE
T
N
ORBIT
PRIMARY AXIS
(b)
T
N
α
PA
(c)
N
r_l
r_s
PA
α
⊖
⊕
r_s
r_l
T

between the horizontal coordinate of the position of the eye and the EOG from a nasal-temporal electrode pair has been described (Bicas, 1972). The more usual electrode placement on humans is bi-temporal since the eyes move conjugately. The meaning of the "horizontal coordinate" is the same here for chameleons as for humans; it is the smallest angle between the line of sight and the primary vertical plane (Figure 31b). Note that the eye can be rotated about a horizontal line in the orbital plane without changing this angle. The horizontal EOG of the human eye is proportional to the sine of this angle. The sinusoidal relationship is derivable from assumptions such as that the eye is an axially symmetric dipole, that this dipole is imbedded in an anisotropic conducting medium, that the eye rotates around a single point and has a radius which is small in comparison to the distance between the recording electrodes, etc. (Figure 31c; Fenn and Hursh, 1937).

I suggest that chameleons satisfy such assumptions as well as humans satisfy them. The chameleon eye is more symmetrically placed in its orbit than is a human eye and the electrodes can be placed more nearly in the plane of the great orbital circle of the eye. The movements considered in this paper are about five degrees and larger in extent, and this is the range for which the sinusoidal approximation is best for humans. On the other hand, chameleon eyes are so close together (essentially tangent) that volume conduction allows their electric fields to extend to the contralateral sides; thus, "cross-talk" between the EOGs of the eyes complicates interpretation of the EOGs. For the purposes of discussion, the magnitude of the horizontal EOG from a chameleon eye is considered proportional to the sine of its angular position with respect to the primary plane. It is obviously desirable to have some independent measure of eye position to calibrate accurately the EOG, but this seems technically difficult.

A theoretical EOG amplitude distribution. To this point, the discussion deals with the standing EOG potential differences between temporal and nasal electrodes. But, as remarked above, these potentials interact bilaterally. The potential *change*, however, due to the saccade of an eye is independent of the position of the other eye, providing that the contralateral eye remains fixed during a saccade. In addition, the range of saccade sizes is smaller than the range of eye positions. Therefore, greater amplification of EOG and consequently better saccade sensitivity can be had by AC-coupled amplification of EOGs. Rather than reflecting eye position, the AC-amplified EOG reflects eye movements. The amplitudes of EOG deflections corresponding to saccades are related to the saccade sizes. Only by integration of past EOG deflections could eye position be inferred from the concurrent AC-coupled EOG records.

But saccades of different sizes may produce EOG deflections of equal size, and saccades of the same size will produce a variety of EOG deflection amplitudes, depending on their origins and terminations. Suppose saccades of a given horizontal angular size started equally frequently from points uniformly distributed on the 200 or so degrees of horizontal freedom available to the eye. What would the size distribution of the corresponding EOG deflections be? To answer this question, a short program was written for the Linc-8 computer (Appendix A2.4) using the sinusoidal approximation above.

The computer-generated frequency distributions of artificial, horizontal EOG deflection sizes (normalized to the maximum deflection size) are observed to be somewhat independent of the chosen saccade angle (Figure 32a). The maximum deflection will occur when the saccade origin and terminus are in the same plane as the electrodes and are equidistant from the primary vertical plane. The distributions show that the most frequent deflection sizes are those close to the maximum size (the modal size is the maximum size). To speculate on what might happen to this distribution if the assumptions were relaxed in "natural" ways, suppose origins were not uniformly distributed, or that EOG deviates from the sinusoidal relationship with angle. The skewed shape of the distribution would probably remain, even under such relaxed assumptions.

Figure 32: Computer-modelled saccadic deflections of horizontal EOG. 10,000 computer "saccades" of identical horizontal, angular extent, θ, are modelled to start at points with uniformly distributed horizontal coordinates. The resulting computer "EOG deflections"* are shown in (a). The deflection sizes are expressed as percentages of the maximum possible deflection size. When computer "saccades" of different horizontal extents are generated, with all horizontal angular extents equally probable up to a maximum, θ_m, beyond which no "saccades" are generated, the deflections distribute as shown in (b); again, deflection sizes are expressed as percentages of the maximum possible size. Note that the distribution shapes, in both (a) and (b), are closely similar and independent of θ or θ_m.

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*The voltage between horizontally-placed nasal and temporal electrodes is modelled to behave as suggested and observed by Fenn and Hursh, 1937:

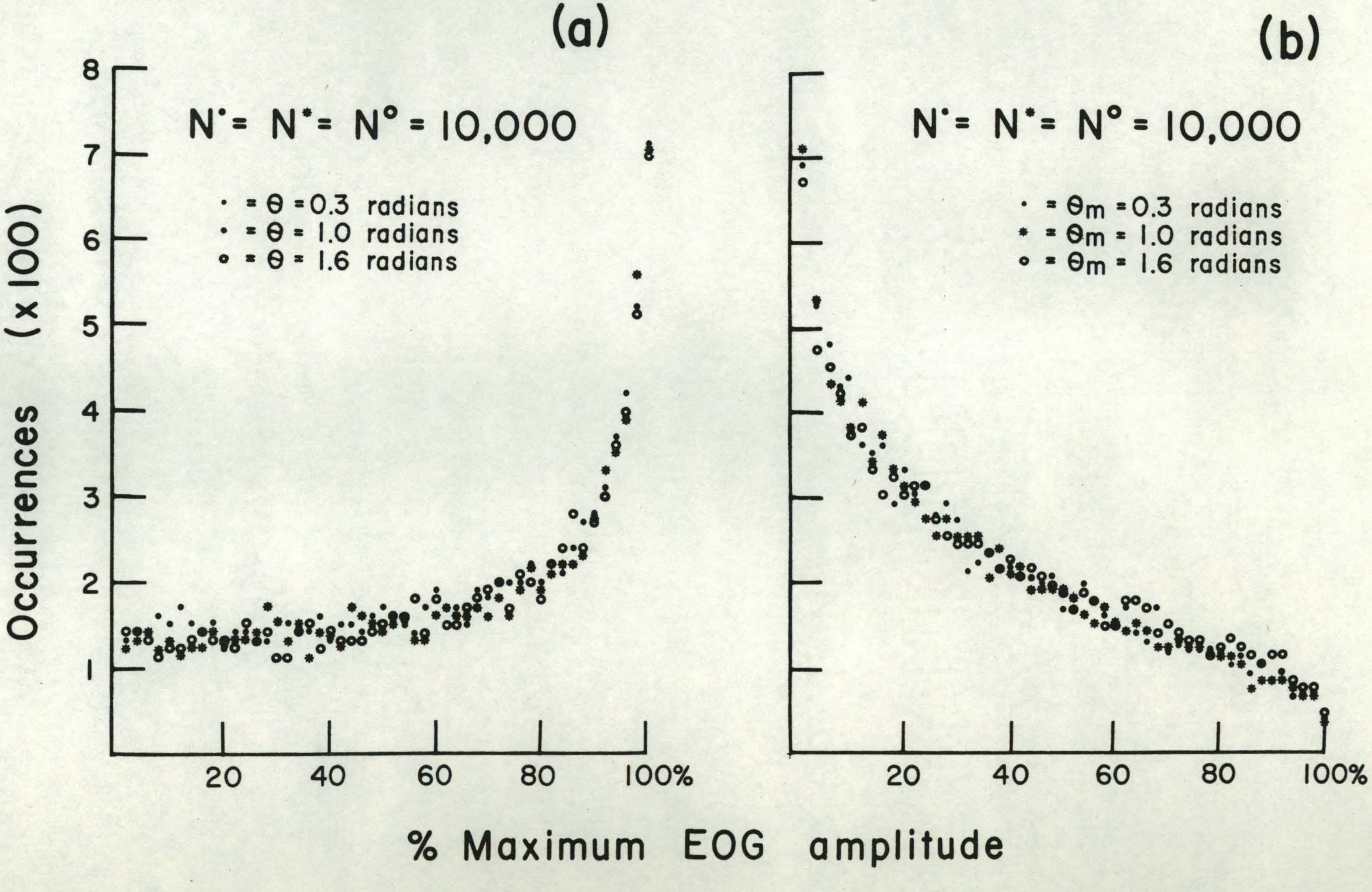
$V_{N-T} = k \sin \alpha$, where α is

the horizontal angular co-ordinate, measured from the primary vertical plane (the vertical plane, passing through the primary axis or rest position of the line of sight). The deflection amplitude, dV, of a saccadic EOG deflection due to eye movement, $d\alpha$, between the positions, and $\alpha + d\alpha$, behaves, in theory, as:

$$dV = k \cdot (\sin \alpha - \sin(\alpha + d\alpha));$$

for a given movement size, α, the

$$dV_{max} = k \cdot (\sin(d\alpha/2) - \sin(-d\alpha/2)).$$


(a)
(b)
N˙= N*= N°= 10,000
• = θ = 0.3 radians
* = θ = 1.0 radians
∘ = θ = 1.6 radians
• = θm = 0.3 radians
* = θm = 1.0 radians
∘ = θm = 1.6 radians
Occurrences (x 100)
1
2
3
4
5
6
7
8
20
40
60
80
100%
% Maximum EOG amplitude

Size and Duration of Saccades

Figure 22 shows that the duration of a horizontal EOG deflection is related to its amplitude with a good deal of scatter. The sharp and symmetric boundaries of the scattergram are presumed to reflect the natural counterpart to the extreme skewness of the artificial, horizontal, EOG size distributions calculated for randomly-distributed saccade origins by the method described above. The margins of the scattergram would therefore represent saccades which are entirely horizontal and which have origins and terminations symmetrical about the primary vertical plane, thus producing maximum horizontal EOG deflections in minimum time. Although insufficient to prove them, the scattergram corroborates the following points: (1) for saccades of the same duration, there seems to be a distinct saccade type whose horizontal EOG size has a smooth, somewhat linear relation to its duration and (2), the scatter of EOG sizes at a particular duration represents saccades of the same size but with different orientations.

A rough estimate of the chameleon's saccadic velocity (based on a maximum observed horizontal saccade size of about 90^{o} and a maximum observed horizontal EOG deflection of about 0.65 millivolts) gives a value of between one and two degrees per millisecond, about three times as fast as the human saccade (Alpern, 1962). Perhaps the difference in velocity can be understood in terms of the relative radii of adult human and adult C. dilepis eyes, about 2.6 cm to 0.7 cm or about four to one, respectively.

In summary, the "saccade" of an eye is a jump-like displacement of its line of fixation. Most chameleon eye movements fit this description, and I have freely termed such movements, "saccades." The human saccade has been studied quantitatively and is found to have a well-defined, spatially symmetric, size to duration proportionality (Robinson, 1964). Horizontal EOG data indicate that those movements of chameleons' eyes that I term "saccades" also exhibit a fixed and symmetric size to duration relationship.

Frequency of Horizontal EOG Amplitudes and Saccade Sizes

The sizes of nasal and temporal saccades (i.e., saccades toward the anterior and saccades toward the posterior) of both eyes of a C. dilepis were probably symmetrically distributed. Though explicit demonstration of the relationship between EOG deflection size and eye movement has not yet been possible, no other likely explanation exists for the symmetry of the distributions of EOG deflection amplitudes from the C. dilepis (Figure 24).

Chameleons have extremely well-developed foveae (Polyak, 1957), and are reported to produce optokinetic nystagmus symmetrically to visual motion in both nasal and temporal directions (Tauber and Atkin, 1967, for C. melleri). These same authors observed that animals with poorly developed foveal regions in their retinae preferentially react with an optokinetic nystagmus to motion in the nasal direction, whereas animals with well-developed foveae react equally well to optokinetic stimuli traveling in both nasal and temporal directions (Tauber and Atkin, 1968). Perhaps such a relationship exists between the presence of a well-developed set of foveae and size-direction symmetry of cumulative saccade distributions.

Because I wanted to know the actual distributions of saccade sizes, I invented a simple computer model. It uses a simple movement distribution hypothesis, and generates the associated EOG amplitude distributions. It requires that (1) the origin of a saccade is as likely to be at any particular horizontal angle (from 0° to 180°, nasal to temporal) as any other angle and that (2) up to some maximum angle all angular sizes (horizontal) of saccades are equally likely. A final assumption, based on the relation between human EOG and eye position (Bicas, 1972), is that (3) the amplitude of horizontal EOG deflection is proportional to the difference between the sines of the initial and terminal horizontal angular positions. Note that the previous model of EOG deflection was based on the first and third assumptions.

Artificial saccades were computed in this way and the consequent amplitudes of the calculated horizontal EOG deflections were collected in frequency distributions. Such distributions look identical to the distributions measured from the real EOG data (Figures 24 and 32b). Furthermore, the form of the theoretical distribution is independent of the size of the arbitrarily-chosen maximum saccade angle. I suggest, therefore, that saccades of horizontal angular extents of all sizes, from about 10° to the observed maximum of about 90°, are equally likely to occur during a long period of time. Good measurements of eye positions are, of course, necessary to test this suggestion further. Such measurements have been too technically difficult to acquire so far.

Invisible Saccades

The proportion of chameleon saccades observed with amplitudes less than five degrees is not known. During fixation, humans make frequent eye movements called "micro-saccades" or "flicks" which are less than one degree in amplitude (Ditchburn and Foley-Fisher, 1967). Although such movements are involuntary in the sense that we are unaware of them, their kinetics suggest that they are produced by the same oculomotor system which generates the large voluntary saccades (Zuber, Stark and Cook, 1965). Furthermore, microsaccades and the larger voluntary saccades have been observed to distribute similarly in time during reading (Cunitz and Steinman, 1969). Whether a continuum of saccade amplitudes extending below five degrees in amplitude is generated by chameleons and whether consideration of such movements would have markedly affected the results of this study must remain matters of conjecture.

Saccade Patterns

(1) Remarks on saccade bursts, (2) comparisons of chameleon data with human data, and (3) descriptions of unilateral saccade patterning, intended to introduce the hypotheses of the next main discussion section, are presented below. Seen over long time spans, unilateral saccade sequences look like renewal processes, but contain serial dependencies.

Are Bursts Real?

A variety of circumstantial evidences lead to the notion that bursts are "units" of saccadic activity. (1) Photographs of the horizontal EOGs show bursts and show also that bursts are bilateral. (2) Saccade frequency changes without trends in interval durations (witness the zero means and symmetry of the second-difference distributions, Table 2). This result can be accounted for by assuming that chameleons change their mean saccade frequency by changes in the number of bursts rather than by changes within bursts. Were this true, the patterning of bursts should be investigated to shed light on long term saccadic behavior control by chameleons. (3) Third-differences suggest that accelerations and decelerations of saccade occurrences are significant. The beginnings and endings of bursts could provide such results. (4) The observed serial correlation between successive, short inter-saccade intervals would tend to keep a burst compact.

Remote Comparisons

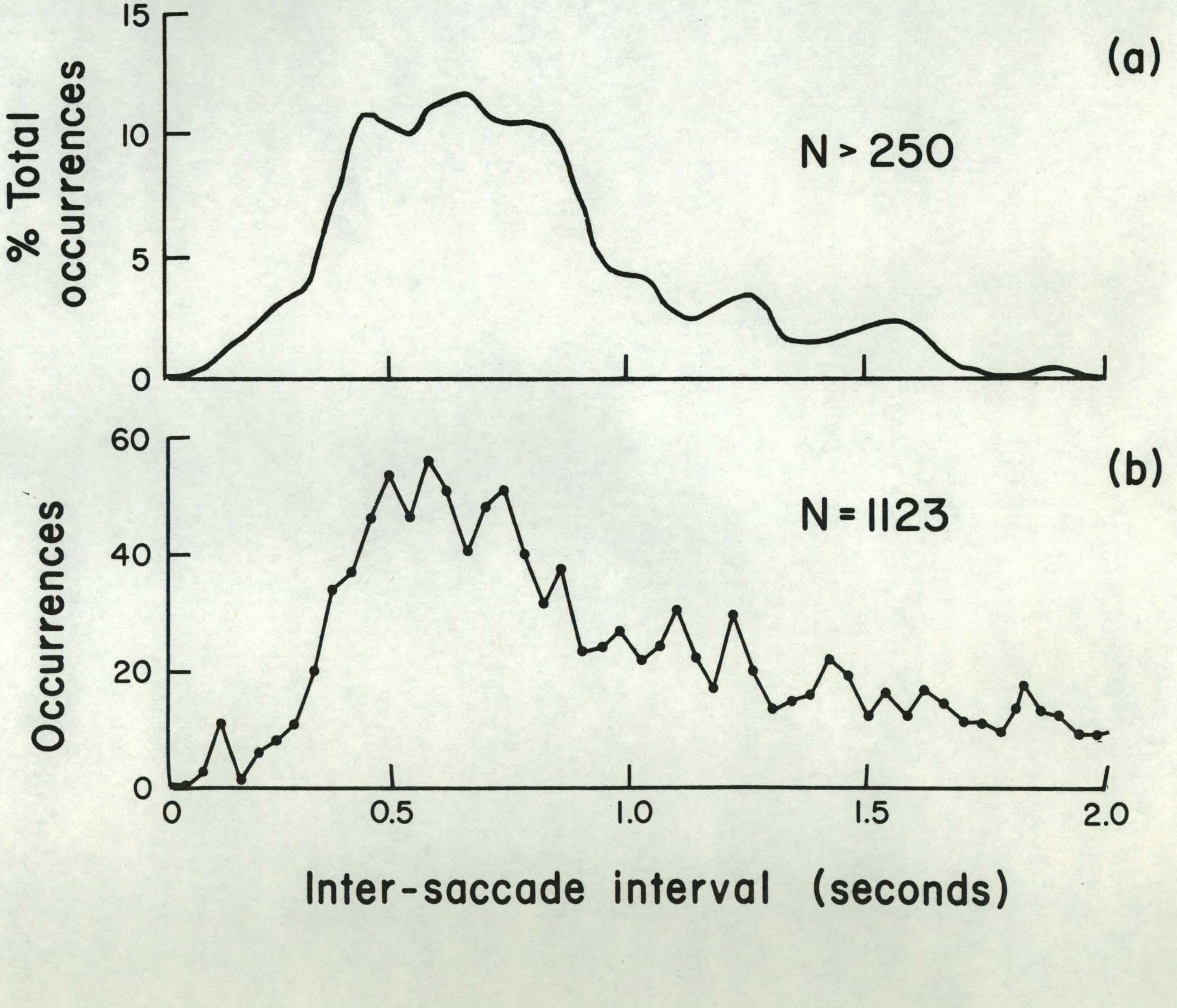
For chameleons, studies of each eye's saccades may give the same insight into chameleon visuo-motor behavior that study of (coupled) human saccades has brought to human visuo-motor behavior (e. g., saccades as indicators of interest and other psychological parameters, Yarbus, 1967; Thomas, 1968; as demonstrating sensory scanning, Jeannerod, Gerin, and Pernier, 1968; Noton and Stark, 1971; as indicators of fatigue, Carmichael and Dearborne, 1947; Poulton, 1958). Such previous studies have usually sought to uncover relationships between particular aspect(s) of the visual environment and the saccades. I think, therefore, that what is notable about these present chameleon results is that they have been so invariant in the wide variety of situations from which they were derived and for such long periods of time (e. g., 4 1/2 hr).

The chameleon saccade sequence may contain structure related to integrative CNS activity. Indeed, if the interval distributions and reaction times for humans are indicative of their central processing, the following observations should be mentioned. Comparisons of the order-independent measures of chameleon and human saccade timing were made. The histograms of the inter-saccade intervals of chameleons are remarkably similar in appearance to those taken from humans (Figure 33; Yarbus, 1967; Jeannerod, Gerin, and Pernier, 1968; West and Boyce, 1968). As is true for chameleons, human saccades are rarely less than about 200 msec apart (Yarbus, 1967). The suggestion that this represents some sort of dead time is indicated by the fact that good readers move their eyes no more often than do poor readers (Yarbus, 1967). Human reaction time, as defined by the time to a saccade contingent on the motion of a visual target spot, is the same as the chameleon reaction time, defined by the time to the first saccade following an auditory "bang" (c.f., Figure 12a to Figure 12b, taken from Latour and Bouman, 1961). I believe these similarities may be widespread among vertebrates and indicative of common aspects of CNS behavior of vertebrates. Therefore, I think that comparative studies should be vigorously pursued.

Contradictory Descriptions of Unilateral Patterns

Superficially, it would seem that the processes structuring chameleon saccadic sequences are simple indeed. After a dead time, the

Figure 33: The inter-saccade interval distributions of *H. sapiens* and *C. dilepis*. The curve in (a) represents data from a human, wearing frosted contact lenses. The frequency-polygon in (b) represents data from a *C. dilepis.* (a) is redrawn from West and Boyce, 1968. The data for (b) were hand-analyzed from 16 mm films of the animal; intervals from both left and right saccade sequences were lumped together.


(a)
% Total occurrences
15
10
5
0
N > 250
(b)
Occurrences
60
40
20
0
N = 1123
0
0.5
1.0
1.5
2.0
Inter-saccade interval (seconds)

saccades of an eye apparently have constant probability of occurrence, suggested by the exponential tails of the interval distributions; and they have symmetric, possibly rectangular, amplitude distributions as derived above (i. e., all sizes equally likely). The dead time does not complicate this model greatly and, were no order-dependent measures available, a simple renewal model would have been conjectured to cover the results. Very similar distributions are derived for model neurons with Poisson inputs and variable spiking thresholds (Stein, 1965), and for binocular rivalry (Levelt, 1968). A major consequence of such simple models is that successive sizes and intervals would be uncorrelated except insofar as required by physical constraints. Obviously, when the eye's position is extremely temporal, saccades must tend to the nasal.

But, successive interval durations are too similar (compared with independent intervals). The tendency seems especially great for the short intervals of about 0. 5 seconds in duration, and in this sense, periodicity of saccade occurrence increases with decreasing intersaccade interval duration. According to the third-difference distributions, saccadic production has accelerative and decelerative phases. These phases may correspond to beginnings and ends of saccade bursts although no direct evidence has been marshalled for this hypothesis. The symmetry of the typical second-difference distribution suggests that acceleration and deceleration are symmetrical. Successive saccades have similar amplitudes and directions. The chameleon eye tends to scan in a "lock to lock" fashion, full nasal line of sight to full temporal (Figure 23), an appropriate behavior if the animals wish to avoid retracing their old fixation pathways for as long as possible.

Perhaps consideration of a "saccade" should be extended to include the antecedent inter-saccade interval. My observations indicate that the sizes of an eye's saccades may be related to the interval duration between them. Large saccades are often associated with locomotion, but have not been observed occurring in rapid sequences (inter-saccade intervals about 0.5 seconds); whereas I have often seen smaller saccades occur in fast "runs" (Figure 21). Strong serial relationships have been demonstrated in chameleon saccade sequences. Any model of saccade production which does not take account of the non-renewal nature of saccade sequences will probably be inadequate (e.g., that of Vasudevan, Phatak, and Smith, 1972).

Hypotheses

Unilateral Patterns: A Hypothesis

An oversimplified picture of unilateral saccade production as a renewal process (i.e., independent intervals and sizes) introduced the previous section. The order-independent measures, taken alone, indicate that saccades, except for the effects of a dead time, are produced with constant likelihood per-unit-time and that all sizes and directions of saccades are equally likely. But serial correlations between successive intervals, sizes and directions have been demonstrated. These contradictory aspects of the way the saccades of a chameleon eye are generated are reconciled in the proposal which follows.

It is reasonable to assume that a saccade's occurrence arises from the pattern of neural behavior preceding it. If that neural pattern's likelihood is thereby temporarily increased in some natural way (e. g., pre-synaptic facilitation), the serial correlations can be accounted for even in the context of a constant tendency to saccades of all sizes at all times. Note that the dead time will be the minimum duration of most of such hypothesized patterns. The accelerations and decelerations at beginnings and endings of bursts remain unexplained for the moment. The constant probability process is conceived to be "neural noise," uniformly distributed with respect to saccade size, direction, and time.

Now that the distributions and correlations observed and calculated from the saccades of chameleon eyes are linked to certain hypothetically physiological causes and effects, some predictions can be developed and tested. The increase of the X^2 measures of the deviation, at increasing frequency, of the saccadic processes from renewal processes can be interpreted as the effect of a decaying facilitatory process. Over a large number of saccades, no particular inter-saccade interval to amplitude relation is presumed. But such relationships are hypothesized to exist for a second or two before decay (loss of facilitiation). In this light, the following prediction was made: that successive saccade size-interval pairs are more correlated than knowledge of successive size correlations and interval correlations would indicate. As previously observed (Figure 21), successive saccades of equal separation in time seem equally sized as well. Quantitative corroboration of the observation would support the above hypothesis.

Electrical stimulation of CNS can cause repeated identically sized saccades independent of initial eye positions (200 Hz stimulation with 1 msec pulse in lateral eye fields of *Macaca mulatta*; Robinson and Fuchs, 1969). The hypothesis, above, suggests that the successive stimulus strengths required to elicit saccades should decrease. This would be a direct test of the hypothesis of facilitation of the "neural pattern" described above. The above observation also indicates that equally-sized saccades can be coded by a repeating neural pattern despite the changing eye position.

The hypothesis predicts that, if the Poisson-like process were externally determined by visual input, and if the visual input were removed, the time constant of the exponential portion of the interval histogram should increase dramatically, leaving the refractory period unchanged. By covering the palpebral fissure of an eye with a small piece of opaque tape and observing the sequence of saccades of the eye, I found that, despite a marked increase in frequency of occurrence of very short intervals, the tail of the interval histogram remained exponential and did have a larger time constant (slope on semilog plot). Nevertheless, the tails of the interval histograms of occluded eyes are quite substantial, indicating that the hypothetical noise generation is not greatly dependent on visual input (Figure 29). The dead time can still be recognized, though swamped with short intervals, because the semilog plots show that the major inflection from linearity (at the mode of the interval distribution from the uncovered eye) remains unchanged after occlusion (Figure 30).

If the above hypothesis is correct, chameleons appear to be maintaining a balance between an unbiased sort of internal response likelihood (i. e., constant probability per-unit-time of saccades directed to equally probable horizontal coordinates with respect to the line of sight) and the repetition of previous visuo-motor behavior. The exponential portions of the interval histograms account for the majority of chameleon saccades. Many, perhaps most chameleon saccades may be generated with little more determination, external or internal, than that with which radioactive particles decay.

Bilateral Patterns: A Revised Hypothesis

The discussion above has referred to the behavior of one eye. It was not necessary to specify which eye, left or right, since both eyes behave identically except when one is occluded and the other is left open. Many of the figures in this thesis show left and right results from concurrent saccade sequences purposely displayed alongside one another to emphasize the similarity in left and right saccadic behavior.

Bursts are bilateral, the beginning and ending accelerations and decelerations of left and right eye saccade occurrences are concurrent. Bursts may be caused by a tonic process simultaneously affecting both left and right saccade generating mechanisms. Returning to the hypothesis of the previous discussion, that neural noise and neural pattern facilitation account for saccade production by a single eye, one can imagine a simple tonic process increasing the noise level in both left and right visuo-motor systems to cause a bilateral burst of saccades.

To account more completely for unilateral saccade behavior together with the observed bilateral correlations, I propose that associated with the occurrence of an eye's saccade is the neural pattern which preceded it; that pattern's likelihood of recurrence is temporarily increased (e. g. ,via pre-synaptic facilitation); and that pattern has some output to the contralateral eye's muscles. The eyes are presumed to be weakly conjugate in the neural sense that each eye receives an attenuated version of the contralateral motor output. Both visuo-motor systems, left and right, are afflicted with a constant probability per-unit-time "neural noise" process which is regulated simultaneously, left and right, by a single tonic influence. The hypothesis, as it applies to a single eye's visuo-motor system, has already been discussed above.

There exists some physiological evidence in favor of such a hypothesis. J. C. Lilly (1962), in addition to reporting that dolphins have independent eye movements, reported that one cannot produce monocular movements of dolphin eyes by ipsilateral stimulation of the motor cortex; only by contralateral stimulation can this be done. But stimulation of either side alone can produce "binocular" movements. Shanklin (1930) reported that, in _C. vulgaris_, many oculomotor nerve fibers are crossed, connecting left and right visuo-motor systems.

According to the hypothesis, there are two regions in time in which the saccade of one eye should particularly enhance the likelihood of a saccade of the other eye: (1) immediately upon the occurrence of a saccade and (2) after an interval which distributes as the inter-saccade intervals of the eye whose saccade just occurred. These two predicted correlations are verified (Figure 17, 18). If, as expected, the hypothetical neural cross-talk decays after a saccade, the X^2 variates should show a frequency dependence in the deviations of the backward cross-interval distributions from those expected, given independent left and right sequences. This result was indirectly observed over a threefold range in saccade frequencies (Figure 15). Size and direction similarities between contralateral saccades should and do increase with shorter times between them (Figure 21). When contralateral saccades are simultaneous, they are often coordinate (Figure 26).

When an eye was occluded, the post-saccadic probability per-unit-time of a next saccade occurrence was about constant, after the dead time; but it was less than for the same eye, free from occlusion, or for the free contralateral eye. A much greater fraction of its saccades closely followed a contralateral saccade than vice versa (i. e., less than 100 msec away). When both eyes were occluded, both eyes again closely followed each other with equal frequency. Seen in the light of the above hypothesis, with less "noise" in its visuomotor system, the occluded eye's saccades are enriched for those programmed by the other eye.

As saccade frequency increases, as in a burst, each saccade sequence becomes more periodic and the effects of the correlation between left and right sides become more intense. The net effect is the production, at high saccade rates, of bilateral saccadic patterns. One would expect the patterns to occur in fairly restricted sequences if the above hypothesis is true, but this point has not been investigated.

Final Remarks

It is clear that left and right visuo-motor outputs in terms of saccades are not statistically independent. Beyond mere correlation, there is the above-mentioned evidence of physiological-connectivity between left and right visual systems, at least at the motor level. Yet, if the dead time mentioned earlier of about 200 msec duration can be taken to represent a central integrative process, then the two sides do appear to be capable of independent integrative processing. One can argue that if all saccades are waiting upon a single integrative system, there should be a refractory period during which no two saccades of any eye(s) could occur. This is plainly not so in chameleons (Figure 18). But a minimum interval, the 200 msec dead time, must normally elapse between two successive saccades of a single eye. As has been shown, the more rapidly saccades occur (in triads), the more likely they are to be coordinated. Whether left and right sides share a common dead time while conjugate cannot be determined since their individual dead times are equal.

The chameleon data suggest that, even in animals whose eye movements are binocularly-coupled, initiations of left side visual processing can occur independently of happenings in the right side and vice versa. I do not suggest that the two sides do not share information above the motor output level, only that they need not process time-locked input in parallel. The existence of binocular rivalry (Levelt, 1968) supports this contention. Animals whose eyes are conjugate may have functionally identical visual systems as animals with independent eye movements, except for a stronger oculomotor coupling. Tests of such speculations will require a greater depth of analysis than has been presented here and much more comparative study of the saccadic eye movements of vertebrates.

SUMMARY

Chameleons were studied in a variety of stationary environments and the results reported here are invariant despite environmental variations. Two stages were involved in the study, a stage in which techniques of saccade observation and recording were developed and applied, and a stage of analysis, involving considerable computation.

Electrooculography was chosen as the technique which allowed the best combination of accurate saccade recording with the greatest efficiency of analysis and with the fewest restrictions of the freedom of the experimental animals. Although electrooculograms (EOGs) have been recorded for only one dimension of movement (horizontal), and are not linearly related to eye position and saccade size, some knowledge of the sizes and directions of saccades can still be inferred from the size and directions of the associated EOG deflections. For example, it is shown that chameleon "saccades" are saccades in the special sense that they have a fixed, directionally symmetrical, size to duration relationship.

This relationship allowed development of matched circuitry which recognized the EOG deflections of saccades. The outputs of the recognition circuits were digitally coded and used as input to computer

programs written to analyze the data. The programs performed some of the standard computations and tests of time series analysis and yielded graphical displays of the results of the computations upon saccade sequences. The results were interpreted in light of the qualitative appearance of the horizontal EOG records.

The bilateral symmetry of the saccadic behavior of the left and right eyes is impressive. In all measured respects, providing that extremely different visual inputs were not presented to each eye, concurrent left and right saccade sequences from the same animal were statistically indistinguishable. If an eye was occluded but still mobile, the bilateral symmetry was lost. Unilateral saccade sequences reflect the properties of a Poisson-like process (causing exponential tails on the interval histograms). They also slow a serial correlation of short (1 sec) inter-saccade intervals and of saccades' horizontal sizes. There is a "dead time," following the occurrence of a saccade, during which further saccades are very rare. The statistically identical left and right saccade sequences are not statistically independent. This relationship is qualitatively observed as the appearance of bilateral saccade patterns, with coordinate behavior at the shortest and most periodic inter-saccade intervals.

Hypotheses are presented suggesting that a majority of saccades occur via a Poisson-like random process, that they occur relatively independently of visual input, that a neural facilitation is responsible for the observed serial correlations, and that left and right chameleon visual systems interact at the motor output level and possibly higher. The chameleon left and right visual integrative processes are considered only weakly coupled, however, as indicated by the absence of a mutual dead time in the presence of identical, individual dead times.

APPENDICES

APPENDIX A1

CIRCUITRY

A1. 1 The recognizer circuit.

The recognizer circuit has one purpose: to produce a rectangular pulse, fixed in height, of the same polarity, and coincident in time with each EOG deflection which corresponds to the horizontal component of a chameleon saccade. Low-frequency drift and high-frequency spikes are ignored by the circuitry. Standard RC-filters introduce phase-shift and consequently were not used. The circuitry is described below; refer to Figures A and B.

The EOGs of left and right eyes pass through variable-gain sections, V_l and V_r, and are both inverted by I_l and I_r, yielding four waveforms. These four enter minimum-slope gates, m_{ld}, m_{lu}, m_{rd}, and m_{ru}, which cannot pass slopes of less than a preset value, thus eliminating low-frequency drift. Note that EOG deflections from saccades in different horizontal directions, nasal or temporal, are separated at this point in the circuitry, and are of the same polarity. Because this stage has a long recovery time, its output is differentiated and clipped above at zero volts by d_{ld}, d_{lu}, d_{rd}, and d_{ru}. The length of

Figure A: Flow chart of saccadic recognition circuit.

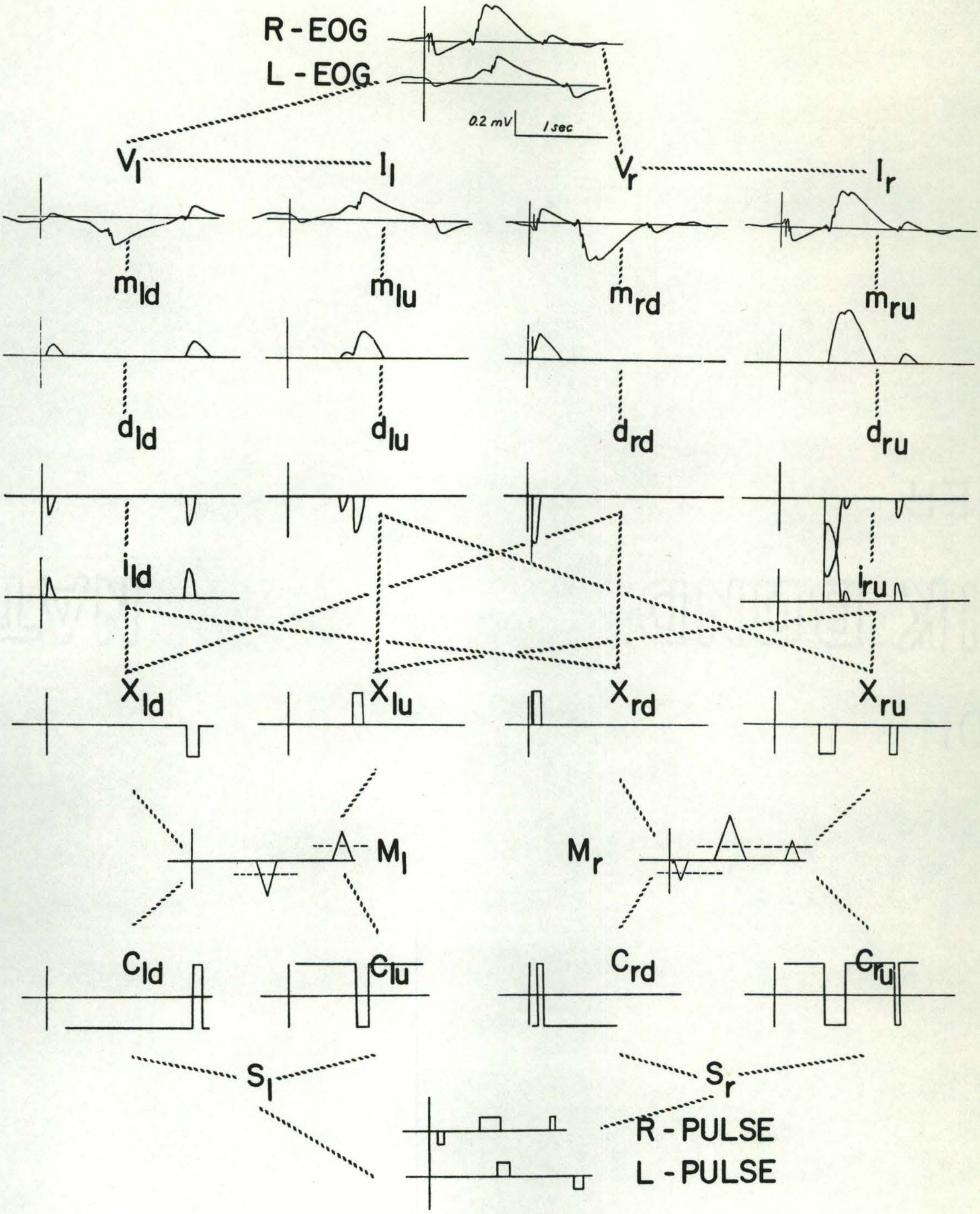
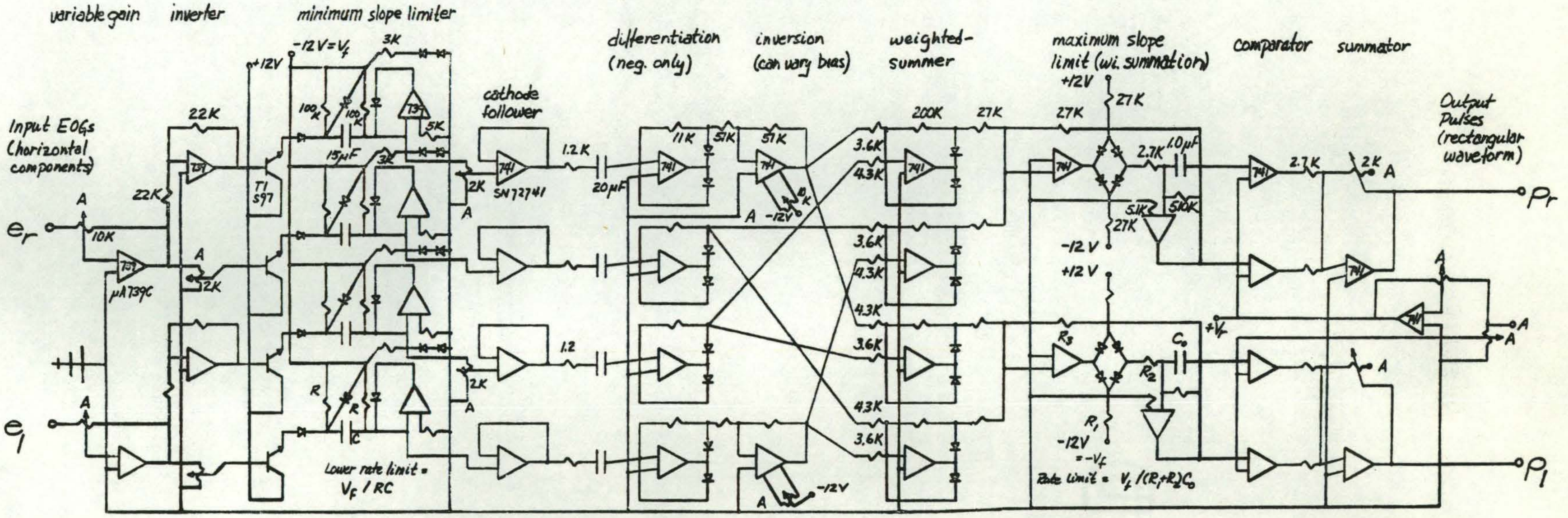

R - EOG
L - EOG
0.2 mV
1 sec
V_l
I_l
V_r
I_r
m_{ld}
m_{lu}
m_{rd}
m_{ru}
d_{ld}
d_{lu}
d_{rd}
d_{ru}
i_{ld}
i_{ru}
X_{ld}
X_{lu}
X_{rd}
X_{ru}
M_l
M_r
C_{ld}
C_{lu}
C_{rd}
C_{ru}
S_l
S_r
R - PULSE
L - PULSE

Figure B: The saccadic recognition circuit.

Saccadic Recognition Circuit



OP. AMPS: FAIRCHILD DUAL LOW-NOISE OP-AMP μA739C
TEXAS INST. HIGH PERFORMANCE OP-AMP SN72741

A = externally available point of adjustment, used for balancing the system.

time a derivative is less than zero corresponds to the duration of the associated saccade.

The circuit now deals with the problem of artifact. Chameleon eyes occupy a major fraction of chameleon heads. Consequently, the EOG of an eye's saccade may pass via volume-conduction to the contralateral electrode pair, appearing on the contralateral EOG to represent a saccade of the contralateral eye. Although this artifact is considerably smaller in amplitude than its causative agent, it often lies within the roughly 20-fold range in amplitude of recognizable EOG responses to saccades. The problem is similar with respect to slopes. I noticed that the real simultaneous eye movements with the same EOG polarity (both eyes rotating to the fore or both to the rear) were rare; furthermore, when they did occur, they were nearly the same size. By the appropriate summations and clipping of waveforms (derived from saccades of the same polarity), I eliminated the left-right artifact. X_{ld}, X_{lu}, X_{rd}, and X_{ru} perform this crossed-summation procedure. Note that subtraction is involved because of the inversions at i_{ld} and i_{ru}. Unless the slope of a hypothetical artifact is greater than about 3/4 of the real saccade slope, it is presumed artifact and deleted.

The gain of the cross-summation circuits was made very large so their outputs would be rectangular pulses (due to saturation of op-amps). The now rectangular waveforms are summed and enter an integrating network, M_l and M_r, with a maximum-slope cutoff at identical positive and negative slope magnitudes. The outputs are triangular waveforms and the heights of the triangles are proportional to the durations that the slopes of the input EOGs were above the thresholds set in m_{ld}, m_{lu}, m_{rd}, and m_{ru}. Schmidt-triggers, C_{ld}, C_{lu}, C_{rd}, and C_{ru} are triggered at identical positive and negative magnitudes of the integrator outputs. The trigger outputs are appropriately summed by S_l and S_r to produce the final output pulse-waveforms. As Figure B indicates, there are several points in the circuitry, labelled "A," where the network can be balanced.

A1.2 The University of Oregon Asynchronous Data Register

I desired that the interface between the EOG data, as "recognized" by the preceding circuit (Appendix A1.1), and the Varian 620/i computer be (1) fast enough for real-time processing, (2) capable of manual or automatic alternation during operation, and (3) error-free, with respect to incoming data. I wanted to toggle data through the interface and into the computer while the interface concurrently accepted the EOG-pulse waveforms, output by the "recognizer" circuit. The interface was required to forgive such poor high-low transitions of the input wave form as are produced by the magnetic tape playback of EOG-pulses.

Professor C. Klopfenstein of the University of Oregon Chemistry Department determined that such a device would be broadly useful in various automatic data-handling systems. Thus, the description below is taken from that of his assistant, C. Meyers, who built the device. Funds were provided by Health Science Advancement Award 5 504 FR 06027, from the General Research Support Branch, Division of Research Resources, Bureau of Health Professions, Education and Manpower Training, National Institute of Health. Interested parties should write the Science Electronics Shop, University of Oregon, Eugene, Oregon, 97403, for further details.

The University of Oregon Asynchronous Data Register receives data on 16 lines (pins 1, 3, 5, 7 . . . , 31 on J1) which set individual J-K flip-flops on a high to low transition. The lines are normally high at 5V and are pulled to group sinking 1 milliamp. Each line is buffered by a Schmidt trigger. This allows the flip-flop to be set over widely varying transition times. Once the flip-flop is set any action on the line is ignored until the flip-flop is reset by the computer.

The contents of the data register can be input to the computer at any time, and the status of the individual bits can then be monitored. Once a given bit is read by the computer, it is reset at the completion of the input command, regardless of the state of the mask register. Because of unique buffering, no data can be lost.

Input commands:

```
01025xx     CIA     DEVA
01026xx     CIB     DEVA
01020xx     IME     DEVA
01021xx     INA     DEVA
01022xx     INB     DEVA
```

xx and DEVA both refer to the octal device address.

The computer can also output a word to the data register. This word is OR'ed with any previous information in the data register at the time of the output.

The output command sequence is as follows:

```
01001xx    EXC    01xx    SELECT DATA REG. FOR OUTPUT
01031xx    OAR    DEVA    OUTPUT WORD
```

OAR can be replaced, of course, by either OBR or OME.

The device also contains a 16 bit mask register and a STATUS LINE. The computer can output a word to the mask register by the command sequence:

```
01000xx    EXC    Oxx     SELECT MASK REG. FOR OUTPUT
01031xx    OAR    DEVA    OUTPUT WORD
```

The voltage on the STATUS LINE is determined by the following scheme: if any bit in the data register is set AND the corresponding bit in the mask register is one, the STATUS LINE is low; otherwise it is high (5V). The state of the STATUS LINE can be sensed by the computer and if properly enabled, an interrupt can be requested as the STATUS LINE goes low. The commands are:

01010xx	SEN	00xx	SENSE STATUS LINE HIGH true response implies high false reponse implies low
01011xx	SEN	01xx	SENSE STATUS LINE LOW COMPLEMENT OF SEN O
01002xx	EXC	02xx	CONNECT STATUS LINE TO INTERRUPT LINE
01003xx	EXC	03xx	DISCONNECT STATUS LINE FROM INTERRUPT LINE

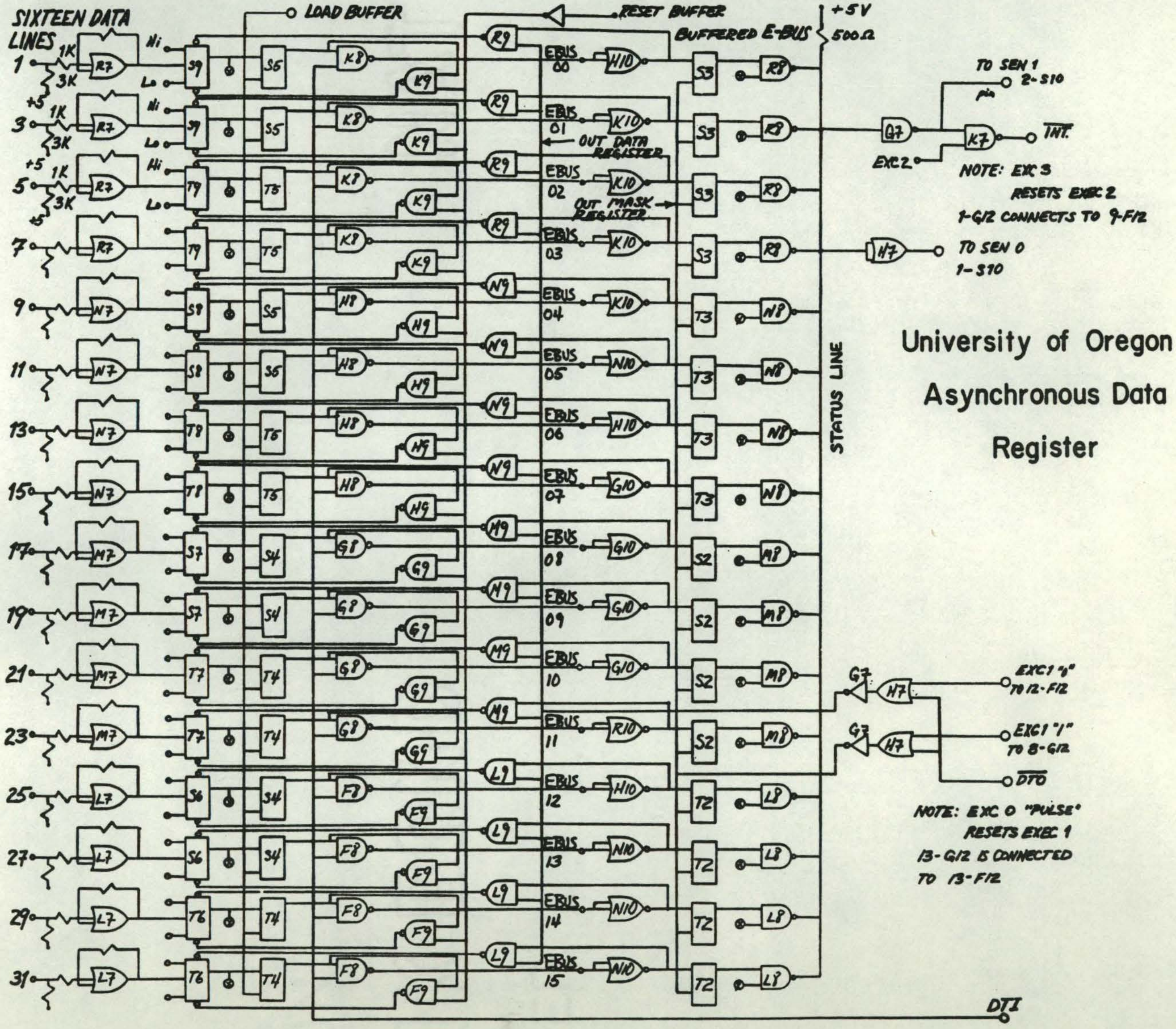
A SYSTEM RESET will have the same effect as EXC O and EXC 3 together.

Circuit Description

Refer to the schematic diagrams of the Asynchronous Data Register and the Peripheral Controller of the Asynchronous Data Register (Figures C and D). The sixteen data lines can be seen at the left. The Schmidt triggers are composed of IC's R7, N7, M7, and L7 along with resister feedback networks. Each sets the corresponding J-K flip-flop when its data line goes from high to low. Since all K inputs of the J-K flip-flops are grounded, they cannot be reset by the data lines.

These sixteen flip-flops form the data register, whose contents can be read into the computer. The LOAD BUFFER signal goes high

Figure C: The University of Oregon Asynchronous Data Register.

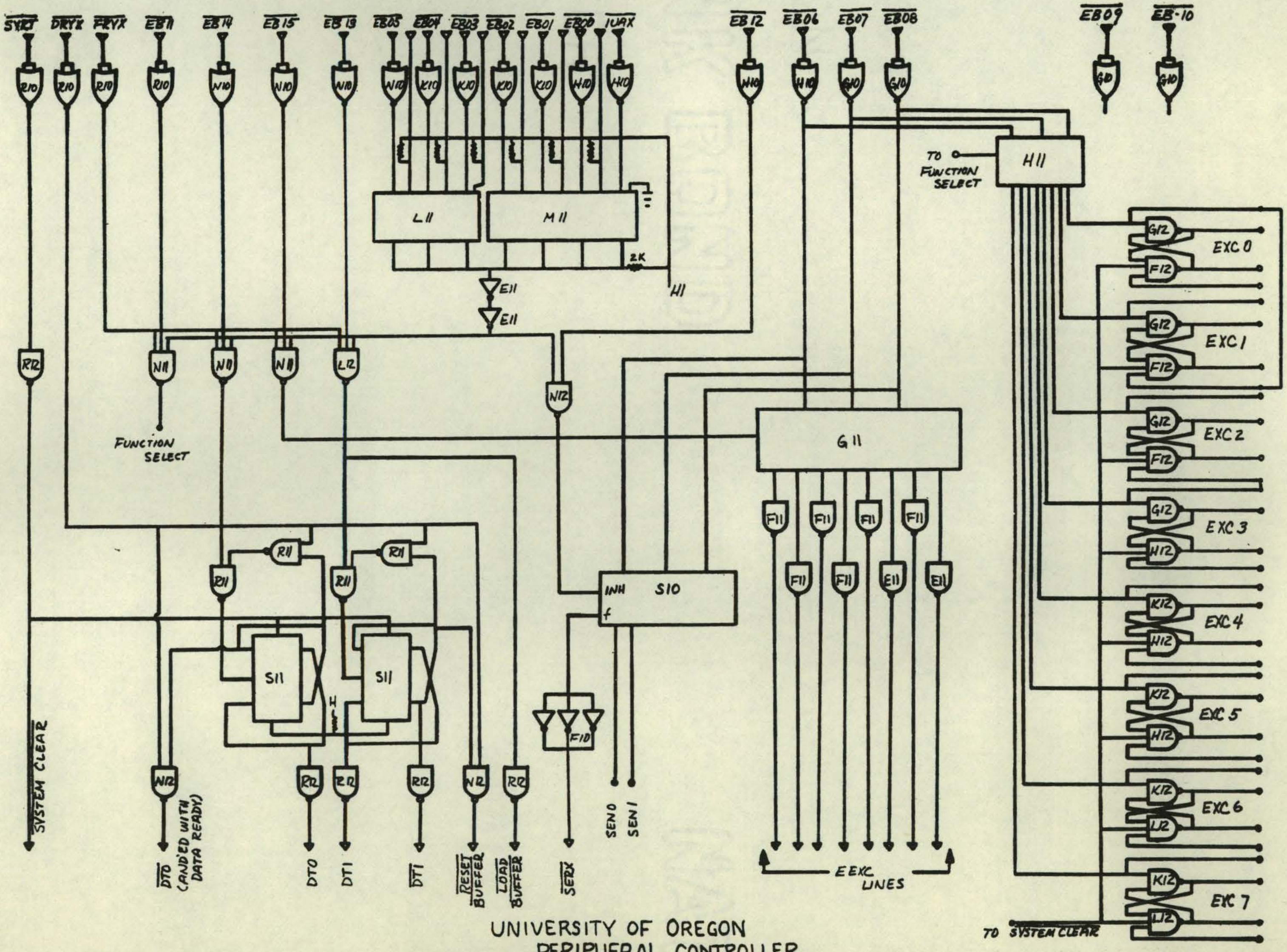


University of Oregon

Asynchronous Data

Register

Figure D: The peripheral controller for the Asynchronous Data Register.



UNIVERSITY OF OREGON
PERIPHERAL CONTROLLER
FOR THE ASYNCHRONOUS DATA REGISTER

during the FRYX part of an input command and strobes the buffer register (IC's S4, T4, S5, T5) with the contents of the data register. On the trailing edge of the FRYX signal DTI (Data Transfer In) goes positive which puts the information in the buffer onto the EBUS in inverted logic through the 8881 drivers (IC's K8, H8, G8, F8). When the computer has read this information, DRYX comes true, bringing $\overline{\text{RESET}}$ $\overline{\text{BUFFER}}$ low. By means of IC's K9, H9, G9, and F9, only those J-K flip-flops in the data register whose output was high at FRYX time (i.e., those bits read as '1') are reset. This prevents possible loss of data. If a bit was set during a computer input command between FRYX and DRYX signals, it is not destroyed and it is read on arrival of the next input command.

The computer can output a word either to the mask register (IC's S2, T2, S3, T3) or to the data register. The EXC1 latch on the peripheral controller is reset when either an EXCO or a system reset is processed. Depending on the state of this latch, either the OUT DATA REGISTER line or the OUT MASK REGISTER line will go high during DRYX in an output command. ($\overline{\text{DTO}}$ goes low.)

Finally, the STATUS LINE goes low if any of the outputs of R8, N8, M8, or L8 go low. This happens whenever both the output of a data register flip-flop and its corresponding mask register bit are high.

SEN0 follows the level of the STATUS LINE directly through the 384 OR gate; SEN1 follows it through an inverter. If the output of the EXC2 latch is high, the interrupt line, INT, goes low as the STATUS LINE goes low. If this line is connected to the PIM an interrupt is requested. The EXC2 latch is reset by either a EXC 3 or SYSTEM RESET.

A1.3 EOG deflection amplitudes and artifact.

Circuitry, intended for the analysis of spike-traffic along nerves, was used to measure the amplitudes of chameleon EOG deflections. Therefore, measurements of artifact were frequent. Recall that a "notch" of summed muscle spikes preceded every saccadic EOG deflection, and that most deflections were accompanied by artifactual cross-talk to the contralateral EOG, due to volume-conduction (Figure 2).

For most saccades, three measurements were taken, (1) the "notch" amplitude, (2) the contralateral artifact amplitude, and (3) the saccadic EOG deflection amplitude. There should be about three times as many such measurements, therefore, as there were saccades. The approximately 60,000 measurements made for Figure 24 were from EOGs containing 20,000 saccades, as measured by the recognition circuitry (Appendix A1.1). Further confirming this line of argument, the deviation of theoretical (Figure 32b) from real (i.e., measured) EOG amplitude distributions becomes very rapidly greater as EOG amplitudes become smaller. This effect starts at about the point where the artifacts of maximum amplitude saccadic deflections appear, namely about 1/4 the maximum deflection size. (Figure 26 indicates that about 4:1 is the ratio of saccadic EOG deflection size to the size of its artifact in the contralateral EOG.) The "notches" also contribute to the very smallest deflections measured.

APPENDIX A2

PROGRAMS

A2.1 The DAS-10 program.

The following program, written for the Varian 620/i in the assembly language, DAS-10, controls the Asynchronous Data Register (Appendix A1.2), and processes input through the ADR from the EOG-pulses, output by the saccadic EOG recognizer circuitry (Appendix A1.1). One of the ADR's 16 bits was used to accumulate counts of the pulses of a regular pulse-train (100/sec, taken at the time of the experiment); a TIM(e) was computed from the count. If other bits were set, they were screened for artifact, and then written as one 16-bit word, along with the TIM word, on IBM-compatible 9-track tape; thus, the analog to digital conversion from tape-recorded (or real-time) EOGs to digitally-coded tape was completed. The coding conventions used by this program and by me for manual introduction of behavior data are shown in Table A2. "Redeyes," an OS/360 program, read the 9-track tapes, produced as above, on the University of Oregon's IBM 360/50 computer.

```
*       JOHN MATES PROGRAM
        ORG     0
        LDXI    BLK1          PUT OUTPUT ARRAY START ADDRESS IN R.A.

        JMP     STR           BRANCH TO STR (BACKGROUND LOOP).

**********************************************************************
**********************************************************************
        ORG     0200
LITE    SET     073
DEVA    SET     077           I/O DEVICE ADDRESS.
BICS    EQU     022
BICE    EQU     023
MBY     EQU     0210
BCKS    EQU     0710
INT     EQU     BICS
BIGO    EQU     BICE
TWRT    EQU     MBY
FILE    EQU     0410
FIX     ORA     OVFL
PANL    DATA    004000        BINARY = '0000100000000000' INTERRUPT BIT.
IBIT    DATA    0173777       BINARY = '1111011111111111'
MASK    DATA    0173777       BINARY = '1111011111111111'
UOVL    DATA    010000        BINARY = '0001000000000000'
DOVL    DATA    020000        BINARY = '0010000000000000'
UDEL    DATA    0177772       BINARY = '1111111111111010'
DDEL    DATA    0177765       BINARY = '1111111111110101'
OVLD    DATA    0147777       BINARY = '1100111111111111'
OVFL    DATA    040000        BINARY = '0100000000000000'
TIM     DATA    1
OLDY    DATA    0
B2FA    DATA    LAST
B1FA    DATA    BLK2-1
B2AD    DATA    BLK2
B1AD    DATA    BLK1
        ORG     01000
BLK1    BSS     512
BLK2    BSS     512
LAST    BSS     0
*********************************************************************
        ORG     0300
*********************************************************************
SERV    ENTR
*       *       *             *
LOOK    ANA     MASK          MASK IS SET TO KILL BUM BITS IN R.A.
        LDB     IBIT          PICK UP INTERRUPT BIT-WIPE IN R.B.
        STB     MASK          MASK IS RESET.
        JAZ     CONT          IF NO GOOD CODE BITS SET, BRANCH TO CONT.

TES1    TAB                   TRANSFER CODE TO R.B FROM R.A.
        ANA     UOVL          CLEAR CODE IN R.A EXCEPT U-OVERLOAD BIT.
        JAZ     TES2          IF BIT NOT SET, BRANCH TO TES2.
```

```
        LDA     MASK          IF BIT SET, PICK UP MASK AND
        ANA     UDEL          SET UDEL INTO MASK
        STA     MASK          AND STORE.
TES2    TBA                   TRANSFER CODE TO R,A FROM R,B.
        ANA     DOVL          CLEAR CODE IN R,A EXCEPT D-OVERLOAD BIT,
        JAZ     LISN          IF BIT NOT SET, BRANCH TO LISN,

        LDA     MASK          IF BIT SET, PICK UP MASK AND
        ANA     DDEL          SET DDEL INTO MASK
        STA     MASK          AND STORE.
LISN    TBA                   TRANSFER CODE FROM R,B TO R,A.
        ANA     OVLD          CLEAR OVERLOAD BITS FROM CODE.
*       *       *             *
CONT    INR     TIM           INCREMENT TIM.
        LDB     TIM           PICK UP TIM IN R,B.
        XBZ     FIX           IF TIM=0, EXECUTE FIX.

        JAZ     BCK           IF R,A IS ZERO, BRANCH TO BCK.

GOON    STA     0,1           IF NOT, PLACE CODE IN OUTPUT ARRAY.
        STB     1,1           PLACE TIM IN NEXT WORD OF OUTPUT ARRAY,
        IXR                   INCREMENT R,X(INDEX REGISTER FOR ARRAY),
        IXR                   INCREMENT R,X(INDEX REGISTER FOR ARRAY),
        TAB                   TRANSFER R,A TO R,B,
        TXA                   TRANSFER INDEX VALUE TO R,A.
        SUBI    BLK2          SUBTRACT END ARRAY ADDRESS,

        JAZ     WR1           IF ARRAY FULL, BRANCH TO WRITE.

        TXA                   TRANSFER INDEX TO R,A.
        SUBI    LAST          SUBTRACT END ADDRESS OF ARRAY2.

        JAZ     WR2           IF ARRAY FULL, BRANCH TO WRITE.

        TBA                   REPLACE CONTENTS OF R,A.
        STA     OLDY
        JAN     GOON          IF R,A NEGATIVE, LOOP TO GOON.

BCK     TZA                   PUT '0' IN R,A
        JMP*    SERV          JUMP TO ROUTINE WHICH CALLED SERV.

***********************************************************************
***********************************************************************
WR1     CALL    BUSY          IS UNIT BUSY?

        OME     BICS,B1AD     LOAD INITIAL REG. FROM MEMORY.

        OME     BICE,B1FA     LOAD FINAL REG. FROM MEMORY.

        JMP     WRT           BRANCH TO WRITE.

*--------------------------------------------------------
BUSY    ENTR
```

```
WAIT    SEN*    MBY,BUSY        IS MTU READY? YES; BRANCH TO CALLING

        JAN     WAIT

        HLT     01              STOP, PUT 1 IN R.U, I STEP TO START,
        JMP     STR             BRANCH TO START OVER,

*-----------------------------------------------------------------
WR2     LDXI    BLK1            RESET ARRAY INDEX (R.X),

        CALL    BUSY            IS UNIT BUSY?

        OME     BICS,B2AD       LOAD INITIAL REG, FROM MEMORY,

        OME     BICE,B2FA       LOAD FINAL REG, FROM MEMORY,

*-----------------------------------------------------------------
WRT     EXC     BIGO            INITIALIZE BIC,
        EXC     INT             ACTIVATE ENABLE,
        EXC     TWRT            WRITE ONE BINARY RECORD,
        TBA                     TRANSFER R.B TO R.A,
        JAN     DON             IF R.A NEGATIVE, BRANCH TO DON(E),

        JMP     BCK             OTHERWISE, BRANCH BACK,

*-----------------------------------------------------------------
DON     CALL    BUSY            IS UNIT BUSY?

        EXC     FILE            WRITE FILE MARK,
        TZA                     PUT '0' IN R.A,
        HLT     02              STOP, PUT '2' IN R.U, I CAN STEP TO START,
***NOTE: IF I SET R.A < 0, VOLUME IS ENDED,***
        JAZ     STR             IS R.A UNTOUCHED? YES; JUMP TO START,

        CALL    BUSY            NO, IS UNIT BUSY?

        EXC     FILE            WRITE SECOND FILE MARK,
        CALL    BUSY            IS UNIT BUSY?

        EXC     BCKS            REWIND TAPE,
        CALL    BUSY            IS UNIT BUSY?

        HLT                     STOP***FOR REAL, THIS TIME***
************************************************************************
STR     INA     DEVA            CLEAR DEV DATA REG,
        TZA                     CLEAR R.A,
        IAR                     R.A = 1,
        STA     TIM             TIM = 1,
        TZA                     R.A = 0,
        TZB                     R.B = 0,
        STA     OLDY
LOP     INAB    DEVA            R.A = R.B = DEV, DATA REG,
        OME     LITE,OLDY       PUT CODE TO LITES,

        ANA     PANL            LOOK FOR 'INTERRUPT' BIT,
        JAZ     LOP             IF BIT NOT SET, GO THRU LOOP AGAIN,

        TBA                     IF BIT IS SET, TRANSFER R.B TO R.A,
        JMPM    SERV            BRANCH TO PROCESSING ROUTINE,

        TZA                     R.A = 0,
        TZB                     R.B = 0,
        JMP     LOP             GO BACK TO INPUT LOOP,

        END
```

Table A2: Coding for the 16-bit Asynchronous Data Register. Any combination of bits may be set (except for bit-16). A periodic interruption (bit-12) increased a count, TIM. Whenever bits other than bit-12 were set, a small DAS-10 program "filtered" the code-word and, if bits remained set, the code-word and TIM were written, as a pair, onto 9-track IBM-compatible tape. Shown here are the codes which controlled the program, the codes which were set by the saccade recognizer circuitry and the codes which were set by hand (behavior recording). The program, "Redeyes," sorts and analyzes these codes at the University of Oregon's IBM 360/50. (Appendix 2. 2). The blank spaces in the table are equivalent to zero.

TABLE A2

Code Meanings	Sixteen-bit buffer of Asynchronous Data Register															
	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Interrupt	0	0	0	0	1	0	0	0								
TIM(e) Word Size = $(2^{16}-1)$	0	1	0	0	0	0	0	0								
Stop; end tape file	1	0	0	0	0	0	0	0								
R-eye saccade; nasad													0	0	0	1
R-eye saccade; temporad													0	0	1	0
L-eye saccade; nasad													0	1	0	0
L-eye saccade; temporad													1	0	0	0
Erase nasad saccades (temporary)	0	0	0	1												
Erase temporad saccades (temporary)	0	0	1	0												
Moving					0	0	0	1								
Moving to rear					0	1	0	1								
Moving forward					0	0	1	1								
Turning					0	1	1	1								
Quiet									0	1	0	0				
Asleep					0	1	0	0	0	1	0	0				
Waking					0	1	1	0	0	1	0	0				
Looking					0	0	1	0	0	1	0	0				
Both eyes shut									0	0	1	0				
L-eye shut					0	1	0	0	0	0	1	0				
R-eye shut					0	0	1	0	0	0	1	0				
Animal hanging					0	1	1	0	0	0	1	0				
External "stimulus"									0	0	0	1				
Audible bang					0	1	0	0	0	0	0	1				
Inteference by observer					0	0	1	0	0	0	0	1				
	Program control					Behavior code--manually toggled in at run-time							Output of Saccadic EOG Recognizer			

A2.2 Redeyes: a fast data sort and check.

```
*                              *REDEYES                          *
*       THIS PROGRAM READS A NO-LABEL, 9-TRACK, IBM-             *
* COMPATIBLE TAPE OF UP TO NINE FILES LONG.  RECORD LENGTH       *
* IS FIXED.  THE TAPE WAS CREATED BY A VARIAN 620I INTER-        *
* FACED WITH EITHER ONLINE DATA OR FM TAPE-RECORDED DATA.        *
* OF EVERY 32 BITS, THE 16 RIGHTMOST BITS INDICATE THE           *
* BINARY TIME OF AN EVENT (EYE MOVEMENT AND/OR BEHAVIOR)         *
* AND THE 16 LEFTMOST BITS INDICATE THE TYPE OF THAT EVENT.      *
*       SOURCE TAPE FILES ARE SEQUENTIALLY PROCESSED AND A       *
* CORRESPONDING SEQUENCE OF DD CARDS **MUST** BE PROVIDED        *
* TO THE PROGRAM (INPUT1,INPUT2,INPUT3,...).  EVERY FILE ON      *
* THE SOURCE TAPE IS TAKEN TO REPRESENT ONE EXPERIMENT.          *
*       THE PROGRAM SORTS THROUGH THE DATA, SEPARATING RIGHT     *
* EYE DATA FROM LEFT EYE DATA FROM BEHAVIORS.                    *
*       'BAD' DATA IS REJECTED.  (FOR EXAMPLE, IF TWO IPSI-      *
* LATERAL EYE MOVEMENTS ARE TOO CLOSE IN TIME, THE SECOND IS     *
* REJECTED ALTHOUGH THE FIRST IS CODED WITH THE SECOND'S         *
* DIRECTION (PROVIDING THAT THE FIRST IS NOT A CLOSE SECOND      *
* TO A PREVIOUS IPSILATERAL MOVEMENT)).                          *
*       ON RECEIPT OF A 'GOOD' EYE MOVEMENT, THE FIRST,          *
* SECOND, AND THIRD ORDER LATENCIES ARE COMPUTED FOR THE         *
* IPSILATERAL SIDE AND THE BACK LATENCY TO THE CONTRALATERAL     *
* SIDE IS COMPUTED, YIELDING FOUR WORDS.  THESE FOUR WORDS       *
* PLUS TWO MORE, ONE FOR THE CODE OF THE ABOVE 'GOOD' MOVE-      *
* MENT , ONE FOR ITS TIME, ARE MOVED (AS SIX WORDS) INTO ONE     *
* OF TWO OUTPUT ARRAYS (FOR LEFT AND RIGHT) WHICH, WHEN FULL     *
* IS WRITTEN ONTO 9-TRACK TAPE.  (THE FIRST ARRAY MEMBERS        *
* ARE CODE PARAMETERS INDICATING ARRAY TYPE, EXPERIMENT, AND     *
* CUMULATIVE NUMBER OF MOVEMENTS OF THE TYPE TO THIS POINT).     *
* A THIRD ARRAY IS FILLED WITH CODE FOR THE ONGOING BEHAVIOR     *
* AND WHEN FULL IS ALSO OUTPUT TO THE SAME 9-TRACK TAPE.         *
* THE SINGLE FILE SO FORMED IS STORED AND CATALOGUED.            *
*       IN ADDITION, ON RECEIPT OF A 'GOOD' EYE MOVEMENT,        *
* ARRAYS REPRESENTING HISTOGRAMS (1ST,2ND,3RD,AND BACK           *
* LATENCIES) ARE UPDATED AND PERIODICALLY SENT TO A SINGLE       *
* DISC FILE FOR PLOTTING BY THE NEXT JOB STEPS.  EACH HGRAM      *
* DERIVES FROM THE DATA FOR A FIXED INTERVAL OF AN EXPERIMENT.*
* THE LAST STEP IN THE PROGRAM IS A TRANSFER OF HGRAM DATA       *
* ON DISC TO THE 2ND FILE OF THE OUTPUT TAPE.                    *
*       PRINTED DIAGNOSTICS FOR EACH INTERVAL ARE PUT OUT        *
* AT THE SAME TIMES THAT HGRAM DATA GOES TO DISC THROUGHOUT      *
* THE PROGRAM.                                                   *
*       THE PROGRAM IS FLEXIBLE TO THE EXTENT THAT THE BLOCK     *
* SIZE OF THE SOURCE TAPE (RECFM=F,BLKSIZE=LRECL), THE DEAD-     *
* TIME REQUIRED BETWEEN SUCCESSIVE IPSILATERAL MOVEMENTS,        *
* THE INTERVAL LENGTH OF HGRAMS AND PRINTOUTS, AND THE           *
* "PERIOD" (THE LARGEST INTEGER THE SOURCE COMPUTOR CAN          *
* PUT IN A SINGLE WORD) ARE SET WITH A SINGLE SYSIN DATA         *
* CARD.  (NOTE:  THE BLKSIZE SPECIFIED BY THE INPUT CARD         *
* **MUST** BE THE SAME AS SPECIFIED ON THE DD CARDS FOR THE      *
* SOURCE TAPE INPUT FILES.)                                      *


          MACRO
```

```
&NAME    PUTOUT &IDEN,&COUNT,&LOCATOR,&NAME2
&NAME    LA     4,&IDEN          R4 GETS BEGINNING ADDRESS OF ARRAY.
         MVC    8(4,4),&COUNT MOVE COUNT INTO ARRAY.
         PUT    TAPE2,(4)        PUT ARRAY TO TAPE2.
&NAME2   MVC    16(256,4),ZEROES            CLEAR ARRAY WITH ZEROES,
         MVC    272(256,4),ZEROES           EXCEPT FOR FIRST FOUR
         MVC    528(256,4),ZEROES           CODING WORDS.
         MVC    784(240,4),ZEROES
         LA     4,16(4)          R4 GETS BEGIN ADDRESS + 16.
         ST     4,&LOCATOR       R4=LOCATOR=START DATA ADDRESS.
         BR     10               BRANCH TO CALLING STATEMENT+1.
         MEND


REDEYES  START 0
         B      12(15)           BRANCH TO STORE REGISTERS.
         DC     X'07'            FOR FORTRAN
         DC     CL7'REDEYES'     CALLING ROUTINE.
         STM    14,12,12(13)     STORE REGISTERS.
         ST     13,28(15)        STORE R13 IN SAVE+4.
         BAL    13,96(15)
         USING  SAVE,13
SAVE     DS     18F              R13 IS SAVE ADDRESS AND BASE REGISTER.
         B      ONMARK           BRANCH AROUND DCB'S AND ARRAYS.
*        *
         DS     0F
         PRINT  NOGEN


*        * TAPE1 IS THE SOURCE TAPE FOR REDEYE......................... *

TAPE1    DCB    DSORG=PS,RECFM=F,MACRF=(GL,PM),BUFNO=8,DDNAME=INPUT1,    X
               EODAD=CHOKE


*        * TAPE2 IS THE FIRST FILE OF OUTPUT TAPE AND IT CONTAINS       *
*        * SORTED DATA................................................. *

TAPE2    DCB    DSORG=PS,RECFM=F,MACRF=(GM,PM),BLKSIZE=1024,LRECL=1024, X
               BUFNO=8,DDNAME=OUTAPE


*        * TAPEF2 IS THE SECOND FILE OF OUTPUT TAPE AND IT CONTAINS     *
*        * HGRAM DATA.................................................. *

TAPEF2   DCB    DSORG=PS,RECFM=F,MACRF=(GM,PM),BLKSIZE=6144,LRECL=6144, X
               BUFNO=4,DDNAME=OUTAP2


*        * PLOTDISC IS THE TEMPORARY STORAGE FOR THE HGRAM DATA....... *
```

```
256 PLOTDISC DCB    DSORG=PS,RECFM=F,MACRF=(GL,PM),BLKSIZE=6144,LRECL=6144, X
                    BUFNO=4,DDNAME=OUTDISC,EODAD=CLOSEUP


311 *         * THIS IS DCB FOR PARAMETER CARD READING.................... *

313 CARDIN   DCB    DSORG=PS,RECFM=F,MACRF=GM,BLKSIZE=80,LRECL=80,          X
                    DDNAME=SYSIN


368 *         * THIS IS DCB FOR DIAGNOSTIC PRINTOUTS...................... *

370 PRNT     DCB    DSORG=PS,MACRF=PM,DDNAME=SYSPRINT


425 *THESE NEXT REGIONS ARE FOR DATA ARRAYS AWAITING OUTPUT*
426 *
427          DS     0D
428 BIDENTIT DC     F'4080'         CODE FOR B. B-ARRAY STARTS HERE.
429          DC     F'4080'         =B'111111110000'
430 BCOUNT   DC     F'0'            BCOUNTB IS PUT HERE.
431          DC     F'0'            FILE COUNT PLACED HERE.
432 BSTART   DS     252F            DATA STARTS HERE.
433 *        *
434 RIDENTIT DC     F'3'            CODE FOR R. R-ARRAY STARTS HERE.
435          DC     F'3'            =B'011'
436 RCOUNT   DC     F'0'            RCOUNTR IS PUT HERE.
437          DC     F'0'            FILE COUNT PLACED HERE.
438 RSTART   DS     252F            DATA STARTS HERE.
439 *        *
440 LIDENTIT DC     F'12'           CODE FOR L. L-ARRAY STARTS HERE.
441          DC     F'12'           =B'01100'
442 LCOUNT   DC     F'0'            LCOUNTL IS PUT HERE.
443          DC     F'0'            FILE COUNT PLACED HERE.
444 LSTART   DS     252F            DATA STARTS HERE.
445 ENDATA   DS     0F
446 *        *      NOTE:
447 *BIDENTIT=(CODE,CODE,BCOUNTB,ZERO,126*(BCODE,TIME)).
448 *RIDENTIT=(CODE,CODE,RCOUNTR,ZERO,42*(RCODE,TIME,D1,D2,D3,R-L)).
449 *LIDENTIT=(CODE,CODE,LCOUNTL,ZERO,42*(LCODE,TIME,D1,D2,D3,L-R)).
450 *        *


452 *        *
453 DDNAME   EQU    TAPE1+X'28'     LOCATION OF DDNAME.
454 OPENFLAG EQU    TAPE1+X'30'     LOCATION OF FLAG.
455 *        *


457 ONMARK   EQU    *
```

```
458          BALR  12,0
459          USING *,12            R12 IS IMPLIED BASE REGISTER.
460 GETSET   LA    11,4095(12)
461          USING GETSET+4095,11     R11 IS EXTRA IMPLIED BASE REGISTER.
462          LA    4,RPLOT         PICK UP ADDRESS OF R-HGRAM ARRAY.
463          A     4,PLOTSIZE      ADD SIZE OF PLOT IN BYTES.
464          ST    4,LPLOT         SUM=ADDRESS OF L-HGRAM ARRAY.
465          A     4,PLOTSIZE      ADD SIZE OF PLOT IN BYTES.
466          ST    4,ENDWORK       SUM=FIRST ADDRESS BEYOND HGRAMS.


468 GETPARAM EQU   *               READ EBCDIC PARAMETERS AND STORE IN BINRY.
469          OPEN  (CARDIN,INPUT)
475          GET   CARDIN,CARD     READ PARAMETER CARD.
480          NI    CARD+9,X'CF'  MAKE EBCDIC 'PERIOD' POS. SIGN.
481          NI    CARD+19,X'CF' MAKE EBCDIC 'INTERTIM' POS. SIGN.
482          NI    CARD+29,X'CF' MAKE EBCDIC 'DEADTIME' POS. SIGN.
483          NI    CARD+39,X'CF' MAKE EBCDIC 'INBUFSIZ' POS. SIGN.
484          PACK  DOUBLE(8),CARD(10)        PACK AND CONVERT 'PERIOD'
485          CVB   4,DOUBLE                  TO BINARY.
486          ST    4,PERIOD        STORE BINARY 'PERIOD'
487          PACK  DOUBLE(8),CARD+10(10)     PACK AND CONVERT'INTERTIM'
488          CVB   4,DOUBLE                  TO BINARY.
489          ST    4,INTERTIM      STORE BINARY 'INTERTIM'.
490          PACK  DOUBLE(8),CARD+20(10)     PACK AND CONVERT 'DEADTIME'
491          CVB   4,DOUBLE                  TO BINARY.
492          ST    4,DEADTIME      STORE BINARY 'DEADTIME'.
493          PACK  DOUBLE(8),CARD+30(10)     PACK AND CONVERT 'INBUFSIZ'
494          CVB   4,DOUBLE                  TO BINARY.
495          ST    4,INBUFSIZ      STORE BINARY 'INBUFSIZ'.
496          CLOSE CARDIN


503 OPENOUTS EQU   *
504          OPEN  (TAPE2,OUTPUT,PLOTDISC,OUTPUT,PRNT,OUTPUT)


515 *        *
516 LETSGO   EQU   *
517          OPEN  TAPE1           OPEN INPUT FILE.
523          TM    OPENFLAG,B'00010000'  IS FILE THERE?
524          BZ    SLAMSHUT        BRANCH TO END, IF NOT.

526          PUT   PRNT,HEIGHO     INDICATE START OF PROCESSING OF FILE.


533 SWEEPOUT EQU   *               FILL ALL OUTPUT ARRAYS WITH ZEROES.
534          LA    4,BIDENTIT      PICK UP ADDRESS OF B-ARRAY.
535          BAL   10,B            CLEAR B-ARRAY WITH ZEROES.
536          LA    4,RIDENTIT      PICK UP ADDRESS OF R-ARRAY.
```

```
          BAL   10,R            CLEAR R-ARRAY WITH ZEROES.
          LA    4,LIDENTIT      PICK UP ADDRESS OF L-ARRAY.
          BAL   10,L            CLEAR L-ARRAY WITH ZEROES.
          BAL   10,BIGZERO      CLEAR HGRAMS.


INITIALS  EQU   *
          LM    5,8,DUMMYDEL  LOAD REGISTERS 5-8 WITH DUMMY 1ST ARGS.
          MVC   DOUBLE(148),ZEROES        CLEAR LAST FILE'S CONSTANTS.
          MVC   INTERVAL(4),ONE           INITIALIZE INTERVAL.
          MVC   PRNTPLOT(4),INTERTIM      INITIALIZE PRNTPLOT.
          LA    4,BIDENTIT    INSERT FILE COUNT IN:
          MVC   12(4,4),FILECNT           FOURTH WORD OF B-ARRAY,
          MVC   1036(4,4),FILECNT         FOURTH WORD OF R-ARRAY.
          MVC   2060(4,4),FILECNT         FOURTH WORD OF L-ARRAY.


IGETMORE  EQU   *
          GET   TAPE1           GET A RECORD.

          LR    2,1             LOAD R2 WITH ADDRESS OF RECORD.
          LR    4,2             LOAD R4 WITH ADDRESS OF RECORD.
          A     4,INBUFSIZ      COMPUTE END OF INPUT BUFFER ADDRESS.
          ST    4,ENDBUFIN      STORE ADDRESS IN ENDBUFIN.
          B     ERRTEST1        RESUME PROCESSING.


INHALE    EQU   *
          LA    2,4(2)          MOVE FORWARD ONE WORD IN INPUT BUFFER.
          C     2,ENDBUFIN      ARE WE STILL IN INPUT BUFFER?
          BNL   IGETMORE        NO: GET ANOTHER RECORD.


ERRTEST1  EQU   *
          TM    0(2),B'10000000'          (-) WORD IS EITHER END OF FILE
          BO    INHALER1                  SIGNAL OR TYPE1 ERROR.


TIMEFIX   EQU   *
          TM    0(2),B'01000000'          HAS TIME CYCLED?
          BO    UPDATE                    YES: INCREASE INCR.
          L     3,0(2)          ISOLATE TIME (RIGHT 16 BITS).
          N     3,CODEMASK
FIXUP     A     3,INCR          ADD INCR; LEAVE IN R3.


ERRTEST2  EQU   *
          C     3,PREVTIME      IF TIME NOT GREATER THAN PREV.TIME,
          BNH   INHALER2        BRANCH TO ERROR ROUTINE 2.
```

```
          ST    3,PREVTIME     STORE TIME IN PREV.TIME.


TRIGGER   EQU   *
          C     3,PRNTPLOT     IS IT TIME TO PRINT AND PLOT?
          BL    BEHAVIOR       NO: SKIP OUTPUT.
          BAL   9,HARDCOPY     YES: PUT HGRAMS TO DISC, AND DIAG. PRNT.


BEHAVIOR  EQU   *
          TM    0(2),B'00111111'          IF ANY OF B-CODES SET,
          BM    GOBEHAVE                  BRANCH TO GOBEHAVE (WHICH
          BO    GOBEHAVE                  FILLS B ARRAY WITH DATA).
          TM    1(2),B'11110000'
          BM    GOBEHAVE
          BO    GOBEHAVE


RIGHT     EQU   *
          TM    1(2),B'00000011'          IF R BITS ON GO TO GORIGHT.
          BM    GORIGHT
          BO    GORITERR       IF BOTH BITS ON WE HAVE ERROR TYPE3.


LEFT      EQU   *
          TM    1(2),B'00001100'          IF L BITS ON, GO TO GOLEFT.
          BM    GOLEFT
          BO    GOLEFTER       IF BOTH BITS ON, WE HAVE ERROR TYPE4.
          B     INHALE


*         *



*         *     *******COMING FROM TAPE1 EODAD*******
CHOKE     EQU   *              FILE ENDED. PUT OUT LAST RECORDS.
          BAL   10,BPUT        PUT LAST B RECORD.
          BAL   10,RPUT        PUT LAST R RECORD.
          BAL   10,LPUT        PUT LAST L RECORD.

          PUT   PRNT,LASTGASP

          BAL   9,HARDCOPY     PUT LAST HGRAMS TO DISC, AND PRINT

          PUT   PRNT,PASSOUT   LAST DIAGNOSTICS.
```

```
MODCLOSE EQU   *             CLOSE INPUT FILE. MODIFY DDNAME.
         CLOSE (TAPE1,LEAVE)
         LE    6,FILEFLO     UPDATE F.P. FILE INDEX FOR HGRAMS.
         AE    6,FLONE
         STE   6,FILEFLO
         L     9,FILECNT     LOAD FILE COUNT REFERENCE.
         LA    9,1(9)        ADD ONE.
         ST    9,FILECNT     FILECNT IS SCAN POSITION TO GET NUMBER.
         STC   9,DDNAME+5    PLANT IN DDNAME TO MODIFY.
         TR    DDNAME+5(1),NUMBER
         B     LETSGO        GO BACK AND SEE IF NEW FILE EXISTS.


SLAMSHUT EQU   *
         CLOSE (TAPE2,LEAVE,PLOTDISC,REREAD)


         OPEN  (TAPEF2,OUTPUT,PLOTDISC,INPUT)
COPY     GET   PLOTDISC
         PUTX  TAPEF2,PLOTDISC
         B     COPY


CLOSEUP  CLOSE (TAPEF2,REREAD,PLOTDISC,REREAD)


RETURN   EQU   *
         L     13,SAVE+4     GET ADDRESS OF SAVE AREA.
         LM    14,12,12(13)  RESTORE REGISTERS.
         MVI   12(13),X'FF'  NOTIFY FORTRAN OF CONTROL.
         BR    14            RETURN TO CALLING PROGRAM.


*        *
******** END OF MAIN PROGRAM. SUBROUTINES FOLLOW.********************
*        *


UPDATE   EQU   *
         NI    0(2),B'00111111'        CLEAR TIME CYCLE INDICATOR BIT.
         L     4,INCR        PICK UP INCR.
         A     4,PERIOD      ADD PERIOD (=LENGTH OF CYCLE)
         ST    4,INCR        STORE UPDATED INCR.
         L     3,0(2)        PICK UP INPUT WORD WITH R3.
         N     3,CODEMASK    CLEAN OUT NON-TIME CODE IN R3.
         B     FIXUP         GO AHEAD WITH PROCESSING.
```

```
705 GOBEHAVE EQU   *
706          L     4,BCOUNTB      PICK UP BEHAVIOR COUNT.
707          LA    4,1(4)         ADD ONE.
708          ST    4,BCOUNTB      PUT NEW COUNT BACK.

710          L     4,BLOCATOR     FIND END OF DATA IN B-ARRAY.
711          MVC   2(2,4),0(2)    MOVE NEW DATA TO B-ARRAY.
712          NI    3(4),B'11110000'       WIPE OUT OTHER CODE.
713          ST    3,4(4)         MOVE NEW DATA TIME TO B-ARRAY.
714          LA    4,8(4)
715          ST    4,BLOCATOR     UPDATE DATA END ADDRESS.
716          LA    10,RIDENTIT    PICK UP ADDRESS OF R-ARRAY.
717          CR    4,10           COMPARE PRESENT ADDRESS TO END OF ARRAY.
718          BL    RIGHT          IF ARRAY NOT FILLED, CONTINUE.
719          BAL   10,BPUT        ARRAY FULL: PUT IT OUT.
720          B     RIGHT          CONTINUE PROCESSING.


722 GORIGHT  EQU   *
723          C     3,RALARM       IS PREV.R TOO RECENT?
724          BH    GOODRITE       NO: R IS 'GOOD'--GO PROCESS IT.
725          CLI   RFLAG,X'00'    IS R FLAG SET?  YES: TWO OR MORE
726          BH    TOOMANYR       RECENT R'S.  SKIP CODE CHANGE.
727          MVI   RFLAG,X'01'    NO: SET RFLAG AND
728          LH    5,0(2)         CHANGE CODE IN R5 TO
729          N     5,RRESERVE     CODE IN PRESENT INPUT.
730 TOOMANYR LR    4,3            PUT TIME IN R4.
731          A     4,DEADTIME     ADD DEADTIME.
732          ST    4,RALARM       PUT RESULT IN RALARM.
733          B     LEFT           CONTINUE PROCESSING.


735 GOLEFT   EQU   *
736          C     3,LALARM       IS PREV.L TOO RECENT?
737          BH    GOODLEFT       NO: L IS 'GOOD'--GO PROCESS IT.
738          CLI   LFLAG,X'00'    IS L FLAG SET?  YES: TWO OR MORE
739          BH    TOOMANYL       RECENT L'S. SKIP CODE CHANGE.
740          MVI   LFLAG,X'01'    NO: SET LFLAG AND
741          LH    7,0(2)         CHANGE CODE IN R7 TO
742          N     7,LRESERVE     CODE IN PRESENT INPUT.
743 TOOMANYL LR    4,3            PUT TIME IN R4.
744          A     4,DEADTIME     ADD DEADTIME.
745          ST    4,LALARM       PUT RESULT IN LALARM.
746          B     INHALE         GET ANOTHER INPUT WORD.


748 GOODRITE EQU   *
749          MVI   RFLAG,X'00'    LOWER R FLAG.
750          N     5,RRESERVE     LEAVE ONLY R-CODE IN R5.

752          L     4,RCOUNTR      PICK UP RIGHT EYE COUNT.
753          LA    4,1(4)         ADD ONE.
```

```
         ST    4,RCOUNTR     PUT RIGHT EYE COUNT BACK.

         STM   5,6,CTRDELTA  PREV.R-CODE,TIME PUT IN HOLD ARRAY.
         LR    4,3           PUT TIME IN R4.
         LM    9,10,CTRDELT8 PUT PREV. D1,D2 IN R9,R10.
         SR    4,6           CALCULATE AND PUT IN HOLD ARRAY:
         ST    4,CTRDELT8    WORD 3: R-D1,
         SR    4,9
         ST    4,CTRDELTA+12 WORD 4: R-D2,
         SR    4,10
         ST    4,CTRDELTA+16 WORD 5: R-D3,
         LR    4,3
         SR    4,8
         ST    4,CTRDELTA+20 WORD 6: R-TIME(NOW) - L-TIME(PREV.).

         LH    5,0(2)        MOVE R-CODE(NOW) TO R5 (R-CODE(PREV.)).
         LR    6,3           MOVE R-TIME(NOW) TO R6 (R-TIME(PREV.)).

         STM   5,6,FIVESIX   STORE R5,R6 TEMPORARILY.
         LA    5,CTRDELT8    PICK UP ADDRESS OF R-D1.
         LA    9,RPLOT       PICK UP ADDRESS OF R-HGRAM.
         BAL   10,GRAPHER1   UPDATE R-D1 HGRAM.
         BAL   10,GRAPHER2   UPDATE R-D2 HGRAM.
         BAL   10,GRAPHER2   UPDATE R-D3 HGRAM.
         BAL   10,GRAPHER1   UPDATE R-L HGRAM.
         LM    5,6,FIVESIX   RESTORE R5,R6.

         L     4,RLOCATOR    PICK UP ADDRESS IN R-ARRAY.
         MVC   0(24,4),CTRDELTA        MOVE SIX WORDS INTO R-ARRAY.
         LA    4,24(4)       MOVE R4 UP SIX WORDS.
         ST    4,RLOCATOR    RLOCATOR=NEXT ADDRESS IN R-ARRAY.
         LA    10,LIDENTIT   PICK UP ADDRESS OF L-ARRAY.
         CR    4,10          IS R-ARRAY FULL?
         BL    UPRLAG        NO: SKIP PUT.
         BAL   10,RPUT       YES: PUT OUT ARRAY.

UPRLAG   L     4,DEADTIME    PICK UP DEADTIME CONSTANT.
         AR    4,3           ADD TIME.
         ST    4,RALARM      RALARM IS UPDATED.
         B     LEFT          CONTINUE PROCESSING.


GOODLEFT EQU   *
         MVI   LFLAG,X'00'   LOWER FLAG.
         N     7,LRESERVE    LEAVE ONLY L-CODE IN R7.

         L     4,LCOUNTL     PICK UP LEFT EYE COUNT.
         LA    4,1(4)        ADD ONE.
         ST    4,LCOUNTL     PUT LEFT EYE COUNT BACK.

         STM   7,8,CTLDELTA  PREV. L-CODE,TIME PUT IN HOLD ARRAY.
         LR    4,3           PUT TIME IN R4.
         LM    9,10,CTLDELT8 PUT PREVIOUS D1,D2, IN R9,R10.
         SR    4,8           CALCULATE AND PUT IN HOLD ARRAY:
```

```
          ST    4,CTLDELT8      WORD 3: L-D1,
          SR    4,9
          ST    4,CTLDELTA+12   WORD 4: L-D2,
          SR    4,10
          ST    4,CTLDELTA+16   WORD 5: L-D3,
          LR    4,3
          SR    4,6
          ST    4,CTLDELTA+20   WORD 6: L-TIME(NOW) - R-TIME(PREV.).

          LH    7,0(2)          MOVE L-CODE(NOW) TO R7 (L-CODE(PREV.)).
          LR    8,3             MOVE L-TIME(NOW) TO R8 (L-TIME(PREV.)).

          STM   5,6,FIVESIX     STORE R5,R6 TEMPORARILY.
          LA    5,CTLDELT8      PICK UP ADDRESS OF L-D1.
          L     9,LPLOT         PICK UP ADDRESS OF L-HGRAM.
          BAL   10,GRAPHER1     UPDATE L-D1 HGRAM.
          BAL   10,GRAPHER2     UPDATE L-D2 HGRAM.
          BAL   10,GRAPHER2     UPDATE L-D3 HGRAM.
          BAL   10,GRAPHER1     UPDATE L-R HGRAM.
          LM    5,6,FIVESIX     RESTORE R5,R6.

          L     4,LLOCATOR      PICK UP ADDRESS IN L-ARRAY.
          MVC   0(24,4),CTLDELTA          MOVE SIX WORDS INTO L-ARRAY.
          LA    4,24(4)         MOVE R4 UP SIX WORDS.
          ST    4,LLOCATOR      LLOCATOR=NEXT ADDRESS IN L-ARRAY.
          LA    10,ENDATA       PICK UP ADDRESS OF ENDATA.
          CR    4,10            IS L-ARRAY FULL?
          BL    UPLLAG          NO: SKIP PUT.
          BAL   10,LPUT         YES: PUT CUT L-ARRAY.

UPLLAG    L     4,DEADTIME      PICK UP DEADTIME CONSTANT.
          AR    4,3             ADD TIME.
          ST    4,LALARM        LALARM IS UPDATED.
          B     INHALE          GET ANOTHER INPUT WORD.


INHALER1  EQU   *
          L     4,ERRORS1       PICK UP TYPE1 ERROR COUNT.
          A     4,ONE           ADD ONE.
          ST    4,ERRORS1       STORE TYPE1 ERROR COUNT.
          B     INHALE          IGNORE INPUT WORD; GET THE NEXT WORD.


INHALER2  EQU   *
          L     4,ERRORS2       PICK UP TYPE2 ERROR COUNT.
          A     4,ONE           ADD ONE.
          ST    4,ERRORS2       STORE TYPE2 ERROR COUNT.
          B     INHALE          IGNORE INPUT WORD; GET THE NEXT WORD.


GORITERR  EQU   *
          L     4,ERRORS3       PICK UP RIGHT UP?DOWN ERROR COUNT.
```

```
          LA    4,1(4)          ADD ONE.
          ST    4,ERRORS3       STORE COUNT.
          B     GORIGHT         GO ON PROCESSING.


GOLEFTER  EQU   *
          L     4,ERRORS4       PICK UP LEFT UP?DOWN ERROR COUNT.
          LA    4,1(4)          ADD ONE.
          ST    4,ERRORS4       STORE COUNT.
          B     GOLEFT          GO ON PROCESSING.


HARDCOPY  EQU   *
          LA    4,RPLOT         PICK UP ADDRESS OF R-HGRAM.

          PUT   PLOTDISC,(4)    PUT THE ARRAY OUT.

          L     4,LPLOT         PICK UP ADDRESS OF L-HGRAM.
          PUT   PLOTDISC,(4)    PUT THE ARRAY OUT.
          BAL   10,BIGZERO      CLEAR HGRAMS.
          B     TYPESET         GO TO DIAGNOSTIC PRINTING ROUTINE.


TYPESET   EQU   *
          PUT   PRNT,HEADER     PRINT DIAGNOSTIC HEADINGS.
          STM   2,7,TWOSEVEN    STORE R2--R7.
          LA    2,CTRDELTA      PICK UP END ADDRESS OF DIAG. DATA ARRAY.
          ST    2,ENDING        PUT ADDRESS IN ENDING.
          LA    4,INTERVAL      PICK UP BEGIN ADDRESS OF DIAG. DATA ARRAY.
          LA    5,LINE          ADDRESS OF DECIMAL LINE TO BE PRINTED.
          LA    6,12
          LA    7,108
          AR    7,5             R7 HAS END ADDRESS OF LINE.
          BAL   10,PRINTIT      BRANCH TO PRINT ROUTINE.
          L     4,INTERVAL      UPDATE INTERVAL# (NUMBER OF
          LA    4,1(4)          INTERTIM INTERVALS + 1 THAT HAVE
          ST    4,INTERVAL      BEEN PROCESSED.
          L     4,PRNTPLOT      UPDATE PRNTPLOT (TIME OF
          A     4,INTERTIM      OF NEXT PRINTING)
          ST    4,PRNTPLOT      =PRNTPLOT.
          LM    2,7,TWOSEVEN    RESTORE R2---R7.
          BR    9               BRANCH TO CALLING STATEMENT+1.


PRINTIT   EQU   *
          L     2,0(4)          THIS ROUTINE CHANGES
          CVD   2,DOUBLE        BINARY ARRAY INTO SIGNED
          UNPK  4(8,5),DOUBLE(8)         DECIMAL ARRAY AND
          LA    4,4(4)          PRINTS IT.
          CLI   11(5),X'DO'
          BL    POS
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 915          MVI   3(5),C'-'
 916          B     CHDIG
 917 POS      MVI   3(5),C'+'
 918 CHDIG    OI    11(5),X'F0'
 919          C     4,ENDING
 920          BNL   WRITE
 921          BXLE  5,6,PRINTIT

 923 WRITE    PUT   PRNT,LINE

 929          LA    5,LINE
 930          MVC   LINE(120),BLANKOUT
 931          C     4,ENDING
 932          BL    PRINTIT
 933          BR    10


 935 BIGZERO  EQU   *                CLEARS HGRAMS WITH 0'S; INSERTS FILEFLO.
 936          LA    4,RPLOT          PICK UP START ADDRESS OF HGRAMS.
 937 ZEROPLOT MVC   0(256,4),ZEROES
 938          LA    4,256(4)
 939          C     4,ENDWORK        COMPARE WITH END ADDRESS OF HGRAMS.
 940          BL    ZEROPLOT
 941          L     4,LPLOT          INSERT FILE COUNT IN
 942          A     4,HGRAMEND       LAST WORD OF L-PLOT.
 943          MVC   0(4,4),FILEFLO
 944          BR    10


 946 BPUT     PUTOUT BIDENTIT,BCOUNTB,BLOCATOR,B


 961 RPUT     PUTOUT RIDENTIT,RCOUNTR,RLOCATOR,R


 976 LPUT     PUTOUT LIDENTIT,LCOUNTL,LLOCATOR,L


 991 GRAPHER1 EQU   *                THIS SEGMENT MAKES D1R,D1L,R-L,& L-R
 992          L     4,0(5)           HGRAMS.  BINS ARE SEQUENTIAL ADDRESSES
 993          SRL   4,1              IN CORE.  TIMES ARE FIRST DIVIDED BY
 994          SLL   4,2              TWO (WITH TRUNCATION).  LARGEST BIN
 995          C     4,MAX1           NUMBER IS SET BY MAX1.  LARGER DATA
 996          BNH   STORE1           ARE STORED IN THE LAST BIN (ADDRESS).
 997          L     4,MAX1
 998 STORE1   LE    6,FLONE
 999          AE    6,0(4,9)
1000          STE   6,0(4,9)
1001          LA    9,1024(9)
1002          LA    5,4(5)
```

```
1003              BR     10


1005 GRAPHER2 EQU    *                  THIS SEGMENT MAKES D2R,D3R,D2L,&D3L
1006              L      4,0(5)         HGRAMS.  BINS ARE INCREMENTED BY
1007              SRL    4,1            INCREMENTING THE CORRESPONDING CORE
1008              SLL    4,2            ADDRESS CONTENTS AS ABOVE IN GRAPHER1.
1009              A      4,MAX1         SINCE TIMES MAY BE NEGATIVE (I.E.
1010              BNM    TEST2          D2 AND D3 VALUES), THEY ARE FIRST
1011              SLR    4,4            INCREMENTED BY MAX1.  OUT OF RANGE
1012              B      STORE2         VALUES ARE PUT IN THE HIGH AND LOW
1013 TEST2        C      4,MAX2         ADDRESSES (BINS).
1014              BNH    STORE2
1015              L      4,MAX2
1016 STORE2       LE     6,FLONE
1017              AE     6,0(4,9)
1018              STE    6,0(4,9)
1019              LA     9,2048(9)
1020              LA     5,4(5)
1021              BR     10


1023 DATA         DS     OF
1024 FILEFLO      DC     E'0'
1025 FLONE        DC     E'1'


1027              DS     OF
1028 CODEMASK DC     XL4'OFFFF'     USED TO WIPE OUT EVENT TYPE CODE.
1029 RRESERVE DC     BL4'011'       USED TO WIPE OUT ALL BUT R-CODE.
1030 LRESERVE DC     BL4'01100'     USED TO WIPE OUT ALL BUT L-CODE.
1031              DS     OF

1033 PERIOD       DC     F'65536'       MAX VARIAN620I 16 BIT INTEGER.
1034 INTERTIM DC     F'131072'      THE INTERVAL DURATION (IN 100THS SEC.)
1035 DEADTIME DC     F'7'           IF 2 IPSIS<(DEADTIME/100)SEC APART, KILL.

1037 ONE          DC     F'1'
1038 DUMMYDEL DC     F'0,-1000000,0,-1000000'
1039 MAX1         DC     F'1000'
1040 MAX2         DC     F'2000'

1042 INBUFSIZ DC     F'128'         #BYTES IN AN INPUT TAPE RECORD.
1043 HGRAMEND DC     F'6140'
1044 PLOTSIZE DC     F'6144'
1045 NUMBER       DC     C'123456789'
1046              DS     OF

1048 BLOCATOR DC     F'0'
1049 RLOCATOR DC     F'0'
1050 LLOCATOR DC     F'0'

1052 ENDBUFIN DC     F'0'
```

```
ENDING   DC    F'0'
FILECNT  DC    F'0'

HEIGHO   DC    CL120'1*****BEGIN RUN****EXPERIMENT IDENTIFIER:........'
HEADER   DC    CL36'0  INTERVAL#      STOP    LAST EVENT'
         DC    CL36'    #ERR(1)-----#ERR(2)-----#ERR(3)-'
         DC    CL36'----#ERR(4)     #BEHAVS-----#RIGHTS-'
         DC    CL12'----#LEFTS  '
LINE     DC    120C' '
BLANKOUT DC    120C' '
LASTGASP DC    CL120'0     LAST DATA:      '
PASSOUT  DC    CL60'0*****END RUN******EXPERIMENT IDENTIFIER:........'
         DC    CL60'DATA TAPE IDENTIFIER:........'
CARD     DS    CL80

         DS    0D
ZEROES   DC    64F'0'
DOUBLE   DC    D'0'
FIVESIX  DC    2F'0'
TWOSEVEN DC    6F'0'
RFLAG    DC    F'0'
LFLAG    DC    F'0'
RALARM   DC    F'0'
LALARM   DC    F'0'

INCR     DC    F'0'

INTERVAL DC    F'0'
PRNTPLOT DC    F'0'
PREVTIME DC    F'0'
ERRORS1  DC    F'0'
ERRORS2  DC    F'0'
ERRORS3  DC    F'0'
ERRORS4  DC    F'0'
BCOUNTB  DC    F'0'
RCOUNTR  DC    F'0'
LCOUNTL  DC    F'0'

CTRDELTA DC    2F'0'
CTRDELT8 DC    4F'0'
CTLDELTA DC    2F'0'
CTLDELT8 DC    4F'0'

LPLOT    DC    F'0'
ENDWORK  DC    F'0'
RPLOT    DS    4000F
         END
```

A2. 3 Voyeur: analysis and plots.

```
C       *************************************************************
C       *                        * * VOYEUR * *                     *
C       *       THIS PROGRAM PROVIDES SUMMARY INFORMATION ON THE    *
C       *  DATA GENERATED BY REDEYE.  REDEYE PRODUCES HISTOGRAMS   *
C       *  (D1,D2,D3,BK) FOR RIGHT AND LEFT EYE MOVEMENTS FOR EVERY *
C       *  INTERVAL IN AN EXPERIMENT FOR ALL EXPERIMENTS (FILES) IT *
C       *  PROCESSES.                                               *
C       *       VOYEUR IS SUB-DIVIDED INTO 3 MAJOR SECTIONS,        *
C       *  *ADJUSTOR, EYEBALL I, AND EYEBALL II.                    *
C       *       *ADJUSTOR ESSENTIALLY COMPRESSES THE DATA FROM       *
C       *  REDEYE, DEPENDING ON A CODE ON THE FIRST INPUT CARD TO   *
C       *  VOYEUR.                                                  *
C       *       EYEBALL I CALCULATES SIMPLE STATISTICS ON THE       *
C       *  HISTOGRAMS AND PRINTS THEM.                              *
C       *       EYEBALL II PLOTS THE HGRAMS GIVEN INFO. FROM        *
C       *  EYEBALL I AND SCALING FACTORS FROM THE REMAINING INPUT   *
C       *  CARDS TO VOYEUR (THERE **MUST** BE AS MANY SCALING CARDS *
C       *  AS THERE ARE COMPRESSION CODES ON THE 1ST INPUT CARD     *
C       *  FOR *ADJUSTOR).                                          *
C       *       INPUT TO VOYEUR IS EITHER A TEMP. DISC FILE (PASSED *
C       *  BY REDEYE IN A PREVIOUS JOB STEP) OR THE CATALOGUED SL   *
C       *  9-TRACK TAPE (EVEN # FILES) PRODUCED EARLIER BY REDEYE.  *
C       *  (NOTE:  DD CARD **MUST** BE APPROPRIATE.)                *
C       *************************************************************
C
      CALL LABEL ('JOB EYES FOR J.MATES:  START',28)
C
C       *************************************************************
C       *       TWO SUBROUTINES ARE USED, PLOT AND LABEL.  THEY     *
C       *  RESIDE IN U. OF O. OS/360 SYS1.FORTLIB AT 2/20/1972.     *
C       *  OFFSET IS AN ENTRY POINT IN PLOT WHICH PUTS              *
C       *  X<---(X-XOFF)/XFAC, AND Y<---(Y-YOFF)/YFAC.  "CALL       *
C       *  OFFSET (XOFF,XFAC,YOFF,YFAC)" SETS THESE FACTORS.  "CALL *
C       *  PLOT (X,Y,IC)" PLOTS POINT (X,Y) USING OFFSET IF IC HAS  *
C       *  TENS DIGIT(OTHERWISE NOT); IF THE ONES DIGIT =3 IT CAUSE *
C       *  PEN LIFT BEFORE MOVING, IF =2, PEN GOES DOWN BEFORE      *
C       *  MOVING; IF IC IS NEG, A NEW ORIGIN IS SET AT (X,Y).      *
C       *  "CALL LABEL (.....,I) WRITES I CHARACTERS UP THE Y-AXIS  *
C       *  AND RESETS THE ORIGIN 1" TO THE RIGHT.                   *
C       *************************************************************
```

```
C     **************************************************************
C
      CCMMON/WORKA/ARRAY(3072)
      DIMENSION RIGHT(1536),ELEFT(1536)
      DIMENSICN RSORC(1536),ELSORC(1536)
      DIMENSION KGRAPH(10),TEMP(30)
      EQUIVALENCE (ARRAY(1),RIGHT(1)),(ARRAY(1537),ELEFT(1))
      CATA NREAD,NPRINT,KDISC /1,3,9/
C
C     **************************************************************
C     *  ARRAY(N) ACCEPTS 2 ARRAYS,RIGHT AND ELEFT. DATA IS READ   *
C     *  INTO RSORC AND ELSORC FROM STORAGE. TEMP(N) IS AN ARRAY   *
C     *  USED BY EYEBALL I; KGRAPH IS AN ARRAY (ON A CARD)         *
C     *  LISTING INTERVAL FACTORS & READ IN AT EXECUTION TIME.     *
C     **************************************************************
C
      READ (NREAD,1002) KGRAPH
 1002 FORMAT (10I2)
C
C     **************************************************************
C     *       IF NREAL=2, HGRAM ARRAYS WILL BE ALTERED BY          *
C     *  SUBROUTINE *EXPECT*.  SEE *EXPECT* COMMENTS FOR MORE      *
C     *  DETAIL.  NREAL IS ON THE 2ND CARD READ AT EXECUTION       *
C     *  TIME (1ST COLUMN).                                        *
C     **************************************************************
C
      READ (NREAD,1004) NREAL
 1004 FORMAT (1I1)
C
C     **************************************************************
C     *                          *ADJUSTOR                         *
C     *       *ADJUSTOR USES HGRAM DATA FROM EITHER THE TEMP. DISC *
C     *  STORAGE OR FROM THE PERMANENT SL-9TRK TAPE (EVEN # FILES) *
C     *  PRODUCED BY REDEYE. MUST MAKE GO.FT09F00X CORRESPOND TO   *
C     *  DESIRED DATA SOURCE,HERE CALLED 'KDISC'. THE 1' FUNCT. OF *
C     *  *ADJUSTOR IS TO READ A PAIR OF RCDS (FOR R&L) AND SUM     *
C     *  THEM 1:1 WITH THE NEXT PAIR OF RECORDS...(ICUM) TIMES.    *
C     *  SO A DATA SET IS GENERATED, CONSISTING OF HGRAMS FOR      *
C     *  MULTIPLES OF THE BASIC HGRAM INTERVAL OF REDEYE. THIS     *
C     *  DERIVED DATA SET IS PASSED TO EYEBALLI & EYEBALL II FOR   *
C     *  STAT. & PLOTTING. THEN A RETURN TO *ADJUSTOR SETS A NEW   *
C     *  ACCUMULATION FACTOR,ETC.                                  *
C     **************************************************************
C
C     **************************************************************
C     *  FIND NEXT INTERVAL MULTIPLE. IF IT IS ZERO, TERMINATE     *
C     *  THE PROGRAM.                                              *
C     **************************************************************
      IGRAPH=0
 1005 IGRAPH=IGRAPH+1
      ICUM=KGRAPH(IGRAPH)
      IF(ICUM.EQ.0) GO TO 2600
C
C     **************************************************************
C     *  ZEFO ALL ARRAYS BEFORE PROCESSING BEGINS.                 *
C     **************************************************************
      DO 1010 N=1,30
      TEMP(N)=0.0
```

```
 1010 CONTINUE
      DO 1015 N=1,1536
      RIGHT(N)=0.0
      RSORC(N)=0.0
      ELEFT(N)=0.0
      ELSORC(N)=0.0
 1015 CONTINUE
C
C       ***************************************************************
C       *  IF INTERVAL MULTIPLE IS -1, USE ORIGINAL KDISC DATA IN     *
C       *  EYEBALL I AND EYEBALL II AND SKIP ACCUMULATION STEP.       *
C       *  THIS IS DONE BY MAKING NDISC = KDISC = 9.                  *
C       ***************************************************************
      IF(ICUM.NE.-1) GO TO 1018
      NDISC=9
      GO TO 1150
C
C       ***************************************************************
C       *  EVERY 2ND RECORD HAS THE # OF THE EXP. TO WHICH IT         *
C       *  BELONGS IN THE LAST WORD.  THIS # MUST STAY THE SAME IN    *
C       *  THE CORRESPONDING COMPRESSED RECORD.                       *
C       ***************************************************************
 1018 NDISC=13
      EXP=0.0
      IEXP=0
C    >+++++++++++++++++++++++++++++++++++++++++++++
 1020 ITER=0
C    >+++++++++++++++++++++++++++++++++++++++++++++
 1021 READ (KDISC,1025,END=1050) RSORC
      READ (KDISC,1025) ELSORC
 1025 FORMAT (12(128A4))
C    >+++++++++++++++++++++++++++++++++++++++++++++
      ICODE=INT(ELSORC(1536)+0.1)
      IF(ICODE.GT.IEXP) GO TO 1040
C    >+++++++++++++++++++++++++++++++++++++++++++++
 1030 DO 1035 N=1,1536
      RIGHT(N)=RIGHT(N)+RSORC(N)
      ELEFT(N)=ELEFT(N)+ELSORC(N)
 1035 CONTINUE
C    >+++++++++++++++++++++++++++++++++++++++++++++
      ITER=ITER+1
      IF(ITER.LT.ICUM) GO TO 1021
C    >+++++++++++++++++++++++++++++++++++++++++++++
 1040 IF(ITER.EQ.0) GO TO 1044
C    >+++++++++++++++++++++++++++++++++++++++++++++
C
C       ***************************************************************
C       *  ARE HGRAMS TO BE ALTERED BY *EXPECT*???                    *
C       ***************************************************************
      IF(NREAL.NE.2) GO TO 1042
      CALL EXPECT(ITER)
 1042 ELEFT(1536)=EXP
      WRITE (NDISC,1025) RIGHT
      WRITE (NDISC,1025) ELEFT
C    >+++++++++++++++++++++++++++++++++++++++++++++
 1044 DO 1045 N=1,3072
      ARRAY(N)=0.0
 1045 CONTINUE
```

```
C    >++++++++++++++++++++++++++++++++++++++++++++
      IF(ICODE.EQ.IEXP) GO TO 1020
C    >++++++++++++++++++++++++++++++++++++++++++++
      ITER=0
      EXP=EXP+1.0
      IEXP=IEXP+1
      GO TO 1C30
C    >++++++++++++++++++++++++++++++++++++++++++++
 1050 IF(ITER.EQ.0) GO TO 1060
C    >++++++++++++++++++++++++++++++++++++++++++++
C
C       **************************************************************
C       *  ARE HGRAMS TO BE ALTERED BY *EXPECT*???                   *
C       **************************************************************
      IF(NREAL.NE.2) GO TO 1052
      CALL EXPECT(ITER)
 1052 ELEFT(1536)=EXP
      WRITE (NDISC,1025) RIGHT
      WRITE (NDISC,1025) ELEFT
C    >++++++++++++++++++++++++++++++++++++++++++++
 1060 END FILE NDISC
      REWIND NDISC
      REWIND KDISC
C       **************************************************************
C
C
C       **************************************************************
C       *                         *EYEBALL 1                         *
C       *       EYEBALL I  CALCULATES AND PRINTS MEANS, COUNTS, S.    *
C       *  DEVIATIONS, ETC., FOR HISTOGRAM DATA PLACED ON DISC BY    *
C       *  REDEYES.  THE LOCATION AND MAGNITUDE OF A WORD ON DISC    *
C       *  INDICATES A HIST. BIN INDEX AND ITS CONTENTS.  A SINGLE   *
C       *  DISC RECORD REPRESENTS 8 HISTOGRAMS, 4 FOR THE RIGHT, 4   *
C       *  FOR THE LEFT; IT SUMMARIZES A FIXED INTERVAL OF AN WHOLE  *
C       *  EXPERIMENT.  A RECORD IS COMPOSED AS FOLLOWS:             *
C       *  WORDS (1-251)=D1-R; WORDS (257-757)=D2-R                 *
C       *  WORDS (769-1269)=D3-R; WORDS (1281-1531)=R-L.            *
C       *  THE LAST WORDS OF D1-R,R-L ARE OVERFLOW BINS.  SO ARE     *
C       *  THE FIRST AND LAST WORDS OF D2-R AND D3-R.  THE FOLLOW-   *
C       *  ING RECORD IS THE SAME FOR THE LEFT EYE (RECORD PAIRS ARE *
C       *  FRCM THE SAME INTERVAL).  THE TOTAL NO. INTERVALS,        *
C       *  MAX(D1-R,D1-L), MAX(D2-R,D2-L),MAX(D3-R,D3-L), AND        *
C       *  MAX(R-L,L-R) ARE PLACED IN 5 WORDS OF TEMP(N) FOR EACH    *
C       *  EXPERIMENT (LATER PASSED TO EYEBALL II  FOR PLOTTING      *
C       *  PURPOSES).  EXPERIMENTS ARE ANALYZED UNTIL DISC DATA SET  *
C       *  IS EXHAUSTED.                                             *
C       **************************************************************
C
 1150 NOFILE=-1
      MSTART=-4
C
C       **************************************************************
C       *  READ A NEW PAIR OF RECORDS INTO RIGHT AND LEFT.  IF NO    *
C       *  MORE PAIRS EXIST IN CATA SET,JUMP OUT  OF PROG. SECTION.  *
C       **************************************************************
 1160 READ (NDISC,1165,END=1500) RIGHT
      READ (NDISC,1165) ELEFT
 1165 FORMAT (12(128A4))
```

```
C
C        ****************************************************************
C        *  EVERY 2ND RECORD CARRIES THE NUMBER OF THE EXP. TO WHICH    *
C        *  IT BELONGS IN THE LAST WORD.  IF A NEW EXP. APPEARS,        *
C        *  THE INDEX TO ARRAY, TEMP, IS INCREASED BY 5 AND PRO-        *
C        *  CESSING GOES ON AS BEFORE.                                  *
C        ****************************************************************
      NOEXP=INT(0.2+ELEFT(1536))
 1170 IF(NOFILE.GE.NOEXP) GO TO 1200
C
C     >+++++++++++++++++++++++++++++++++++++++++++++
 1180 WRITE (NPRINT,1400) NOEXP
      NOFILE=NOFILE+1
      MSTART=MSTART+5
C     >+++++++++++++++++++++++++++++++++++++++++++++
 1200 WRITE (NPRINT,1410) TEMP(MSTART)
      LRGAP=0
C
C        ****************************************************************
C        *  THIS IS THE MAJOR LOOP OF THIS PROGRAM SECTION.  TO         *
C        *  EVERY PAIR OF RECORDS BELONG 8 HISTOGRAMS.                  *
C        ****************************************************************
 1220 DO 1380 I=1,8
      GO TO (1235,1240,1260,1280,1230,1240,1260,1280),I
C
C        ****************************************************************
C        *  THIS CODING PROVIDES ADDRESSES OF BEGINING AND ENDING       *
C        *  WORDS FOR EACH HISTOGRAM AND PROVIDES FOR THE PRINTING      *
C        *  OF THE JUST CALCULATED STATISTICS OF THE PREVIOUS HIST.     *
C        ****************************************************************
 1230 BINLO=ARRAY(LRGAP+1281)
      BINHI=ARRAY(LRGAP+1531)
      WRITE (NPRINT,1420) COUNT,TMEAN,SIGMA,IMED,BINLO,BINHI,TMOM,TDAD
      LRGAP=1536
 1235 MAXS=MSTART+1
      BIN=0.0
      ISTART=LRGAP+1
      ISTOP=LRGAP+250
      ISTOP2=ISTOP+1
      GO TO 1300
C     >+++++++++++++++++++++++++++++++++++++++++++++
 1240 BINLO=ARRAY(LRGAP+1)
      BINHI=ARRAY(LRGAP+251)
      WRITE (NPRINT,1430) COUNT,TMEAN,SIGMA,IMED,BINLO,BINHI,TMOM,TDAD
      MAXS=MAXS+1
      BIN=-249.0
      ISTART=LRGAP+258
      ISTOP=LRGAP+756
      ISTOP2=ISTOP
      GO TO 1300
C     >+++++++++++++++++++++++++++++++++++++++++++++
 1260 BINLO=ARRAY(LRGAP+257)
      BINHI=ARRAY(LRGAP+757)
      WRITE (NPRINT,1440) COUNT,TMEAN,SIGMA,IMED,BINLO,BINHI,TMOM,TDAD
      MAXS=MAXS+1
      BIN=-249.0
      ISTART=LRGAP+770
      ISTOP=LRGAP+1268
```

```
      ISTOP2=ISTOP
      GO TO 1300
C     >++++++++++++++++++++++++++++++++++++++++++++
 1280 BINLO=ARRAY(LRGAP+769)
      BINHI=ARRAY(LRGAP+1269)
      WRITE (NPRINT,1450) COUNT,TMEAN,SIGMA,IMED,BINLO,BINHI,TMOM,TDAD
      MAXS=MAXS+1
      BIN=0.0
      ISTART=LRGAP+1281
      ISTOP=LRGAP+1530
      ISTOP2=ISTOP+1
C
C
C        **************************************************************
C        *  THIS LOOP, ON ISTART TO ISTOP, DOES STAT. OF THE HIST.    *
C        **************************************************************
 1300 TMOM=0.0
      TCAD=0.0
      COUNT=0.0
      IMED=0
      DO 1305 N=ISTART,ISTOP2
      COUNT=CCUNT+ABS(ARRAY(N))
 1305 CONTINUE
      ALFCO=CCUNT/2.
      COUNT=0.0
C
 1310 DO 1350 N=ISTART,ISTOP
      AR=ARRAY(N)
      ABAR=ABS(AR)
      IF(ABAR.LE.TEMP(MAXS)) GO TO 1340
 1330 TEMP(MAXS)=ABAR
 1340 COUNT=CCUNT+ABAR
      IF(ALFCO.GE.COUNT) IMED=N-ISTART+1
      TMOM=TMCM+BIN*ABAR
      TCAD=TDAC+(BIN**2)*ABAR
 1345 BIN=BIN+1.0
 1350 CONTINUE
C     >++++++++++++++++++++++++++++++++++++++++++++
      IF(COUNT.GT.1.1) GO TO 1370
C     >++++++++++++++++++++++++++++++++++++++++++++
 1360 TMEAN=0.0
      SIGMA=-1.0
      GO TO 1380
C     >++++++++++++++++++++++++++++++++++++++++++++
 1370 TMEAN=TMCM/COUNT
      SIGMA=SQRT((TDAD-TMEAN*TMCM)/(COUNT-1.0))
 1380 CONTINUE
C
C        **************************************************************
C        *  THE FINAL, 8TH, HIST. STAT. IS PRINTED AND THE CUMULATIVE *
C        *  NUMBER OF INTERVALS, TEMP(MSTART), IS INCREMENTED.        *
C        **************************************************************
      BINLO=ARRAY(LRGAP+1281)
      BINHI=ARRAY(LRGAP+1531)
      WRITE (NPRINT,1420) COUNT,TMEAN,SIGMA,IMED,BINLO,BINHI,TMOM,TDAD
 1390 TEMP(MSTART)=TEMP(MSTART)+1.0
C
C        **************************************************************
```

```
C       *  LOOP BACK AND READ ANOTHER RIGHT,LEFT PAIR OF RECORDS,   *
C       *  CORRESPONDING TO THE NEXT INTERVAL OF THIS EXP. OR THE   *
C       *  FIRST OF THE NEXT EXP.                                    *
C       **************************************************************
      GO TO 1160
C
C       **************************************************************
C       *  PRINTING FORMATS FOLLOW.                                  *
C       **************************************************************
 1400 FORMAT ('1','EXPERIMENT NUMBER:  ',1I3,3X,///)
 1410 FORMAT ('0','  INTERVAL NUMBER:  ',1F3.0)
 1420 FORMAT (' ',1X,'CONTRA-EYE DIFFS.:   ','NO.=',1F6.0,2X,'MEAN='
     X,1F6.2,2X,'SD=',1F6.2,2X,'MED=',I3,2X,'L-BIN=',1F6.1
     X,2X,'H-BIN=',1F6.1,2X,'SF=',1F9.0,2X,'SQ=',1F11.0)
 1430 FORMAT ('0',1X,'FIRST ORDER DIFFS.:  ','NO.=',1F6.0,2X,'MEAN='
     X,1F6.2,2X,'SD=',1F6.2,2X,'MED=',I3,2X,'L-BIN=',1F6.1
     X,2X,'H-BIN=',1F6.1,2X,'SF=',1F9.0,2X,'SQ=',1F11.0)
 1440 FORMAT (' ',1X,'SECOND ORDER DIFFS.: ','NO.=',1F6.0,2X,'MEAN='
     X,1F6.2,2X,'SD=',1F6.2,2X,'MED=',I3,2X,'L-BIN=',1F6.1
     X,2X,'H-BIN=',1F6.1,2X,'SF=',1F9.0,2X,'SQ=',1F11.0)
 1450 FORMAT (' ',1X,'THIRD ORDER DIFFS.:  ','NO.=',1F6.0,2X,'MEAN='
     X,1F6.2,2X,'SD=',1F6.2,2X,'MED=',I3,2X,'L-BIN=',1F6.1
     X,2X,'H-BIN=',1F6.1,2X,'SF=',1F9.0,2X,'SQ=',1F11.0)
C
C       **************************************************************
C       *  THIS IS DATA SET TERMINATION ADDRESS.  THIS PROGRAM       *
C       *  SECTION ENDS ITS CALCULATIONS.                            *
C       **************************************************************
 1500 WRITE (NPRINT,1510)
 1510 FORMAT ('0','END OF RUN; NC MORE EXPERIMENTS; IDENTIFIERS:',///)
C
C       **************************************************************
```

```
C
C     ****************************************************************
C     *                        *EYEBALL II                           *
C     *        EYEBALL II  PLOTS HISTOGRAMS GENERATED BY REDEYES     *
C     *  AND EXAMINED BY EYEBALL I.  EACH PLOT IS THE SET OF HIST    *
C     *  OGRAMS OF A GIVEN TYPE FOR ALL THE INTERVALS IN AN          *
C     *  EXPERIMENT.  THE PLOTS ARE LOGARITHMICALLY COMPRESSED ON    *
C     *  THE ABSCISSA. EVERY RECD PAIR FROM INPUT REPRESENTS 8 HGS.*
C     *  (4R,4L,INTERVAL(N)) WHICH ARE PLOTTED (IN ORDER: D1R,D2R    *
C     *  D3R,R-L,D1L,D2L,D3L,L-R) WRT. A BASE LINE(N). THE NEXT      *
C     *  INTERVAL(N+1) HAS BASE LINE DISPLACED,BL(N+1)=BL(N)+XSLIP *
C     *  +YSLIP, THUS 8 3-DIM. PLOTS WITH INTERVAL #S ALONG THE      *
C     *  OBLIQUE AXES ARE FORMED FOR EACH EXP.. PLOTTING CONTINUES *
C     *  UNTIL DATA SET IS EXHAUSTED.                                *
C     ****************************************************************
      CALL PLOT (8.5,0.0,-3)
C
C     ****************************************************************
C     *  IN ORDER TO CENTER PLOTS ON FAN-FOLDED PAPER, START PEN     *
C     *  ORIGIN AT (6.5+TAC) RELATIVE TO 8.5"X11" PAGE (FOR          *
C     *  PLOTTER INCREMENTS OF .01" AND XPAGE1=8.5,AND XPAGE2=       *
C     *  17.0).                                                      *
C     ****************************************************************
C
C     ****************************************************************
C     *  EACH PASS THRU EYEBALL II CAN HAVE A DIFFERENT DATA SPAN  *
C     *  (INTERVAL LENGTH) AND/OR SCALING FACTORS (READ BELOW).      *
C     ****************************************************************
      READ (NREAD,2010) YHIGH,XBASE,XPAGE1,XPAGE2,YFRAC,XFRAC,TIC,TAC
 2010 FORMAT (8F10.6)
      READ (NREAD,2015) KPASS
 2015 FORMAT (I1)
C
C     ****************************************************************
C     *  ALL PLOTS HAVE 1 OF 2 FORMATS(SHORT AND LONG ABSCISSA),     *
C     *  ALLOWING USE OF ONLY 4 ARRAYS OF ABSCISSA POINTS (GENER-  *
C     *  ATED BELOW)TOGETHER WITH A SERIES OF X-OFFSETS TO GENERATE*
C     *  ALL X-COORDINATES OF ALL 8 PLOTS.                           *
C     ****************************************************************
      XBASE2=XBASE+XBASE
      XGAP1=XPAGE1-XBASE
      XGAP2=XPAGE2-XBASE2
C
C     ****************************************************************
```

```
C        *  THESE TWO ARRAYS ARE X-COORDINATES FOR SCALING TIC            *
C        *  MARKS FOR THESE PLOTS.                                        *
C        ******************************************************************
      DIMENSION XSHORT(250),XLONG(499),XARRAY(749)
      EQUIVALENCE (XSHORT(1),XARRAY(1)),(XLONG(1),XARRAY(251))
      XMUL=XBASE/249.
      DO 2020 N=1,250
      XSHORT(N)=XMUL*(N-1)
 2020 CONTINUE
      DO 2025 N=1,250
      XLONG(N)=XBASE-XSHORT(251-N)
      XLONG(N+249)=XBASE+XSHORT(N)
 2025 CONTINUE
C
C        ******************************************************************
C        *  THESE TWO ARRAYS ARE THE HGRAM X-COORDINATES.                 *
C        ******************************************************************
      DIMENSION XHISTO(751),XHISTS(251),XHISTL(500)
      EQUIVALENCE (XHISTS(1),XHISTO(1)),(XHISTL(1),XHISTO(252))
      XHISTS(1)=XSHORT(1)
      DO 2030 N=2,250
      XHISTS(N)=(XSHORT(N)+XSHORT(N-1))/2.0
 2030 CONTINUE
      XHISTS(251)=XSHORT(250)
      XHISTL(1)=XLONG(1)
      DO 2035 N=2,499
      XHISTL(N)=(XLONG(N)+XLONG(N-1))/2.0
 2035 CONTINUE
      XHISTL(500)=XLONG(499)
C
C        ******************************************************************
C        *  EACH EXP. IS REPRESENTED BY 5 CONTIGUOUS WORDS IN TEMP.       *
C        *  THE 1ST WORD IS THE NO. OF INTERVALS.  IF THIS IS 0,          *
C        *  THE DATA SET ON DISC IS CONSIDERED EXHAUSTED, A REWIND        *
C        *  PERFORMED, AND A NEW SET OF HGRAM PLOTS IS PRODUCED.          *
C        ******************************************************************
      REWIND NDISC
      MSTART=-4
C
C    >++++++++++++++++++++++++++++++++++++++++++++++
 2100 MSTART=MSTART+5
      INTVLS=INT(TEMP(MSTART)+0.1)
      IF(INTVLS.LE.0) GO TO 2500
C    >++++++++++++++++++++++++++++++++++++++++++++++
C
C        ******************************************************************
C        *  THE PRINTOUT OF TEMP(N) MAXS. FOR AN EXP. ALLOW INTER-        *
C        *  PRETATION OF THE Y-AXIS SCALING OF THE PLOTS.                 *
C        ******************************************************************
      MEXP=(MSTART-1)/5
      MSTOP=MSTART+4
      WRITE (NPRINT,2105) MEXP,(TEMP(N),N=MSTART,MSTOP)
 2105 FORMAT (' ','EXP=',I3,3X,'LINES=',1F4.0,3X,'MAX(D1)=',1F8.2,3X,
     X'MAX(D2)=',1F8.2,3X,'MAX(D3)=',1F8.2,3X,'MAX(BK)=',1F8.2,3X)
C
C        ******************************************************************
C        *  THE 'STEPPING FCTRS',XSLIP, AND YSLIP, ARE DETERMINED         *
C        *  GIVEN AN OVERLAP FACTOR,YFRAC, THE HGRAM MAXS, THE            *
```

```
C        *  PHYSICAL WIDTH AND THE LENGTH JF THE PLJTS. THE JFFSET     *
C        *  YFAC'S FOR THE 4 PLOT TYPES ARE DETERMINED.                *
C        ***************************************************************
      XFAC=1.0
      YMAX1=TEMP(MSTART+1)
      YMAX2=TEMP(MSTART+2)
      YMAX3=TEMP(MSTART+3)
      YMAX4=TEMP(MSTART+4)
      YLINES=TEMP(MSTART)-1.J
      YCONST=ABS(YHIGH/((YFRAC*YLINES)+2.J))
      CALL PLOT (0.0,YCONST,-3)
      YFAC1=YMAX1/YCONST
      YFAC2=YMAX2/YCONST
      YFAC3=YMAX3/YCONST
      YFAC4=YMAX4/YCONST
      YSLIP=YCONST*YFRAC
      XSLIP=YSLIP*XFRAC
      YDEL=YSLIP*YLINES
      XDEL=XSLIP*YLIVES
C
C        ***************************************************************
C        *  ALL PLJTS ARE ENCIRCLED BY SCALED PARALLELOGRAMS; THE      *
C        *  BASIC (X,Y) COORDINATES LIE IV XSJ AND YSQ.                *
C        ***************************************************************
      DIMENSION XSQ(299),YSQ(299)
C
C        ***************************************************************
C        *  THE CORNER PTS. OF THE 'STANDARD' PARALLELOGRAM ARE        *
C        *  DESCRIBED.                                                 *
C        ***************************************************************
      XSQ(1)=0.0
      YSQ(1)=0.0
      XSQ(149)=XBASE
      YSQ(149)=0.0
      XSQ(150)=XBASE+XDEL
      YSQ(150)=YDEL
      XSQ(298)=XDEL
      YSQ(298)=YDEL
      XSQ(299)=0.0
      YSQ(299)=0.0
C
C        ***************************************************************
C        *  THE PGRAM SIDES (INCL. TIC MARKS EVERY 5 AND 50 PTS.)     *
C        *  ARE GENERATED.                                             *
C        ***************************************************************
      I=4
      NPOINT=297
      DO 2140 N=6,250,5
      XSQ(I)=XARRAY(N)
      XSQ(I-1)=XSQ(I)
      XSQ(I-2)=XSQ(I)
      XSQ(NPOINT)=XSQ(I)+XDEL
      XSQ(NPOINT-1)=XSQ(NPOINT)
      XSQ(NPOINT-2)=XSQ(NPOINT)
      YSQ(I)=0.0
      YSQ(I-1)=TIC
      YSQ(I-2)=0.0
      YSQ(NPOINT)=YDEL
```

```
      YSQ(NPOINT-1)=YDEL+TIC
      YSQ(NPOINT-2)=YDEL
      I=I+3
      NPOINT=NPOINT-3
 2140 CONTINUE
      NPOINT=299
      DO 2145 N=30,120,30
      YSQ(N)=YSQ(N)+TIC
      NPOINT=NPOINT-30
      YSQ(NPOINT)=YSQ(NPOINT)+TIC
 2145 CONTINUE
C
C       ****************************************************************
C       *  THE FOLLOWING SEQUENCE PLOTS THE PGRAMS.(8).                *
C       ****************************************************************
      YOFF=0.0
      YFAC=1.0
C
C       ****************************************************************
C       *  THESE SECTIONS INITIALIZE XOFF FOR DISPLACING EACH PGRAM   *
C       *  FROM THE PREVIOUS ONE. THE LONG PLOT PGRAMS ARE MADE FROM *
C       *  TWO SHORT ONES.                                             *
C       ****************************************************************
      CALL OFFSET (0.0,1.0,0.0,1.0)
      XOFF=0.0
      I=1
      GO TO 2202
C     >++++++++++++++++++++++++++++++++++++++++++++++
 2150 XOFF=-XPAGE1-XBASE
      I=2
      J=1
      GO TO 2200
C     >++++++++++++++++++++++++++++++++++++++++++++++
 2155 XOFF=XOFF-XPAGE2
      I=3
      J=2
      GO TO 2200
C     >++++++++++++++++++++++++++++++++++++++++++++++
 2160 XOFF=-XPAGE1-XPAGE2-XPAGE2
      I=4
      GO TO 2200
C     >++++++++++++++++++++++++++++++++++++++++++++++
 2165 XOFF=XOFF-XPAGE1
      I=5
      GO TO 2200
C     >++++++++++++++++++++++++++++++++++++++++++++++
 2170 XOFF=XOFF-XPAGE1-XBASE
      I=6
      J=3
      GO TO 2200
C     >++++++++++++++++++++++++++++++++++++++++++++++
 2175 XOFF=XOFF-XPAGE2
      I=7
      J=4
      GO TO 2200
C     >++++++++++++++++++++++++++++++++++++++++++++++
 2180 XOFF=XOFF+XBASE-XPAGE2
      I=8
```

```
C
C       ***************************************************************
C        *  SHORT PLOT PGRAM IS PLOTTED AT APPROPRIATE OFFSET.          *
C       ***************************************************************
 2200 CALL OFFSET (XOFF,XFAC,YOFF,YFAC)
      CALL PLOT (0.0,0.0,13)
C     >++++++++++++++++++++++++++++++++++++++++++++
 2202 DO 2210 N=2,299
      X=XSQ(N)
      Y=YSQ(N)
      CALL PLOT (X,Y,12)
 2210 CONTINUE
C     >++++++++++++++++++++++++++++++++++++++++++++
      GO TO (2150,2215,2215,2165,2170,2215,2215,2300),I
C
C       ***************************************************************
C        *  ADDITIONAL PGRAM IS ADDED LEFT OF 0.0 OF LONG PLOT TO       *
C        *  MAKE THE LONG PLOT PGRAM.                                   *
C       ***************************************************************
 2215 DO 2220 N=2,149
      X=-XSQ(N)
      Y=YSQ(N)
      CALL PLOT (X,Y,12)
 2220 CONTINUE
C     >++++++++++++++++++++++++++++++++++++++++++++
      DO 2230 N=150,298
      X=-XSQ(N)+XDEL+XDEL
      Y=YSQ(N)
      CALL PLOT (X,Y,12)
 2230 CONTINUE
C     >++++++++++++++++++++++++++++++++++++++++++++
      GO TO (2155,2160,2175,2180),J
C
C       ***************************************************************
C        *  THIS LOOP DOES HGRAM PLOTTING. IT LOOPS ONCE FOR EVERY      *
C        *  INTERVAL IN THE EXPERIMENT.                                 *
C       ***************************************************************
 2300 XOFF=0.0
      XOFFR=XSLIP
      YOFFR=0.0
      YOFF=0.0
C
C     >++++++++++++++++++++++++++++++++++++++++++++
 2310 DO 2410 LINES=1,INTVLS
      READ (NDISC,1025) RIGHT
      LRGAP=0
      XOFFR=XOFFR-XSLIP
      XOFF=XOFFR
      GO TO 2325
C     >++++++++++++++++++++++++++++++++++++++++++++
 2320 READ (NDISC,1025) ELEFT
      LRGAP=1536
      XOFF=XOFF-XPAGE1
C
C       ***************************************************************
C        *  THESE SECTIONS INITIALIZE XOFF,YOFF,YFAC FOR EACH OF 8      *
C        *  PLOTS.                                                      *
C       ***************************************************************
```

```
C
C        ******************************************************************
C        *  INITIALS FOR D1 PLOT (R IF LRGAP=0,L IF LRGAP=1536).          *
C        ******************************************************************
 2325 M=1
      ISTART=LRGAP+1
      ISTOP=LRGAP+250
      YMAX=YMAX1
      YFAC=YFAC1
      YOFF=YOFFR*YFAC
      I=1
      GO TO 2350
C
C        ******************************************************************
C        *  INITIALS FOR D2 PLOT (R IF LRGAP=0,L IF LRGAP=1536).          *
C        ******************************************************************
 2330 XOFF=XOFF-XPAGE1
      M=252
      ISTART=LRGAP+258
      ISTOP=LRGAP+756
      YMAX=YMAX2
      YFAC=YFAC2
      YOFF=YOFFR*YFAC
      I=2
      GO TO 2350
C
C        ******************************************************************
C        *  INITIALS FOR D3 PLOT (R IF LRGAP=0,L IF LRGAP=1536).          *
C        ******************************************************************
 2335 XOFF=XOFF-XPAGE2
      M=252
      ISTART=LRGAP+770
      ISTOP=LRGAP+1268
      YMAX=YMAX3
      YFAC=YFAC3
      YOFF=YOFFR*YFAC
      I=3
      GO TO 2350
C
C        ******************************************************************
C        *  INITIALS FOR BK PLOT (R-L IF LRGAP=0, L-R IF LRGAP=1536)      *
C        ******************************************************************
 2340 XOFF=XOFF-XPAGE2
      M=1
      ISTART=LRGAP+1281
      ISTOP=LRGAP+1530
      YMAX=YMAX4
      YFAC=YFAC4
      YOFF=YOFFR*YFAC
      I=4
C
C        ******************************************************************
C        *  THIS LOOP WRITES A Y-AXIS SCALE. THO PECULIAR IT CAN BE       *
C        *  INTERPRETED GIVEN THE MAX FROM THE PRINTOUT, ABOVE.           *
C        ******************************************************************
 2350 ARRAY(ISTOP+1)=-1.0
      CALL OFFSET (XOFF,XFAC,YOFF,YFAC)
      CALL PLOT (0.0,0.0,13)
```

```
      Y=0.1250
 2355 IF(Y.GT.YMAX) GO TO 2360
      CALL PLOT (0.0,Y,12)
      X=-TAC
      CALL PLOT (X,Y,12)
      CALL PLOT (0.0,Y,12)
      Y=Y*2.0
      GO TO 2355
 2360 CALL PLOT (0.0,0.0,12)
C
C       ****************************************************************
C       *  THIS LOOP KILLS BIN VALUES >MAX O3 <0 (BUM BI\S).           *
C       ****************************************************************
      DO 2370 N=ISTART,ISTOP
      ABAR=ABS(ARRAY(N))
      IF(ABAR.LE.YMAX) GO TO 2370
      ARRAY(N)=0.0
 2370 CONTINUE
      CALL SMOOTH (ISTART,ISTOP,KPASS)
C       ****************************************************************
C       *  THIS LJJP PLOTS HGRAM (A BROKE\ LI\E) SJ AS TJ ELIMINATE  *
C       *  THE PLJTTI\G OF EXTRA POINTS (IE.,TH3EE PTS. WITH THE      *
C       *  SAME Y-VALUE IN A ROW).                                     *
C       ****************************************************************
      JSTART=ISTART+1
      X=XHISTO(M)
      Y=ARRAY(ISTART)
      CALL PLOT (X,Y,12)
      X=XHISTO(M+1)
      DO 2390 N=JSTART,ISTOP
      M=M+1
      IF(ARRAY(N).\E.A3RAY(N+1)) GO TO 2385
      IF(ARRAY(N).NE.ARRAY(N-1)) GO TO 2385
      GO TO 2390
 2385 X=XHISTO(M)
      Y=ARRAY(N)
      CALL PLOT (X,Y,12)
      X=XHISTO(M+1)
 2390 CONTINUE
C     >++++++++++++++++++++++++++++++++++++++++++++++++
      GU TO (2330,2335,2340),I
C
C       ****************************************************************
C       *  IF THE L(EFT) PLJTS NOT DONE, SET LRGAP=1536 AND JO THEM. *
C       ****************************************************************
 2400 IF(LR3AP.EQ.0) 3O TO 2320
C
C       ****************************************************************
C       *  DO NOT SLIP XSLIP,YSLIP, AFTER LAST INTERVAL HAS BEEN       *
C       *  PLOTTED. MJVE TO NEXT EXPERIMENT.                           *
C       ****************************************************************
      IF(LINES.GE.INTVLS) GO TO 2420
C
C       ****************************************************************
C       *  SLIP XSLIP,YSLIP, AND PLOT (BACKW3DS) THE NEXT BASE LINE  *
C       *  BACK TO 0.0 OF THE NEXT INTERVAL JF DIR.                    *
C       ****************************************************************
      XOFF=XOFF-XSLIP
```

```
      YOFFR=YOFFR-YSLIP
      YFAC=1.0
      CALL OFFSET (XOFF,XFAC,YOFFR,YFAC)
      CALL PLOT (XBASE,0.0,13)
C     >++++++++++++++++++++++++++++++++++++++++
      CALL PLOT (0.0,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
      X=-XGAP2
      CALL PLOT (X,0.0,13)
      X=X-XBASE2
      CALL PLOT (X,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
      X=X-XGAP2
      CALL PLOT (X,0.0,13)
      X=X-XBASE2
      CALL PLOT (X,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
      X=X-XGAP1
      CALL PLOT (X,0.0,13)
      X=X-XBASE
      CALL PLOT (X,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
      X=X-XGAP1
      CALL PLOT (X,0.0,13)
      X=X-XBASE
      CALL PLOT (X,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
      X=X-XGAP2
      CALL PLOT (X,0.0,13)
      X=X-XBASE2
      CALL PLOT (X,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
      X=X-XGAP2
      CALL PLOT (X,0.0,13)
      X=X-XBASE2
      CALL PLOT (X,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
      X=X-XGAP1
      CALL PLOT (X,0.0,13)
      X=X-XBASE
      CALL PLOT (X,0.0,12)
C     >++++++++++++++++++++++++++++++++++++++++
 2410 CONTINUE
C
C        **************************************************************
C        *  RESET ORIGIN BEYOND THE LAST PLOT (L-R) AND RETURN FOR    *
C        *  ANOTHER EXPERIMENT.                                        *
C        **************************************************************
 2420 X=2.*XPAGE1-(XOFF+XDEL)
      YCM=-YCONST
      CALL PLOT(X,YCM,-3)
      GO TO 2100
C
C        **************************************************************
C        *  RETURN TO *ADJUSTOR TO SEE IF FURTHER INTERVAL CHANGES    *
C        *  ARE TO BE MADE AND SENT THRU EYEBALL I AND EYEBALL II.    *
C        **************************************************************
 2500 REWIND NDISC
```

```
      GO TO 1005
C
C       *****************************************************************
C       *  HERE ENDS THE PRGRAM. SIGN OFF THE PLOT PAPER.               *
C       *****************************************************************
 2600 CALL LABEL ('END OF PLOTTING',15)
      CALL LABEL ('PROGRAM: EYES',13)
      CALL LABEL ('OWNER: JOHN MATES',17)
      CALL PLOT (8.0,0.0,-3)
      STOP
      END
```

```
C       **************************************************************
C       *                         *EXPECT*                           *
C       *      *EXPECT* REPLACES THE HGRAMS WRITTEN BY *ADJUSTOR*    *
C       *  WITH ARRAYS CALCULATED ON THE BASIS OF D1R AND D1L AND    *
C       *  TWO HYPOTHESES:  (1) SUCCESSIVE INTERVALS BETWEEN MOVE-   *
C       *  MENTS OF THE SAME EYE ARE INDEPENDENT; (2) LEFT AND       *
C       *  RIGHT EYE MOVEMENT SEQUENCES ARE INDEPENDENT.             *
C       *      D1R AND D1L ARE REPLACED BY 'EXPECTED' ARRAYS,        *
C       *  E(R-L), E(L-R).  D2R,D3R,D2L,AND D3L ARE REPLACED BY      *
C       *  V(D2R),V(D3R),V(D2L),AND V(D3L), WHERE V(X) IS THE        *
C       *  NORMED SQUARED DEVIATION, N.S.D., (X-E(X))**2/E(X),       *
C       *  WITH THE SIGN OF THE ERROR, (X-E(X)).                     *
C       *      *EXPECT* MAKES THESE SUBSTITUTIONS ONLY IF NREAL      *
C       *  =2 (READ IN ON 2ND CARD.                                  *
C       *      IF *EXPECT IS CALLED TO SUBSTITUTE, MANY OF THE       *
C       *  COMMENTS IN *EYEBALL1* AND *EYEBALL2* WILL NOT BE         *
C       *  APPROPRIATE SINCE THEY REFER TO THE ORIGINAL HGRAMS.      *
C       **************************************************************
C
      SUBROUTINE EXPECT(LITER)
      DIMENSION EXRD2(251),EXRD3(501),EXLD2(251),EXLD3(501)
      COMMON/WORKA/RAY(3072)
      DIMENSION RRD1(251),RRD2(501),RRD3(501),RRL(251)
      DIMENSION RLD1(251),RLD2(501),RLD3(501),RLR(251)
      EQUIVALENCE (RAY(1),RRD1(1)),(RAY(257),RRD2(1))
      EQUIVALENCE (RAY(769),RRD3(1)),(RAY(1281),RRL(1))
      EQUIVALENCE (RAY(1537),RLD1(1)),(RAY(1793),RLD2(1))
      EQUIVALENCE (RAY(2305),RLD3(1)),(RAY(2817),RLR(1))
C
C       **************************************************************
C       *      LITER IS NO. OF INTERVALS SUMMED OVER BY *ADJUSTOR*. *
C       *  AT PRESENT, EACH INTERVAL = 32768/50 SECOND.  THIS VALUE  *
C       *  **MUST** BE CHANGED IF THE INTERVAL LENGTH AND/OR THE     *
C       *  SCALING OF HGRAMS CHANGE IN *REDEYE*.                     *
C       **************************************************************
      TIME=LITER*32768.
C
C       **************************************************************
C       *  CALCULATE TOTAL NO. OF INTERVALS BETWEEN MOVEMENTS FOR    *
C       *  RIGHT SIDE AND FOR LEFT SIDE.                             *
C       **************************************************************
      TOTRD1=0.0
      TOTLD1=0.0
C
      DO 3105 K=1,251
      TOTRD1=TOTRD1+RRD1(K)
      TOTLD1=TOTLD1+RLD1(K)
 3105 CONTINUE
C
      IF(TOTRD1.LE.2.0) TOTRD1=3.0
      IF(TOTLD1.LE.2.0) TOTLD1=3.0
C
C       **************************************************************
C       *      TO GET EXPECTED D2 VALUES, SHIFT D1 HGRAM BY J=       *
C       *  1,2,3,... STEPS AND FORM THE PRODUCTS: D1 X D1(J).  THE   *
C       *  SUM OF THESE PRODUCTS/NO. INTERVALS  IS THE EXPECTED      *
C       *  VALUE OF THE J-TH POS. BIN OF THE D2 HGRAM (ALSO OF       *
C       *  THE J-TH NEGATIVE BIN).  THIS IS SIMILAR TO A CON-        *
```

```
C       *  VOLUTION OF D1 WITH ITSELF.                               *
C       **************************************************************
      DO 3240 K1=1,251
      EXRD2(K1)=0.0
      EXLD2(K1)=0.0
C    >++++++++++++++++++++++++++++++++++++++++++++
      DO 3220 K2=K1,251
      EXRD2(K1)=EXRD2(K1)+RRD1(K2)*RRD1(K2-K1+1)
      EXLD2(K1)=EXLD2(K1)+RLD1(K2)*RLD1(K2-K1+1)
 3220 CONTINUE
C    >++++++++++++++++++++++++++++++++++++++++++++
      EXRD2(K1)=EXRD2(K1)/(TOTRD1-1.0)
      EXLD2(K1)=EXLD2(K1)/(TOTLD1-1.0)
 3240 CONTINUE
C
C       **************************************************************
C       *  SAME PROCEDURE PERFORMED ON D2 VALUES TO GET E(D3) AS     *
C       *  JUST DONE ABOVE ON D1 TO GET E(D2).                       *
C       **************************************************************
      DO 3280 K1=1,501
      EXRD3(K1)=0.0
      EXLD3(K1)=0.0
C    >++++++++++++++++++++++++++++++++++++++++++++
      DO 3260 K2=K1,501
      EXRD3(K1)=EXRD3(K1)+RRD2(K2)*RRD2(K2-K1+1)
      EXLD3(K1)=EXLD3(K1)+RLD2(K2)*RLD2(K2-K1+1)
 3260 CONTINUE
C    >++++++++++++++++++++++++++++++++++++++++++++
      EXRD3(K1)=EXRD3(K1)/(TOTRD1-2.0)
      EXLD3(K1)=EXLD3(K1)/(TOTLD1-2.0)
 3280 CONTINUE
C
C       **************************************************************
C       *       THIS CODE REPLACES D2, D3 HGRAMS FOR LEFT AND RIGHT  *
C       *  EYES WITH S.N.DEV.S FROM THE EXPECTED D2, D3 HGRAMS,      *
C       *  ASSUMING INDEPENDENCE OF INTERVALS.  NOTE THAT S.N.D.     *
C       *  CARRIES SIGN OF THE ERROR, (X-E(X)).                      *
C       **************************************************************
      MDIM1=251
      MDIM2=501
C
      CALL VAR1(RRD2,EXRD2,MDIM2,MDIM1)
      CALL VAR1(RLD2,EXLD2,MDIM2,MDIM1)
      CALL VAR1(RRD3,EXRD3,MDIM2,MDIM2)
      CALL VAR1(RLD3,EXLD3,MDIM2,MDIM2)
C
C       **************************************************************
C       *       D1 IS AN ESTIMATE OF THE P.D.F. OF INTERVALS (IF     *
C       *  NORMALIZED).  WE FORM CD1, THE PROB. THAT AN EYE MOVE     *
C       *  WILL HAVE OCCURRED AFTER AN INTERVAL=X, BY SUMMING D1     *
C       *  FROM 0 TO X.  THIS IS THE CUMULATIVE P.D. OF INTERVALS.   *
C       *  1-CD1 IS CALLED THE 'SURVIVOR' FUNCT. AND IS THE PROB.    *
C       *  AN EYE MOVE HAS NOT YET OCCURRED AFTER AN INTERVAL, X.    *
C       *  IF A SEQUENCE, S1, IS RANDOM W.R.T. THE STATIONARY        *
C       *  SEQUENCE, S2, THE 'WAITING TIMES' (FORWARD OR BACKWARD,   *
C       *  S1 TO S2) WILL BE DISTRIBUTED AS (1-CD1(S2))/MEAN S2  .   *
C       *  IN THE FOLLOWING CODE, D1R IS REPLACED BY E(R-L) AND D1L  *
C       *  BY E(L-R).  R-L IS REPLACED BY V(R-L) AND L-R BY V(L-R).  *
```

```
C        ******************************************************************
C
      XK=0.0
      XJ=0.0
C
      DO 3420 M=1,251
      XK=RRD1(M)+XK
      XJ=RLD1(M)+XJ
      RRD1(M)=(TOTRD1-XK)*TOTLD1/TIME
      RLD1(M)=(TOTLD1-XJ)*TOTRD1/TIME
 3420 CONTINUE
C
      CALL VAR2(RRL,RLD1,MDIM1)
      CALL VAR2(RLR,RRD1,MDIM1)
C
C        ******************************************************************
C
      RETURN
      END
```

```
C        ***************************************************************
C        *                           *VAR1*                            *
C        *      THIS SUBROUTINE REPLACES HGRAMS (D) WITH N.S.DEV.S      *
C        *  FRCM THE 'EXPECTED' HGRAMS (XD).  BINS ARE ACCUMULATED     *
C        *  UNTIL A TOTAL OF AT LEAST 5 COUNTS EXIST IN THE SET OF     *
C        *  BINS; THE N.S.D. AGAINST THE EXPECTED COUNTS OVER THE      *
C        *  SAME SET OF BINS IS CALCULATED AND EQUALLY DISTRIBUTED     *
C        *  OVER THE K BINS (N.S.D./K/BIN.                             *
C        ***************************************************************
C
      SUBROUTINE VAR1(D,XD,MD,MX)
C
C        ***************************************************************
C        *  D IS THE REAL DISTRIBUTION (HGRAM); XD IS 'EXPECTED'       *
C        *  DISTRIBUTION.  XD IS CNLY 1/2 OF EXPECTED DIST. WHICH      *
C        *  IS SYMMETRIC ABOUT 0.0 (BIN 251 OF D).                     *
C        ***************************************************************
      DIMENSION D(MD),XD(MX)
C
C        ***************************************************************
C        *  INITIALIZE PARAMETERS.                                     *
C        ***************************************************************
      K=0
      EX=0.0
      TF=0.0
      TB=0.0
      KSTART=1
C
C        ***************************************************************
C        *  INCREMENT BIN LOCATICN INDEX.  IF K IS TOO LARGE, THERE    *
C        *  ARE NO BINS LEFT; SET LAST N.S.D.S TO ZERO.                *
C        ***************************************************************
 4010 K=K+1
      IF(K.GT.250) GO TO 4030
C
C        ***************************************************************
C        *  OTHERWISE ACCUMULATE BINS OF BOTH D AND XD UNTIL           *
C        *  ADEQUATE SAMPLE SIZE (5) HAS BEEN REACHED.                 *
C        ***************************************************************
      EX=EX+XD(K)
      TF=TF+D(K+250)
      TB=TB+D(252-K)
      IF(EX.LT.5.0) GO TO 4010
C
C        ***************************************************************
C        *  CALCULATE N.S.D. AND DISTRIBUTE EQUALLY AMONG K BINS       *
C        *  SAMPLED (K=JGAP).                                          *
C        ***************************************************************
      TF=TF-EX
      TB=TB-EX
      VF=(TF*ABS(TF))/EX
      VB=(TB*ABS(TB))/EX
      KSTOP=K
      JGAP=KSTOP-KSTART+1
C
C        ***************************************************************
C        *  NOTE THAT, SINCE 'EXPECTED' D2, AND D3, ARE SYMMETRIC      *
C        *  ABOUT 0.0 (251ST BIN), I CAN CALCULATE TWO SYMMETRIC       *
```

```
C         *  N.S.D.S.                                                      *
C         ******************************************************************
      DO 4020 JJ=KSTART,KSTOP
      D(250+JJ)=VF/JGAP
      D(252-JJ)=VB/JGAP
 4020 CONTINUE
C
C         ******************************************************************
C         *  NEXT BIN (KSTART) IS NEW STARTING POINT FOR ACCUMULATION. *
C         *  IF KSTART IS OUT OF RANGE, WE ARE DONE.                       *
C         ******************************************************************
      KSTART=K+1
      IF(KSTART.GT.250) GO TO 4050
C
C         ******************************************************************
C         *  OTHERWISE, REINITIALIZE AND CONTINUE ABOVE PROCEDURE.        *
C         ******************************************************************
      EX=0.0
      TF=0.0
      TB=0.0
      GO TO 4010
C
C         ******************************************************************
C         *  SETTING LAST S.N.D.S TO ZERO (BECAUSE NOT BIG ENOUGH          *
C         *  SAMPLE SIZE).                                                 *
C         ******************************************************************
 4030 DO 4040 JJ=KSTART,251
      D(250+JJ)=0.0
      D(252-JJ)=0.0
 4040 CONTINUE
C
C         ******************************************************************
 4050 RETURN
      END
```

```
C        ***************************************************************
C        *                           *VAR2*                            *
C        *      *VAR2* IS THE SAME AS *VAR1* BUT OPERATES ON THE       *
C        *  D1 AND B HGRAMS ONLY.  IT REPLACES B HGRAMS WITH N.S.      *
C        *  DEVIATIONS FROM 'EXPECTED' HGRAMS (DX).  BINS ARE          *
C        *  ACCUMULATED UNTIL A TOTAL OF AT LEAST 5 COUNTS EXIST IN    *
C        *  THE SET OF BINS; THE N.S.D. AGAINST THE EXPECTED COUNTS    *
C        *  OVER THE SAME SET OF BINS IS CALCULATED AND EQUALLY        *
C        *  DISTRIBUTED OVER THE K BINS, N.S.D./K/BIN.                 *
C        ***************************************************************
C
      SUBROUTINE VAR2(B,DX,MDIM)
C
C        ***************************************************************
C        *  B IS REAL DISTRIBUTION; DX IS 'EXPECTED' DISTRIBUTION.     *
C        ***************************************************************
      DIMENSION B(MDIM),DX(MDIM)
C
C        ***************************************************************
C        *  INITIALIZE PARAMETERS.                                     *
C        ***************************************************************
      K=0
      EX=0.0
      TF=0.0
      KSTART=1
C
C        ***************************************************************
C        *  INCREMENT BIN LOCATION INDEX.  IF K IS TOO LARGE, THERE    *
C        *  ARE NO BINS LEFT; SET LAST N.S.D.S TO ZERO.                *
C        ***************************************************************
 5010 K=K+1
      IF(K.GT.250) GO TO 5030
C
C        ***************************************************************
C        *  OTHERWISE ACCUMULATE BINS OF BOTH B AND DX UNTIL ADEQUATE *
C        *  SAMPLE SIZE (5) HAS BEEN REACHED.                          *
C        ***************************************************************
      EX=EX+DX(K)
      TF=TF+B(K)
      IF(EX.LT.5.0) GO TO 5010
C
C        ***************************************************************
C        *  CALCULATE N.S.D. AND DISTRIBUTE EQUALLY AMONG K BINS       *
C        *  SAMPLED (K=JGAP).                                          *
C        ***************************************************************
      TF=TF-EX
      VF=(TF*ABS(TF))/EX
      KSTOP=K
      JGAP=KSTOP-KSTART+1
C
      DO 5020 JJ=KSTART,KSTOP
      B(JJ)=VF/JGAP
 5020 CONTINUE
C
C        ***************************************************************
C        *  NEXT BIN (KSTART) IS NEW STARTING POINT FOR ACCUMULATION. *
C        *  IF KSTART IS OUT OF RANGE, WE ARE DONE.                    *
C        ***************************************************************
```

```
      KSTART=K+1
      IF(KSTART.GT.250) GO TO 5050
C
C       ****************************************************************
C       *  OTHERWISE, REINITIALIZE AND CONTINUE ABOVE PROCEDURE.       *
C       ****************************************************************
      EX=0.0
      TF=0.0
      GO TO 5010
C
C       ****************************************************************
C       *  SETTING LAST S.N.D.S TO ZERO (BECAUSE NOT BIG ENOUGH        *
C       *  SAMPLE SIZE).                                               *
C       ****************************************************************
 5030 DO 5040 JJ=KSTART,251
      B(JJ)=0.0
 5040 CONTINUE
C
C       ****************************************************************
 5050 RETURN
      END
```

```
      SUBROUTINE SMOOTH(LOC1,LOC2,NPASS)
      COMMON/ WORKA/XO(3072)
      IF(NPASS.EQ.0) GO TO 90
   10 DO 80 IP=1,NPASS
      LOC21=LOC2-1
      LOCT1=LOC2+1
      LDEL=LOC2-LOC1
   20 DO 30 N=LOC1,LOC21
      XO(N)=XO(N)+XO(N+1)
   30 CONTINUE
      XO(LOC2)=2.*XO(LOC2)
   40 DO 50 N=1,LDEL
      M=LOCT1-N
      XO(M)=XO(M-1)+XO(M)
   50 CONTINUE
      XO(LOC1)=2.*XO(LOC1)
   60 DO 70 N=LOC1,LOC2
      XO(N)=XO(N)/4.
   70 CONTINUE
   80 CONTINUE
   90 RETURN
      END
```

A2.4 BASIC models.

Two short programs for the Linc-8 computer were written (in BASIC) for me by R. Longley, a generous colleague. The programs tested two simple questions: (1) how would horizontal EOG amplitudes distribute, given saccades of equal size, but with uniformly and randomly distributed origins, and (2) how would the amplitudes distribute if saccades' origins <u>and</u> amplitudes were uniformly and randomly distributed (up to a maximum size)? "EYEFIX" and "EYEMOV" were designed to test questions (1) and (2), respectively. Both models are predicated on the assumption that the EOG change resulting from a saccade is proportional to the difference of the sines of the horizontal angles (Figure 31) of origin and terminus. Given the results of "EYEFIX," however, the results of "EYEMOV" follow. "EYEFIX" indicates that the amplitude distributions for fixed saccade sizes are <u>shaped</u> more-or-less independently of sixe (Figure 32a). If saccade sizes, up to a maximum, are to be uniformly distributed in frequency, then the approximately hyperbolic curve of Figure 32b was to be expected.

```
EYEFIX  BASIC-69

100 DIM A⊕102→
110 LET I=1
120 LET A⊕I→=0
130 LET I=I+1
140 IF I<=100 THEN 120
150 PRINT ⊃CONSTANT CIRCULAR ANGLE IN RADIANS IS⊃
160 INPUT A1
170 PRINT
180 PRINT
190 LET A=⊕3.14159-A1→/2
200 LET M=1-COS⊕A1→
210 LET N=SIN⊕A1→
220 LET X=M*COS⊕A→+N*SIN⊕A→
230 LET X1=ABS⊕X→
240 LET A=0
250 LET C=0
260 LET U=RND⊕1→
270 LET A=2*3.14159*U
280 LET X=M*COS⊕A→+N*SIN⊕A→
290 LET I=ABS⊕X*100/X1→
300 LET I=INT⊕I+.999→
310 LET A⊕I→=A⊕I→+1
320 LET C=C+1
330 IF C <= 10000 THEN 260
340 FOR I=1 TO 100 STEP 2
350 PRINT A⊕I→+A⊕I+1→,
360 NEXT I
370 PRINT
380 PRINT
390 PRINT
400 FOR I=1 TO 100 STEP 2
410 LET K=INT⊕⊕A⊕I→+A⊕I+1→+4.99→/10→
420 IF K=<0 THEN 460
430 LET K=K-1
440 PRINT ⊃ ⊃;
450 GO TO 420
460 PRINT ⊃+⊃
470 NEXT I
480 END
```

```
EYEMOV  BASIC-69

100 DIM A⊕102→
110 LET I=1
120 LET A⊕I→=0
130 LET I=I+1
140 IF I<=100 THEN 120
150 PRINT ⊃MAXIMUM CIRCULAR ANGLE IN RADIANS IS⊃
160 INPUT A1
170 PRINT
180 PRINT
190 LET A=⊕3.14159-A1→/2
200 LET M=1-COS⊕A1→
210 LET N=SIN⊕A1→
220 LET X=M*COS⊕A→+N*SIN⊕A→
230 LET X1=ABS⊕X→
240 LET A2=A1
250 LET A=0
260 LET C=0
270 LET U=RND⊕1→
280 LET A1=A2*U
290 LET X=⊕1-COS⊕A1→→*COS⊕A→+SIN⊕A1→*SIN⊕A→
300 LET I=ABS⊕X*100/X1→
310 LET I=INT⊕I+.999→
320 LET A⊕I→=A⊕I→+1
330 LET A=A+A1
340 LET C=C+1
350 IF C=<10000 THEN 270
360 FOR I=1 TO 100 STEP 2
370 PRINT A⊕I→+A⊕I+1→,
380 NEXT I
390 PRINT
400 PRINT
410 PRINT
420 FOR I=1 TO 100 STEP 2
430 LET K=INT⊕⊕A⊕I→+A⊕I+1→+4.99→/10→
440 IF K=<0 THEN 480
450 LET K=K-1
460 PRINT ⊃ ⊃↓
470 GO TO 440
480 PRINT ⊃+⊃
490 NEXT I
500 END
```

BIBLIOGRAPHY

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Alpern, M. (1962). Types of movement. In: The Eye (edited by H. Davson), pp. 63-143, Academic Press, London.

Anderson, T. W. (1971). The Statistical Analysis of Time Series, John Wiley & Sons, New York.

Aristotle. (1910). Historia Animalium, Bk II (tr. D'Arcy W. Thompson), Clarendon Press, Oxford.

Barmack, N. H. (1970). Modification of eye movements by instantaneous changes in the velocity of visual targets. Vision Res. 10, 1431-1441.

Becker, W. and Fuchs, A. F. (1969). Further properties of the human saccadic system: eye movements and correction saccades with and without visual fixation points. Vision Res. 9, 1247-1258.

Bicas, H. E. A. (1972). Electro-oculography in the investigation of oculomotor imbalance--I. Basic aspects. Vision Res. 12, 993-1010.

Billingsley, P. (1961). Statistical Methods in Markov chains. Ann. Math. Stat. 32, 12-40.

Bourne, J. R., Hudak, P. R. and Duke, J. L. (1972). Computer automated electrooculography. Comp. Biomed. Res. 5, 654-658.

Brindley, G. S. (1960). Physiology of the Retina and Visual Pathway, Arnold, London.

Bustard, H. R. (1963). Herpetological notes. Growth, sloughing, feeding, mating, gestation, life-span, and poor health of chameleons in captivity. Copeia, 704-705.

Carmichael, L. and Dearborn, W. F. (1947). Reading and Visual Fatigue, Houghton, Mifflin, Boston.

Collewijn, H. (1969). Changes in visual evoked responses during the fast phase of optokinetic nystagmus in the rabbit. Vision Res. 9, 803-814.

Cox, D. R. and Lewis, P. A. W. (1966). The Statistical Analysis of Series of Events, Methuen, London.

Cunitz, R. J. and Steinman, R. M. (1969). Comparison of saccadic eye movements during fixation and reading. Vision Res. 9, 683-693.

Ditchburn, R. W. and Foley-Fisher, J. A. (1967). Assembled data in eye movements. Optica Acta 14, 113-118.

Dodge, R. (1903). Five types of eye movement in the horizontal meridian plane of the field of regard. Am. J. Physiol. 8, 307-329.

Fenn, W. O. and Hursh, J. B. (1937). Movements of the eyes when the lids are closed. Am. J. Physiol. 118, 8-14.

Gaillard, J. M. and Tissot, R. (1973). Principles of automatic analysis of sleep records with a hybrid system. Comp. Biomed. Res. 6, 1-13.

Granit, R. (1947). Sensory Mechanisms of the Retina, Oxford University Press, London.

Hermann, H. T. and Constantine, M. M. (1971). Eye movements in the goldfish. Vision Res. 11, 313-331.

Holden, A. L. (1966). Two possible visual functions for centrifugal fibers to the retina. Nature 212, 837-838.

Jeannerod, M., Gerin, P. and Pernier, J. (1968). Deplacements et fixations du regard dans l'exploration libre d'une scene visuelle. Vision Res. 8, 81-97.

Kris, C. (1958). Corneo-fundal potential variations during light and dark adaptation. Nature, Lond. 182, 1027-1028.

Latour, P. L. and Bouman, M. A. (1961). A nonanalog time component in visual pursuit movements. In: Sensory Communication (edited by W. A. Rosenblith), pp. 798-803, M. I. T. Press, Massachusetts and Wiley, New York.

Levelt, W. J. M. (1968). Binocular Rivalry, Mouton, Netherlands.

Lilly, J. C. (1962). Cerebral Dominance. In: Interhemispheric Relations and Cerebral Dominance (edited by V. B. Mountcastle), pp. 112-114, Johns Hopkins Press, Baltimore.

Noton, D. and Stark, L. (1971). Scan paths in saccadic eye movements while viewing and recognizing patterns. Vision Res. 11, 929-942.

Nye, P. W. (1969). The monocular eye movements of the pigeon. Vision Res. 9, 133-144.

Perkel, D. H., Gerstein, G. L. and Moore, G. P. (1967a). Neuronal spike trains and stochastic point processes. I. The single spike train. Biophys. J. 7, 391-418.

Perkel, D. H., Gerstein, G. L. and Moore, G. P. (1967b). Neuronal spike trains and stochastic point processes. II. Simultaneous spike trains. Biophys. J. 7, 419-440.

Polyak, S. L. (1957). The Vertebrate Visual System, University of Chicago Press, Illinois.

Pope, C. H. (1955). The Reptile World, Knopf, New York.

Poulton, E. C. (1958). On reading and visual fatigue. Am. J. Psychol. 71, 609-611.

Rashbass, C. (1961). The relationship between saccadic and smooth tracking movements. J. Physiol. 159, 326-338.

Robinson, D. A. (1964). The mechanics of human saccadic eye movement. J. Physiol. 174, 245-264.

Robinson, D. A. and Fuchs, A. F. (1969). Eye movements evoked by stimulation of frontal eye fields. J. Neurophysiol. 32, 637-648.

Rodieck, R. W., Kiang, N. Y.-S. and Gerstein, G. L. (1962). Some quantitative methods for the study of spontaneous activity of single neurons. Biophys. J. 2, 351-368.

Shanklin, W. B. (1930). The central nervous system of Chameleo vulgaris. Acta Zool. 11, 425-490.

Sokal, R. R. and Rohlf, F. J. (1969). Biometry, Freeman, San Francisco.

Stein, R. B. (1965). A theoretic analysis of neuronal variability. Biophys. J. 5, 173-194.

Tauber, E. S. and Atkin, A. (1967). Disconjugate eye movement patterns during optokinetic stimulation of the African chameleon, Chameleo melleri. Nature 214, 1008-1010.

Tauber, E. S. and Atkin, A. (1968). Optomotor responses to monocular stimulation: relation to visual system organization. Science 160, 1365-1367.

Tauber, E. S., Roffwarg, H. P. and Weitzman, E. D. (1966). Eye movements and electroencephalogram activity during sleep in diurnal lizards. Nature 212, 1612-1613.

Thomas, E. L. (1968). Movements of the eye. Sci. Am. 219, 88-95.

Troy, M., Chen, S. C. and Stern, J. A. (1972). Computer analysis of eye movement patterns during visual search. Aerospace Med. 43, 390-394.

Vasudevan, R., Phatak, A. V., and Smith, J. D. (1972). A stochastic model for eye movements during fixation on a stationary target. Kybernetik 11, 24-31.

Walls, G. L. (1942). The Vertebrate Eye, Cranbrook Press, Michigan.

West, D. C. and Boyce, P. R. (1968)., The effect of flicker on eye movements. Vision Res. 8, 171-192.

Wever, E. G. (1968). The ear of the chameleon: Chamaeleo senegalensis and Chamaeleo quilensis. J. Exp. Zool. 168, 423-436.

Wever, E. G. (1969a). The ear of the chameleon: the round window problem . J. Exp. Zool. 171, 1-6.

Wever, E. G. (1969b). The ear of the chameleon: Chamaeleo hohnelii and Chamaeleo jacksoni. J. Exp. Zool. 171, 305-312.

White, C. T. (1960). Eye movements during simulated radar search. J. opt. Soc. Am. 50, 909-913.

Yarbus, A. L. (1967). Eye Movements and Vision, Plenum Press, New York.

Zuber, B. L., Stark, L. and Cook, G. (1965). Microsaccades and the velocity-amplitude relationship for saccadic eye movements. Science 150, 1459-1460.

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