XVIII. NEUROLOGY*

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A. WORK COMPLETED

Summaries of theses accepted in partial fulfillment of the requirements for the degrees indicated are presented below.

1. A COMPUTER-CONTROLLED EXPERIMENT IN HUMAN PREDICTION

[S. M. Thesis, Department of Electrical Engineering, M. I. T., January 1963.]

A digital-computer program has been written to operate a psychological experiment. This program is designed to be used by experimenters who are not skilled in computer technology. The program ensures that a properly initialized and fully documented experiment will be conducted. The psychological experiment itself is designed to investigate the ability of human subjects to predict successive numbers in a sequence or correlated random numbers. There is an optimum policy by which the subject may minimize the expected cost of his errors. Quantitative measures of the subjects' behavior with respect to the optimum policy show the effects of individual differences and learning. Periodic oscillations may also be present in the subjects' policy behavior. Unless instructed otherwise, the majority of subjects quickly infer "personal causation." They believe that their predictions have an effect on the numbers that they are predicting. Such a hypothesis is false, however. These subjects are actually being superstitious about their unstructured environment. Many possibilities exist for further work in the design, implementation, and conduct of this experiment.

E. C. Van Horn, Jr.

2. A MATHEMATICAL MODEL OF THE STRETCH REFLEX IN HUMAN MUSCLE SYSTEMS

[S. M. Thesis, Department of Electrical Engineering, M. I. T., May 1963.]

The stretch reflex, a biological feedback control system, is studied in the wrist-rotation muscular system of man by examining, first, the performance of its isolated

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components. Then mathematical models of these components are assembled on the basis of their known topology to form an integrated model of the system. This model has the advantage of being generally applicable to any studies that might be conducted on the system.

Experimental studies on human subjects, along with theoretical considerations, justify the simplification to a linear model with situation-variant parameters. Transient responses of the model are studied on an analog computer, and correlation is achieved with responses of human subjects. The comparisons indicate that adaptive behavior under the control of the central nervous system is present. The model is also used to clarify certain related studies.

J. C. Houk, Jr.

3. THE ROLE OF HEAD MOVEMENTS IN HUMAN VISUAL TARGET PURSUIT

[S. B. Thesis, Department of Electrical Engineering, M. I. T., June 1963.]

The study of the interaction of the head and eye pursuit control systems is of interest. A method for measuring both horizontal eye and head rotation, and its disadvantages, are discussed. Also, several methods for processing data are discussed, with suggestions for improving the experimental procedure. Finally, five experiments and their results are described. Specifically described are the responses to square steps of a target angle, single sinusoids, and multiple-sinusoid, constant-velocity, and open-loop techniques. No model has been hypothesized, with the understanding that this work represents only the beginning of a study of an exceedingly complex system.

G. A. Masek

4. ARTIFICIAL PHOTOSENSITIZATION OF THE CRAYFISH VENTRAL NERVE CORD

[S. B. Thesis, Department of Physics, M. I. T., June 1963.]

Problems of artifically photosensitizing the ventral nerve cord of the crayfish, Cambarus astacus are investigated. By using gross-electrode techniques, it was possible to determine the characteristic response of the sensitized nerve to light. The nerve responded to a minimal light stimulus of 0.06 lumen/mm^2 for 0.4 second. The sensitized nerve exhibited four different light responses; this suggests the existence of two types of photoreceptors, an excitatory receptor and an inhibitory receptor.

R. Millecchia

5. AN IMPROVED TELEVISION PUPILLOMETER

[S. B. Thesis, Department of Electrical Engineering, M. I. T., June 1963.]

An existing pupillometer that uses a television unit to scan the pupil had been designed for neurological experiments. The interactions among the various systems of the instrument were investigated and, in certain cases, lessened to give an output insensitive to extraneous experimental conditions. A new design feature allows a calibration system to be built which will not vary from subject to subject.

S. W. Miller

6. INVESTIGATION OF INPUT PARAMETERS FOR DIGITAL COMPUTER ANALYSIS OF ELECTROCARDIOGRAMS

[S. B. Thesis, Department of Electrical Engineering, M. I. T., June 1963.]

Computer diagnosis of clinical electrocardiograms can be simplified by a reduction of input data to a form more suited to pattern-recognition techniques. An understanding of the vectorial properties of the orthogonal three-lead electrocardiogram provides the basis for a geometrical approach to the problem of data reduction.

Computer methods were used to investigate possible geometrical approaches for combining into one signal pertinent data from three electrocardiograms. These studies have produced no one input function, but a framework for extended research on the problem has been established.

E. J. Sadler

7. DIGITAL COMPUTER ANALYSIS OF NERVE PULSE TRAINS

[S. B. Thesis, Department of Electrical Engineering, M. I. T., June 1963.]

An investigation has been made of the use of a digital computer to measure the intervals between spike impulses of a nerve pulse train and plot two characteristic functions, the interval function and the instantaneous-frequency function. The nerve pulse train is obtained from the nerve cord of the crayfish, and the computing was done on the G. E. 225 general-purpose computer. The object of the experiment was to obtain functions from the dynamic characteristics of a sensory organ, by means of a computer, which otherwise would be practically impossible, or at least very painstaking and time-consuming.

E. Zorawowicz

8. A DEVICE FOR THE MEASUREMENT OF FINGER TREMOR

[S. B. Thesis, Department of Electrical Engineering, M. I. T., January 1963.]

In this study the design, building, and testing of an electro-optical instrument for measuring human finger tremor is explained. The "Tremor Measuring Instrument" has a nearly noise-free gain with a sensitivity of 200 microvolts per micron and is simple, inexpensive, accurate within 10 per cent, and easy to operate. This optical system permits recording of the natural tremor and in no way hinders the finger's motion.

E. L. Mudama

9. SAMPLING OR QUANTIZATION IN THE HUMAN TRACKING SYSTEM
[S. B. Thesis, Department of Electrical Engineering, M. I. T., January 1963.]

A theoretical and experimental investigation of the nature of the voluntary movements involved in hand tracking is reported. Attention is given to the detailed nature of transient responses and to the discontinuities of the operator's movements.

Results from a variety of experiments and investigation of the physiology of the system have been used to obtain a model for pursuit tracking of unpredictable signals. A theory about intermittency was advanced and found to be consistent with output measurements. In this theory it is assumed that there is intermittent action of the proprioceptive feedback loop.

In the development of a tracking model the following characteristics of hand-tracking movements have been experimentally established: (a) difference between tracking predictable and unpredictable inputs; (b) intermittency for unpredictable inputs; and (c) position servomechanism nature of the tracking system.

F. Naves

10. A CONTROL SYSTEM STUDY OF HUMAN TEMPERATURE REGULATION
[S. B. Thesis, Department of Electrical Engineering, M. I. T., January 1963.]

A control-system analysis of the temperature regulation system in man and other homeothermic animals is proposed. A model of the human thermoregulatory system based on physiological considerations and information in published works (both seasoned with a fair amount of speculation) is developed. The model contains nonlinearities that may be purposefully employed to achieve fine control. A method is proposed for opening the thermoregulatory loop in unanesthetized animals, and the applicability of the describing function method of nonlinear analysis is discussed. Quantitative aspects of the model are developed to show that it may behave as a linear, second-order system for large error signals. The design of a heat exchanger that is adequate for driving the system is discussed. Some experimental data are presented to indicate the feasibility of the experimental aspects of this study.

R. W. Cornew

11. AN ANALYTIC MODEL FOR THE HUMAN PUPIL LIGHT REFLEX
[S. M. Thesis, Department of Electrical Engineering, M. I. T., August 1963.]

In 1959, Dr. Lawrence Stark, suggested a mathematical model to account for experimentally observed fluctuations of pupil area which are due to changes in incident light intensity. The model is reviewed here. Predictions are derived both analytically and by analog simulation. A description of experiments performed to test these predictions is given. Experimental methods and the apparatus are described; experimentation was greatly facilitated by the use of a digital-computer program, devised by A. A. Sandberg, for on-line control of the experimental apparatus and associated analysis and display of data. Modifications to the model are proposed to account for discrepancies, and suggestions are made for further studies.

I. Sobel

12. PUPIL NOISE – AN EXAMPLE OF A STOCHASTIC PROCESS IN A BIOLOGICAL SYSTEM

[E. E. Thesis, Department of Electrical Engineering, M. I. T., August 1963.]

The random fluctuations in human pupil area have been investigated as an example of a biological random process. A brief description of pupil physiology, physical measuring apparatus, and experimental techniques is presented. Various statistical and computer techniques used during this investigation are also discussed.

Some of the experiments performed in order to discover various properties of the multiplicative pupil noise include: the amplitude histogram of pupillary noise, change of noise level with both illumination and fixation as variables, interaction of noise with sine waves and transient pulse signals, the noise spectrum under different conditions, crosscorrelation between noise and respiration, and verification of the correlation of pupil noise in both eyes.

Two models are presented to describe the measured properties. One, a statistical model, is based upon the time-variant shot-noise process; in the other, an electronic system analogy is utilized.

S. F. Stanten

13. KINEMATICS AND MUSCLES OF THE HUMAN IRIS

[S. M. Thesis, Department of Mechanical Engineering, M. I. T., June 1963.]

A technique for determining the kinematics of the entire human iris during both photic reflex constriction and dilation has been developed. It is believed that this investigation represents the first quantitative determination of the velocity profiles of the whole iris, previous work having been confined to studies of the motion of the pupil edge only. Since the technique permits study of local motions of the iris, it should be useful in investigating the respective roles of the sphincter and dilator muscles of the iris.

A series of color and black-and-white photographs taken at a succession of times during constriction or dilation permits the course of the radial displacement of distinctive surface features of the iris to be followed. Simple numerical differentiation is then applied in the construction of velocity profiles, that is, $v = v(\bar{r})$, with time $\bar{t}$ as a parameter.

An attempt was made to interpret the profiles in terms of the geometry and functions of the sphincter and dilator muscles of the iris with special reference to the problem of whether the dilator acts as an active muscle or as a passive elasticity. The general forms of both the constriction and dilation profiles suggest that a two-component system is present, but the two types of profile are clearly different, with constriction yielding the simpler form. During the early times of dilation, a portion of the iris is found to move toward the center of the pupil; at later times all parts of the iris move away from the pupil center, but complications remain. The complexities that arise during dilation are felt to be more properly explained by the presence of an active dilator, as well as a relaxing sphincter. Also, the dilator may be contracting nonuniformly. Since the number of profiles obtained is small, the results must be considered suggestive and tentative, but they are sufficiently interesting to warrant further application of the technique, especially during dilation.

J. I. Simpson

B. VERGENCE EYE MOVEMENTS

An attempt is being made to determine the dynamics of vergence eye movements in humans.[1,2] Analysis thus far has been restricted to closed- and open-loop frequency response with sinusoidal, impulse, and step inputs. To allow for the possibility of prediction both predictable and unpredictable inputs have been used. A G. E. 225 digital computer with analog-to-digital converter has been used to produce stimuli and analyze responses. The computer is programmed to analyze both predictable and unpredictable sinusoidal responses and to calculate gain and phase. It is also used as an average-response computer for impulse and step responses, as well as for predictable sinusoidal responses.

An average of 90 predictable sine-wave responses at a frequency of 2.0 cps is shown in Fig. XVIII-1. Rashbass and Westheimer[3,4] reported that the 1-cps sinusoidal response of the vergence eye-movement system died out after the first few cycles. The average response of Fig. XVIII-1 was taken from continuous trains of waves, some as long as 30 cycles. The subject responded during every cycle. A clear continuous response was discernible at all frequencies up to 2.5 cps.

Fig. XVIII-1. Average 2.0-cps sine-wave response.

At present, experimentally determined closed- and open-loop frequency responses and impulse and step responses are being analyzed in an attempt to determine a linear transfer function for the system. We have previously published closed-loop frequency response data.[2] It has been seen from phase curves that a predictor apparatus operates to increase the phase margin near the -180° crossover frequency

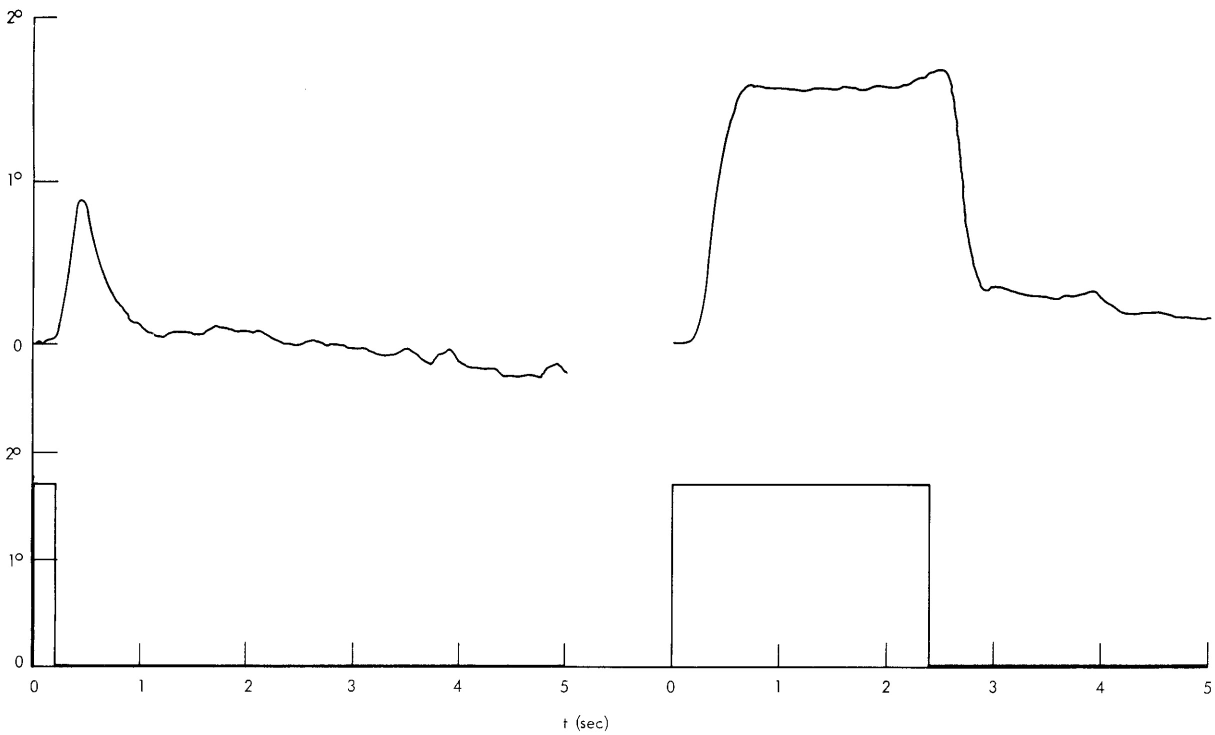


Fig. XVIII-2. Vergence eye movements.

of the unpredictable curve. Both the impulse and step responses (Fig. XVIII-2) show a pure delay amounting to approximately 130-200 msec, thereby indicating the presence of a nonminimum phase element. Combined results of averaged predictable sinusoidal responses and gain and phase data from predictable frequency responses indicate a predictive system of approximately third order with a break frequency of approximately 1.19 cps. This corresponds to a lumped time constant of 0.134 second for the predictive system.

Open-loop frequency response is shown in Fig. XVIII-3. These curves roughly confirm the conclusions made above, and the gain curve is in agreement with previously published data of Rashbass and Westheimer[3] in the frequency bandwidth investigated by those workers (0.4-1.5 cps).

Future experiments and analyses will provide more accurate transfer functions for both predictable and nonpredictable inputs, and it is hoped that the

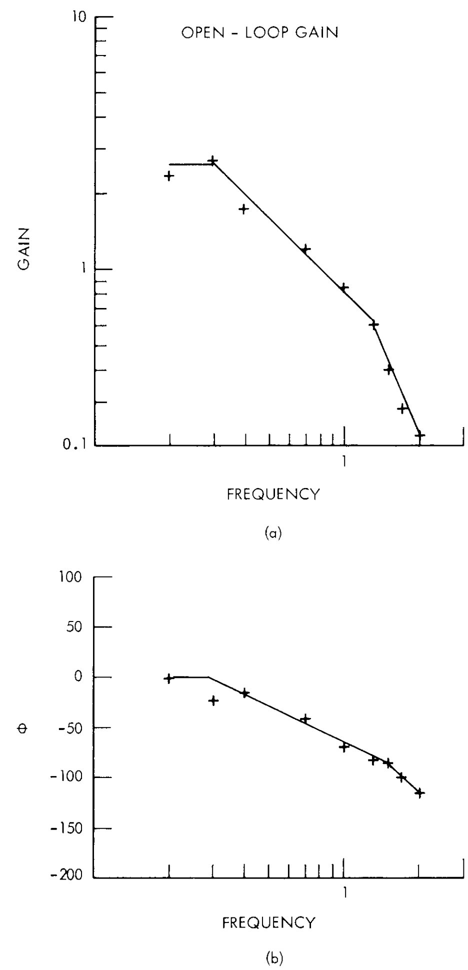


Fig. XVIII-3. Vergence eye movements.

system may be simulated by suitable mathematical models.

B. L. Zuber, A. Troelstra, L. Stark

References

1. B. L. Zuber and L. Stark, Eye convergence, Quarterly Progress Report No. 68, Research Laboratory of Electronics, M.I.T., January 15, pp. 232-234.

2. B. L. Zuber and L. Stark, Eye convergence, Quarterly Progress Report No. 70, Research Laboratory of Electronics, M.I.T., July 15, 1963, pp. 339-342.

3. C. Rashbass and G. Westheimer, Disjunctive eye movements, J. Physiol. 159, 339 (1961).

4. C. Rashbass and G. Westheimer, Independence of conjugate and disjunctive eye movements, J. Physiol. 150, 361 (1961).

C. KINEMATICS AND MUSCLES OF THE HUMAN IRIS

A technique has been developed to determine the kinematics of the entire human iris during both photic reflex constriction and dilation. It is believed that this investigation represents the first quantitative determination of the velocity profiles of the whole iris, previous work being confined to studying the motion of the pupil edge only. Since the technique permits local motions of the iris to be studied, it should be useful in investigating the respective roles of the sphincter and dilator muscles of the iris.

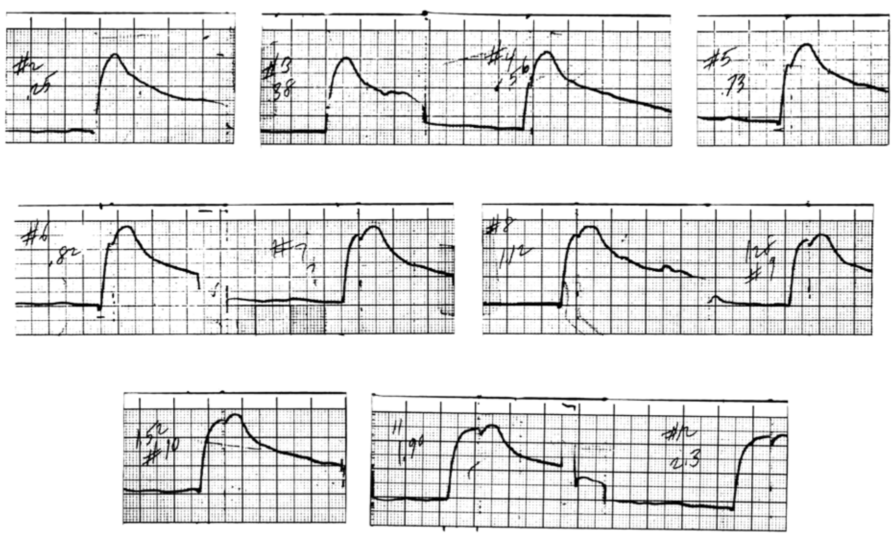


Fig. XVIII-4. Radial displacement of the iris. The numbers on the recordings refer to the photograph number and the time elapsed between onset of stimulation and the photograph. Time scale, 5 mm/sec.

A series of color or black-and-white photographs taken at a succession of times during constriction or dilation permit the course of the radial displacement of distinctive surface features of the iris to be followed (Fig. XVIII-4). Simple numerical differentiation is then applied in the construction of velocity profiles, that is, $v = v(r)$ with time t as a parameter. Examples of velocity profiles are shown in Figs. XVIII-5 and XVIII-6.

An attempt is made to interpret the profiles in terms of the geometry and functions of the sphincter and dilator muscles of the iris with special reference to whether the dilator acts as an active muscle or as a passive elasticity. The general form of both the constriction and dilation profiles suggest that a two-component system is present, but the two types of profiles are clearly different, with constriction yielding the simpler

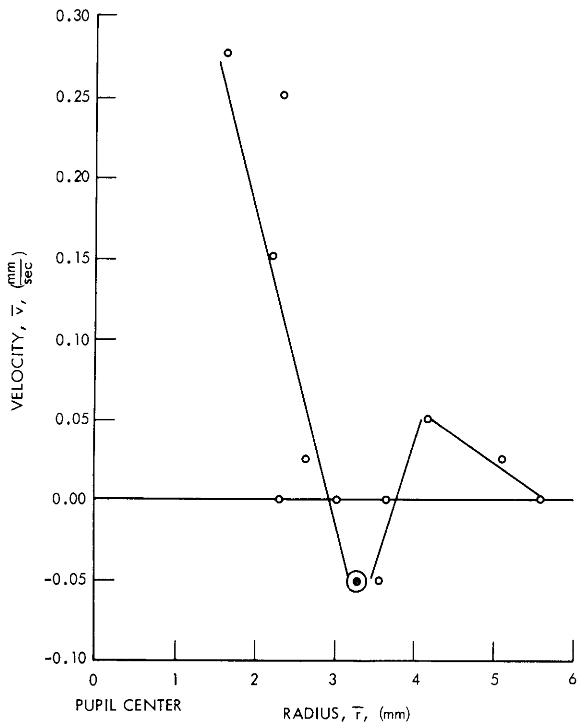


Fig. XVIII-5. Dilation velocity profile at time t.

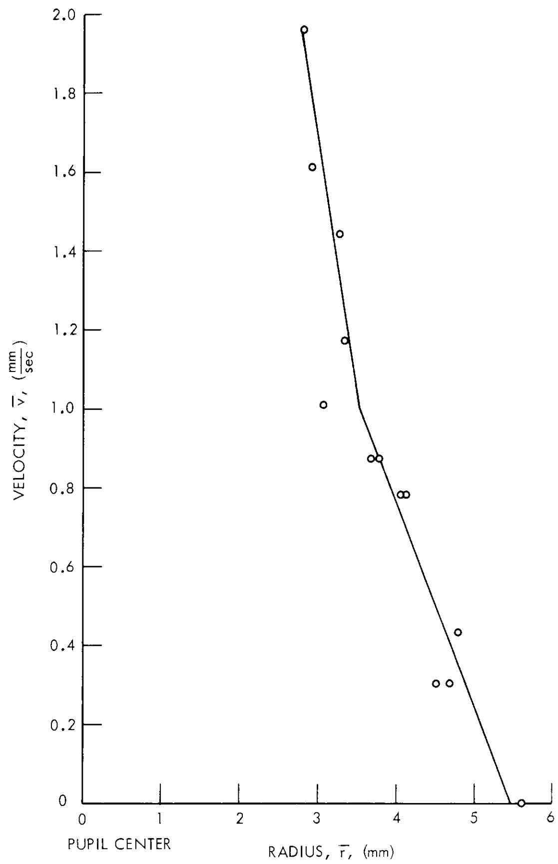


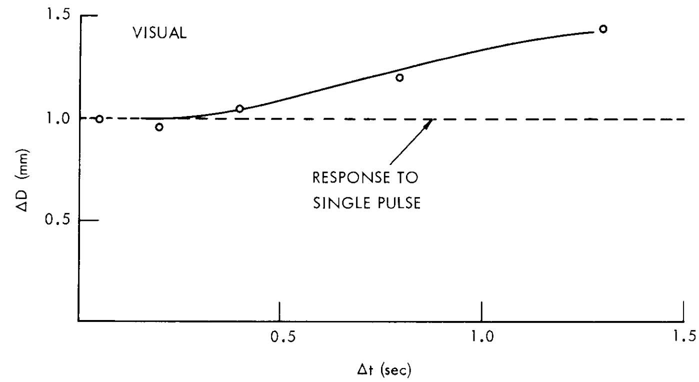
Fig. XVIII-6. Constriction velocity profile at time t.

form. During the early times of dilation, a portion of the iris is found to be moving toward the center of the pupil; at later times all parts of the iris move away from the pupil center, but complications remain. The complexities that arise during dilation are felt to be preferably explained by the presence of an active dilator, as well as a relaxing sphincter. Also, the dilator may be contracting nonuniformly. Since the number of profiles obtained is small, the results must be considered as suggestive and tentative, but they are seen to be sufficiently interesting to warrant further application of the technique, especially during dilation.

J. I. Simpson, L. Stark

D. CAT PUPIL SYSTEM

The aim of this project has been to study the nature of the signal processing in the cat's pupillary response-to-light system. An experimental arrangement is in operation which allows continuous measurement of the pupil diameter under infrared illumination



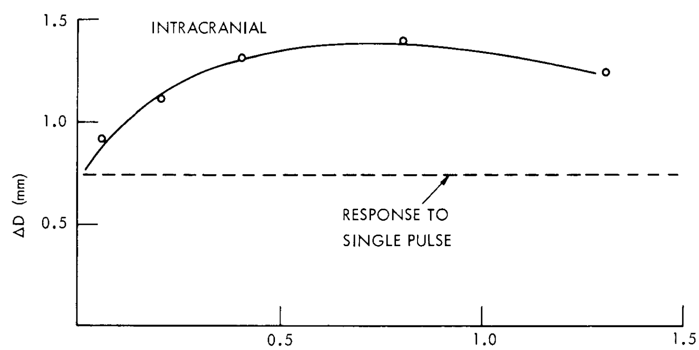


Fig. XVIII-7. Combined double-pulse experiment.

and both light stimulation and stereotaxically controlled brain stimulation. The intracranial electrical stimulation of the reflex pathways has been used as a means of breaking into the system at chosen points to test for the characteristic of response of the succeeding elements. Thus one may demonstrate the hypothesis that the lags of the pupil system seem to be located mainly in the effector organ. Other work has been an attempt to localize the short-term adaptational property to a neurological element by using double-pulse stimulation in which the second pulse enters visually or at various points along the pathways to localize the stereotactic process.

Illustrations of the experimental results of this work are the graphs in Fig. XVIII-7 which represent the results of a combined double-pulse experiment. The second pulse was presented either to the same eye as the first conditioning light pulse (upper curve) or to the associated optic track (lower curve), and the varied parameter was interpulse duration. These results illustrate a definite retinal adaptational effect.

F. H. Baker

E. SMOOTH PHASE OF OPTOKINETIC NYSTAGMUS IN MAN

Several recent experiments suggest the incorrectness of the previous view that optokinetic nystagmus is due to a competition between saccadic fixation and smooth pursuit systems.[1]

1. Modified Apparatus

Figure XVIII-8 shows the apparatus used in these experiments. The circuitry is similar to part of the eye-movement measuring devices previously used in this laboratory.[2] Modifications include: (a) mounting the elements on ball-and-socket joints for flexibility and accuracy of positioning, (b) the use of a biteboard and headrest to minimize head movement, (c) light pipes to illuminate the corneoscleral junction symmetrically about the horizontal axis of the iris, and (d) filtering to remove the visible and far infrared from the illuminating light, to help in reducing the tearing tendency. The

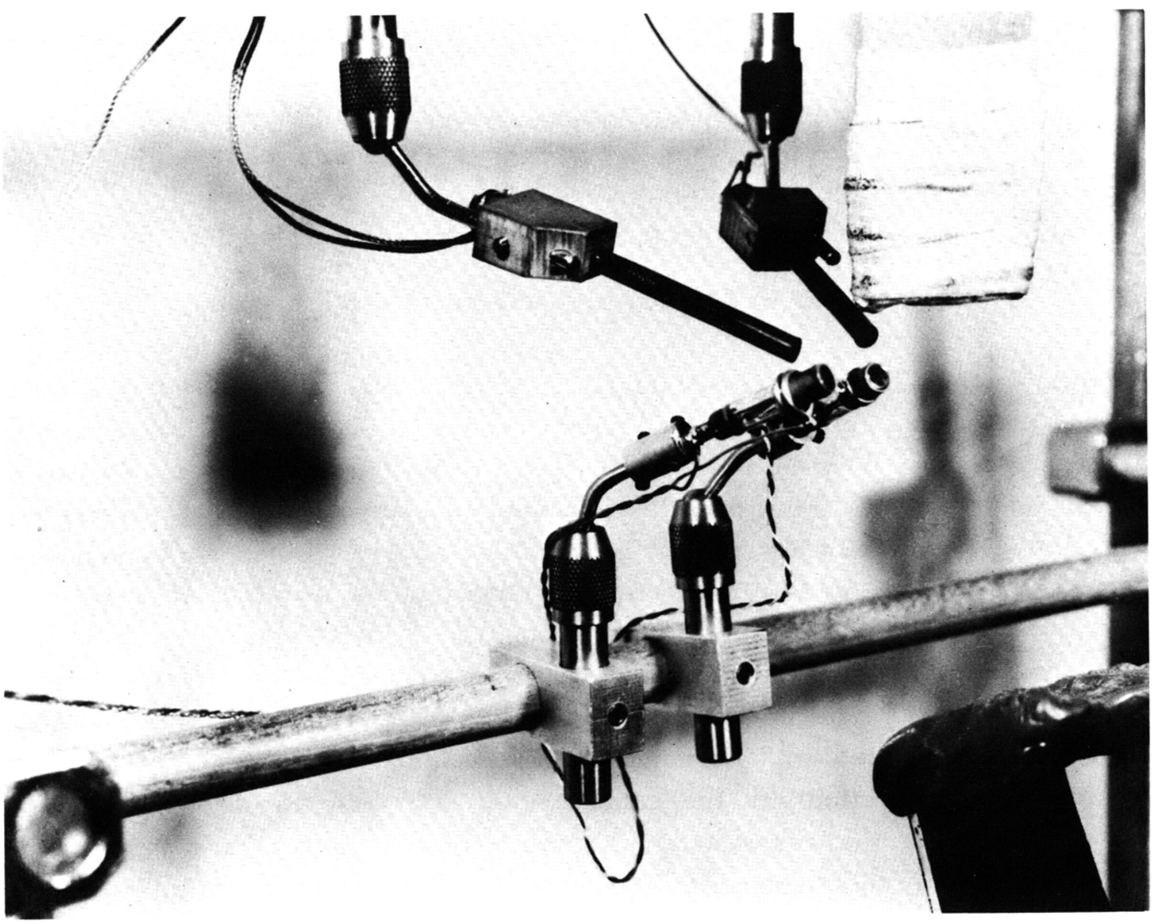


Fig. XVIII-8. Apparatus.

headrest and the light pipes can be seen in the upper half of Fig. XVIII-8 and the 1P42 phototubes and biteboard in the lower half.

2. Fovea and Optokinetic Nystagmus

In the first experiment, the subject is presented with a 5.5 × 15.0 visual field, filled with vertical, smoothly moving stripes. A 4° × 4° square area around the 0.1° fixation point in the center of the visual field is blacked out so that the stripes within this area are not seen. The response to this situation is the same as the response to the stripes

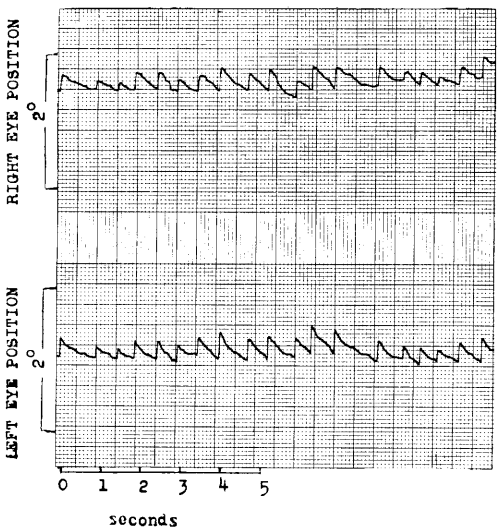


Fig. XVIII-9. Fixated optokinetic nystagmus.

and fixation point without the occluded area. This is the 'fixated optokinetic nystagmus', shown in Fig. XVIII-9. This experiment demonstrates that the fovea is not necessarily implicated in the optokinetic nystagmus response, nor are receptors within a 2° radius around the fovea.

3. Correlation of the Slow and Fast Phases in Optokinetic Nystagmus

Figure XVIII-10 shows scattergrams for two correlations of slow and fast phases in optokinetic nystagmus. In this experiment, a long sequence of optokinetic nystagmus response, similar to that in Fig. XVII-9, was analyzed for the magnitude of the fast and slow phases. Correlation coefficients were calculated for two cases: (1) the fast phase vs the preceding slow phase, and (2) the fast phase vs the following slow phase. These coefficients were 0.14 ($p = 0.005$) and 0.86 ($p = 0.005$), the values demonstrating that the fast phase is practically uncorrelated with the preceding slow phase, but that the slow phase is highly correlated with the preceding fast phase.

These results are contrary to the view that the fast phase is accurately

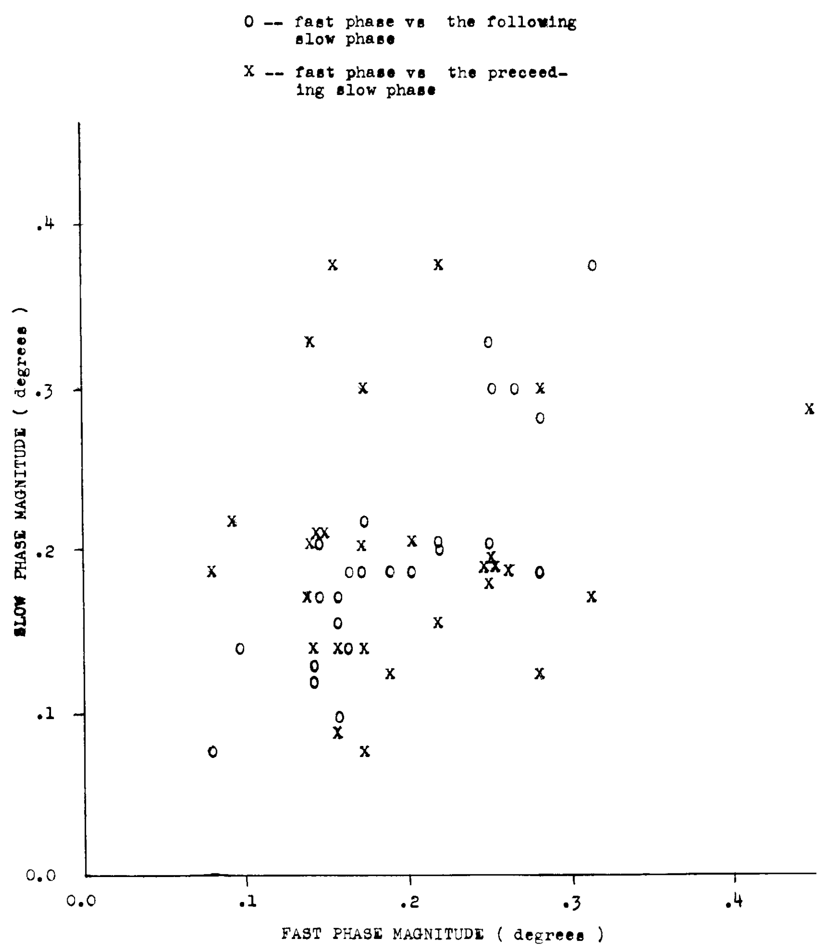


Fig. XVIII-10. Scattergrams for two correlations of slow and fast phases.

correcting retinal error introduced by the preceding slow drift induced by the stripe movement.

4. Smooth Pursuit and Optokinetic Nystagmus Summation

In Quarterly Progress Report No. 70 (pages 357-359), an experiment was described in which two sets of stripes moving in opposite directions were presented simultaneously to the subject. The response was not the summated response to each optokinetic nystagmus input, but rather alternate responses to each set of stripes. This experiment was repeated with two sets of stripes, one directed into each eye. The response was identical to that obtained in the first experiment with both sets into both eyes. Summated responses to 2 optokinetic nystagmus inputs were never demonstrated. Similarly, it is doubtful that one can produce summated responses to 2 tracking inputs (eliminating fusional convergence) — either with 2 tracking inputs into one eye or one into each eye.

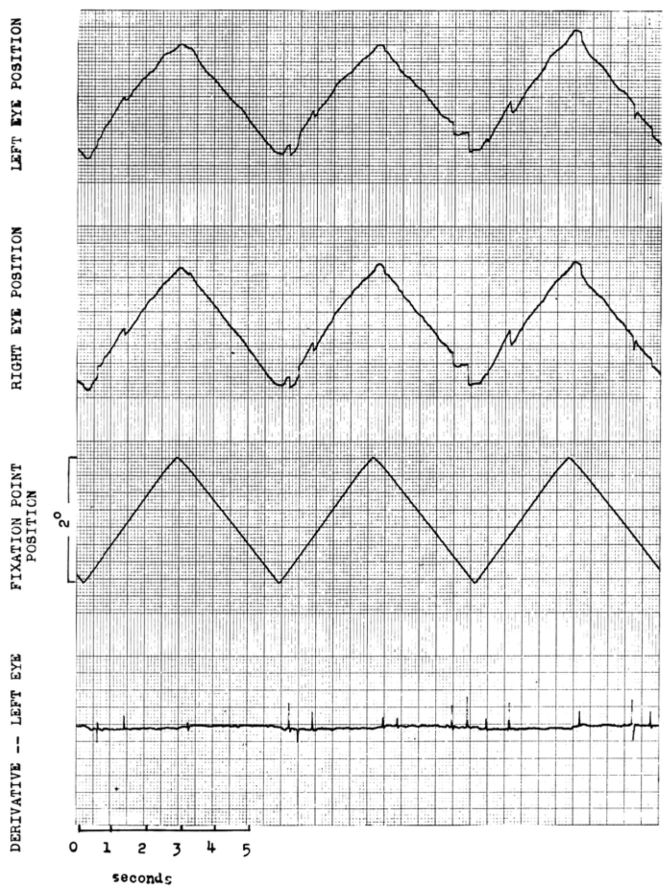


Fig. XVIII-11. Simple tracking.

Figure XVIII-10 shows the fixated optokinetic nystagmus response. If we turn off the stripes and drive the fixation point with a triangular wave input, we obtain the ordinary smooth tracking response to the tracking input as shown in Fig. XVIII-11. When the stripes are turned on and the fixation point driven as before, we obtain a quantitative adding of the fixated optokinetic nystagmus response (as in Fig. XVIII-9) and the tracking response (as in Fig. XVIII-11). This summated response is shown in Fig. XVIII-12.

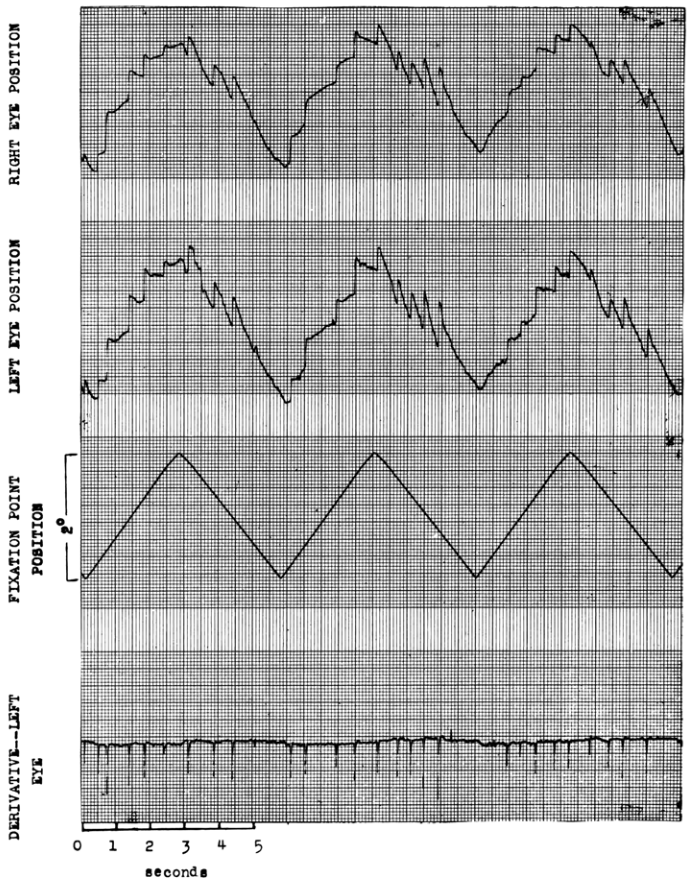


Fig. XVIII-12. Tracking with optokinetic nystagmus.

The velocity of tracking in Fig. XVIII-11 is ±0.76°/sec. The average velocity for the smooth movements on the left half of the middle cycle in Fig. XVIII-12 is +0.19°/sec. The average velocity for the smooth movements in the right half of that cycle is +1.76°/sec. The difference between the tracking velocity in Fig. XVIII-11 and the smooth velocities in Fig. XVIII-12 is +0.93°/sec and +1.02°/sec for the left and right halves of the cycle, respectively. These two velocities correspond to the smooth velocities of the fixated optokinetic nystagmus response, which vary between 0.5°/sec and 1.00°/sec. The mean smooth velocity in Fig. XVIII-9 is 0.67°/sec.

Thus we see that a tracking input plus an optokinetic nystagmus input result in an additive response to both. This result, plus the exclusion of the foveal region in optokinetic nystagmus leads us to the conclusion that the smooth phase of optokinetic nystagmus is not smooth tracking. This view is in line with the weak dependence of the smooth phase velocity on the stripe velocity.[1]

E. G. Merrill, L. Stark

References

1. G. P. Nelson and L. Stark, Optokinetic nystagmus in man, Quarterly Progress Report No. 66, Research Laboratory of Electronics, M.I.T., July 15, 1962, pp. 366-369.

2. G. P. Nelson, L. Stark, and L. R. Young, Phototube glasses for measuring eye movements, Quarterly Progress Report No. 67, Research Laboratory of Electronics, M.I.T., October 15, 1962, pp. 214-216.

F. ELECTROCARDIOGRAM CLASSIFICATION

The goal of our electrocardiogram (EKG) work is to establish an on-line computer facility for automatic diagnosis of heart disease by EKG classification. At present, we have several operational IBM 7090 computer programs for transforming and classifying digitalized EKG. The most important of these is a waveform classification routine that utilizes a template matching scheme. The templates may be preset by the programmer or may be allowed to self-organize by operating on a long history of data.

At present, we are involved in integrating all of our programs and hardware into a complete usable system. This involves

(i) Setting up our operational IBM 7090 computer routines for use with the teletype facility of the Time-Sharing System (CTSS) of the Computation Center, M.I.T.

(ii) Putting input-output terminals on our G.E. 225 computer for teletype (TTP) communication with CTSS and an EKG system control console. The G.E. 225 computer

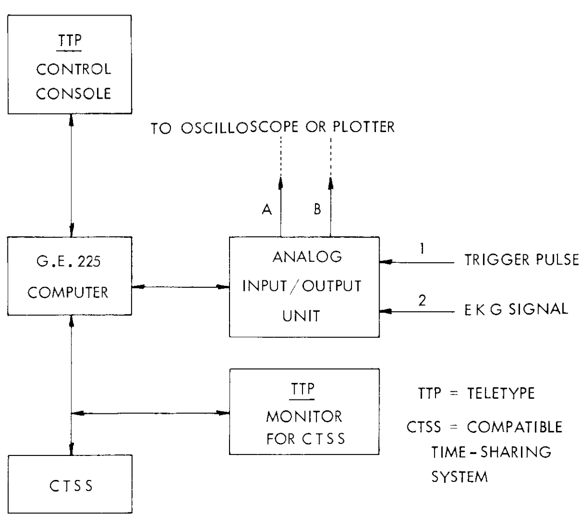


Fig. XVIII-13. System configuration.

will be used for system control, displays, and digitalization and preprocessing of EKG data. The layout is shown in Fig. XVIII-13.

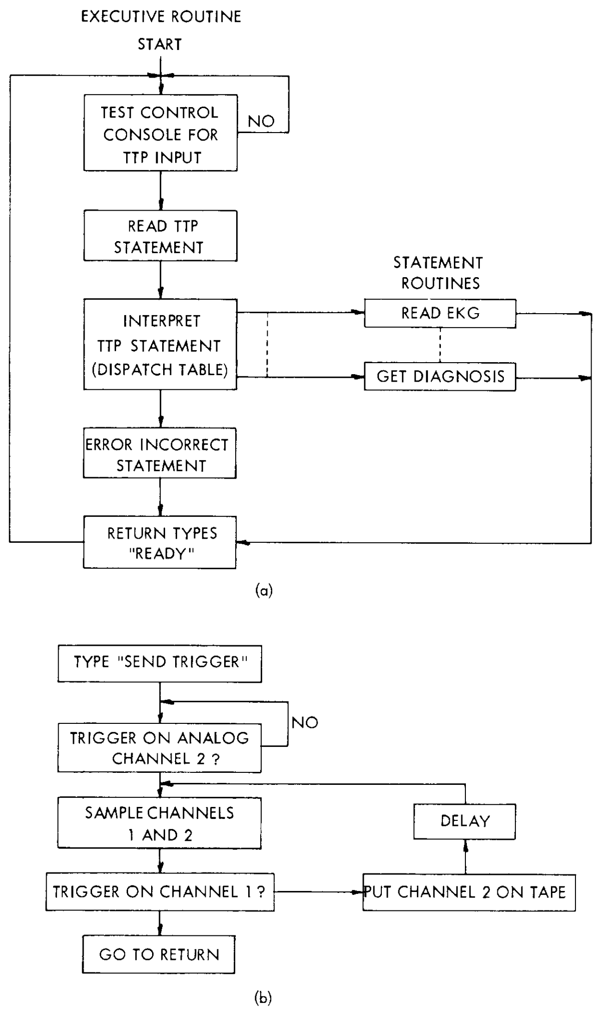


Fig. XVIII-14. (a) Tentative G. E. 225 computer control arrangement. (b) Typical statement routine (READ EKG).

(iii) Logical design of the over-all system, which involves specifying the sequence of operations and flow-charting needed programs. A tentative system arrangement is shown in Fig. XVIII-14.

I. Sobel, O. Sanchez-Felipe

References

1. L. Stark, M. Okajima, and G. Whipple, Computer recognition techniques: Electrocardiographic diagnosis, Commun. Assoc. Computing Machinery 5, 527-532 (1962).

G. ACCOMMODATION TRACKING

In earlier experiments Stark and Takahashi[1] found that in accommodation tracking approximately 50 per cent errors are made, if one ensures that no clues are present, such as change in size of the target, change in illumination of the target or slight lateral movements of the target. These results indicate that in a first-order approximation the accommodation system operates on an even-error signal.

A disadvantage of their experiments is that when the target became blurred on moving away from the subject, the subject could respond only by bringing the target back or by moving it still farther away by means of a hand-operated potentiometer. In this way the subject had to make a conscious decision as to how to move his hand. In an attempt to improve this experiment we used accommodative convergence as a way to measure the direction in which accommodation changes.

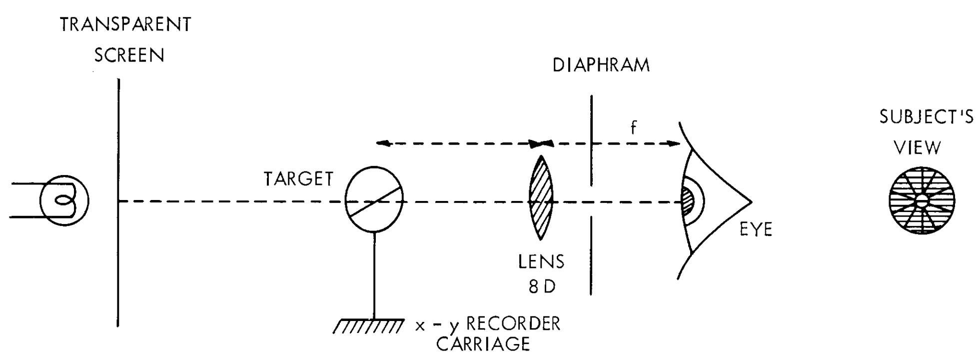


Fig. XVIII-15. Experimental arrangement.

The experimental arrangement is shown in Fig. XVIII-15. The subject's head is fixed behind the apparatus by means of a biteboard.

The plane of the pupil is in the second principal focal plane of the apparatus lens. In this situation the angular size of the target does not change, and at the same time there is a very simple and linear relationship between the target distance θ (in cm) in front of the apparatus lens and the target-image distance (in diopters) in front of the eye. This relation can be written in general as

$$a = \frac{100(f-\theta)}{\theta(f-x) + fx},$$

where a is the distance of target image in front of the eye (in diopters), x is the distance between the apparatus lens and the aperture or pupil plane of the eye (in cm), and f is the focal length of the lens (in cm). In this particular situation $f = x = 8$ cm, hence

$$a = 12.5 - 1.56 \times \theta.$$

This means that equal changes in centimeters of the target distance θ in front of the lens cause equal changes in diopter of the accommodation stimulus and thus equal changes in blur on the retina.

The direction of the accommodative convergence is found by measuring the movement of the left eye.

A far or near step is presented to the subject from a neutral position, the direction of the step being determined from a table of random binary numbers.

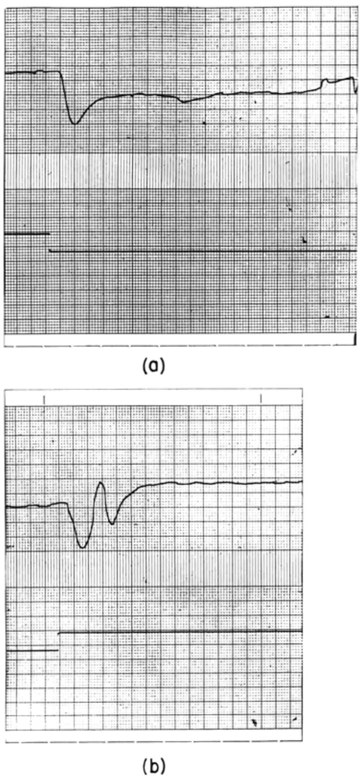


Fig. XVIII-16. (a) Correct response to far step. (b) False response to near step. Note the oscillations in the accommodation convergence before the correct accommodation is found. Subject reported a similar oscillation in his blurred vision.

At present, the experimental results are inconclusive. Sometimes the subject makes approximately 50 per cent errors in a run of 100 trials. More often this percentage is down to approximately 10-20. Sometimes, all errors are made in the same direction. In all situations the subject is not aware of any conscious stimulus for his accommodation. As an example, some recordings are shown in Fig. XVIII-16.

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References

1. L. Stark and Y. Takahashi, Accommodation tracking, Quarterly Progress Report No. 67, Research Laboratory of Electronics, M.I.T., October 15, 1962, pp. 205-212.