XXV. NEUROLOGY*

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RESEARCH OBJECTIVES

The aim of our work is to apply the concept of communication and control theory to our analyses of neurological and biological mechanisms. The group is composed of neurologists, mathematicians, and electrical engineers. Our research endeavors to span a wide field that includes experiments on human control mechanisms, mathematical methods for analysis of nonlinear systems, including simulation, clinical studies with on-line digital-computer techniques employed, neurophsiology of simple invertebrate receptors, and adaptive pattern-recognition techniques with the use of computers.

L. Stark

A. WORK COMPLETED

Short summaries follow of theses accepted by the departments, and in partial fulfillment of the requirements for the degrees, indicated.

1. A Sampled Data Model for Eye-Tracking Movements, Sc.D. Thesis, Department of Aeronautics and Astronautics, M.I.T., May 1962.

A sampled-data model has been developed, based on the following principles: 1) the predictability of the target signal has a profound effect on the system's ability of track continuous and discontinuous target motion; 2) the saccadic and pursuit systems function separately; and 3) the eye-movement tracking characteristics are of a discrete nature.

L. R. Young

2. A Convenient Eye Position and Pupil Size Meter, S.M. Thesis, Department of Electrical Engineering, M.I.T., June 1962.

A specialized television system, in which a technique of circular track scanning is employed, takes continuous readings of eye pupil size and position. The ac components of scanning deflection signals are proportional to the eye pupil diameter, and the dc components are proportional to the coordinates of eye pupil position.

C. A. Finnila

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3. The Design and Construction of a Motor Coordination Testing Servomechanism, Department of Electrical Engineering, M.I.T., June 1962.

An instrument consisting of two electrically identical dc servomechanisms with concentric output shafts was designed to test the dynamic behavior of human motor coordination in the lower arm and wrist.

G. L. Gottlieb

4. Effects of Alcohol and Barbiturates on Rotational Mechanical Responses, S.B. Thesis, Department of Electrical Engineering, M.I.T., June 1962.

The effect of alcohol and barbiturates on the response of subjects following a light spot with a pointer was found to depend on the frequency at which the input light moved on the screen.

W. G. Henrikson

5. Head-Position Indicator, S.B. Thesis, Department of Electrical Engineering, M.I.T., June 1962.

A gyroscope-demodular system was used to indicate head position, so that the place where a subject looks in a given situation can be determined.

H. R. Howland

6. Computer Analysis of Handwriting Applied to Cancer Detection, S.B. Thesis, Department of Electrical Engineering, M.I.T., June 1962.

The Kaufer Neuromuscular Test was programmed on the TX-0 computer, the results analyzed, and improvements suggested.

R. G. Kurkjian

7. A Semiconductor Regulated DC Power Supply, S.B. Thesis, Department of Electrical Engineering, M.I.T., June 1962.

An efficient power supply for application to a servomechanism system is obtained by cascading a transistorized filter and a transistor dc regulator.

K. D. Labaugh

8. A Measuring Device for the Tremor of the Human Finger, S.B. Thesis, Department of Electrical Engineering, M.I.T., June 1962.

With a transducer that employs the change in capacitance of two plates, caused by varying the distance between them, a signal can be detected which indicates finger tremor.

G. Segal

9. The Pupil Light Reflex in the Owl, S.B. Thesis, Department of Biology, M.I.T., May 1962.

The pupil reflex of an owl to light was found to contain nonlinearities that contribute to the variability of the gain results.

G. H. Northrop

10. Linear Light Source for Eye Stimulation, Department of Electrical Engineering, M.I.T., June 1962.

A television screen is used as a light source to stimulate the eye, and thus enable one to observe the pupil under various stimulation conditions.

G. Sever

11. The Effects of Drugs on the Transfer Function of the Human Pupil System, Department of Biology, M.I.T., May 1962.

Using physostignine and hydroxyamphetamine hydrobromide together, we found that the minimum phase lag was increased, and the gain of the transfer function decreased.

J. W. Stark

12. Effect of Operating Conditions on Noise in Human Pupil Servomechanism, S.B. Thesis, Department of Electrical Engineering, M.I.T., June 1962.

The mean-square value of noise was found to be a monotonically increasing function of light intensity: the noise has stationary components from 0.08 cps to 2 cps, and the spectrum contained a relative maximum at 15 cycles per minute which corresponded to the respiration rate.

B. P. Tunstall

13. Transient Adaptation in the Human Pupil Servomechanism, S.B. Thesis, Department of Biology, M.I.T., June 1962.

The rapid rise in visual threshold is concomitant, but not simultaneous, with a rapid rise in pupil response when the steady light input to the pupil is decreased.

W. M. Zapol

B. EYE CONVERGENCE

An apparatus similar to that described by Rashbass and Westheimer[1] (Fig. XXV-1) has been used to present a convergence-divergence stimulus to human subjects.

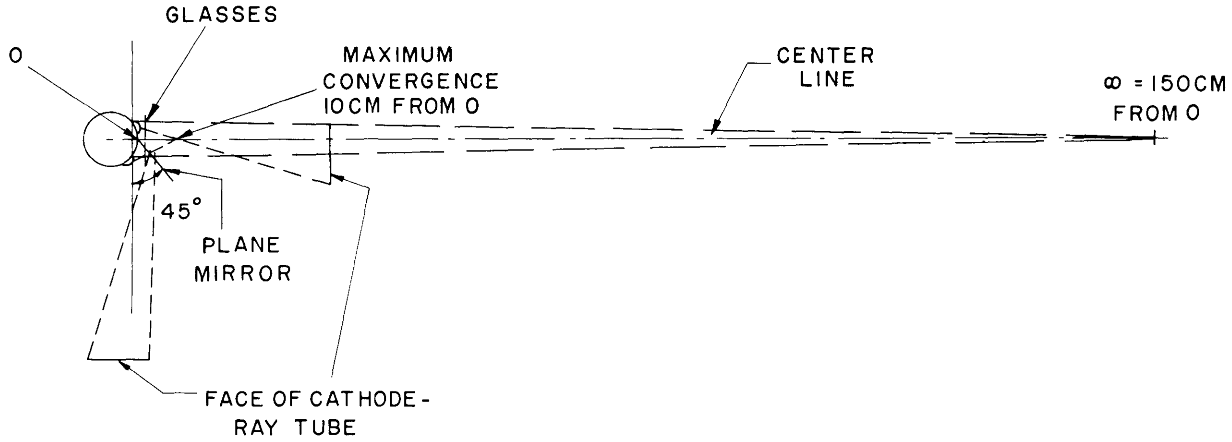


Fig. XXV-1. Eye-convergence apparatus.

The electrical apparatus used is shown in Fig. XXV-2. Eye movements are recorded from photocells mounted on eyeglass frames.[2] The variable measured thus far, the angle of convergence-divergence (α_r), is defined as the angle between the line of sight when the eye is focused at infinity and the line passing through the target and the center of the eye. Calibration of eye movements (Fig. XXV-3) is accomplished by having the subject focus on a light appearing at infinity and then on a light that is a known distance from the first. Thus a known α_r is subtended. Subjects have been presented with sinusoidal and step stimuli. Records of stimuli and responses appear in Fig. XXV-3. Future investigations will include closed-loop predictable and unpredictable frequency responses with single and

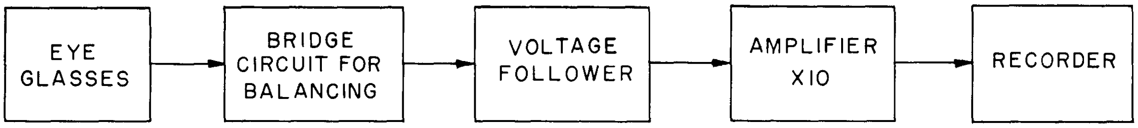


Fig. XXV-2. Electrical circuit for eye-convergence apparatus.

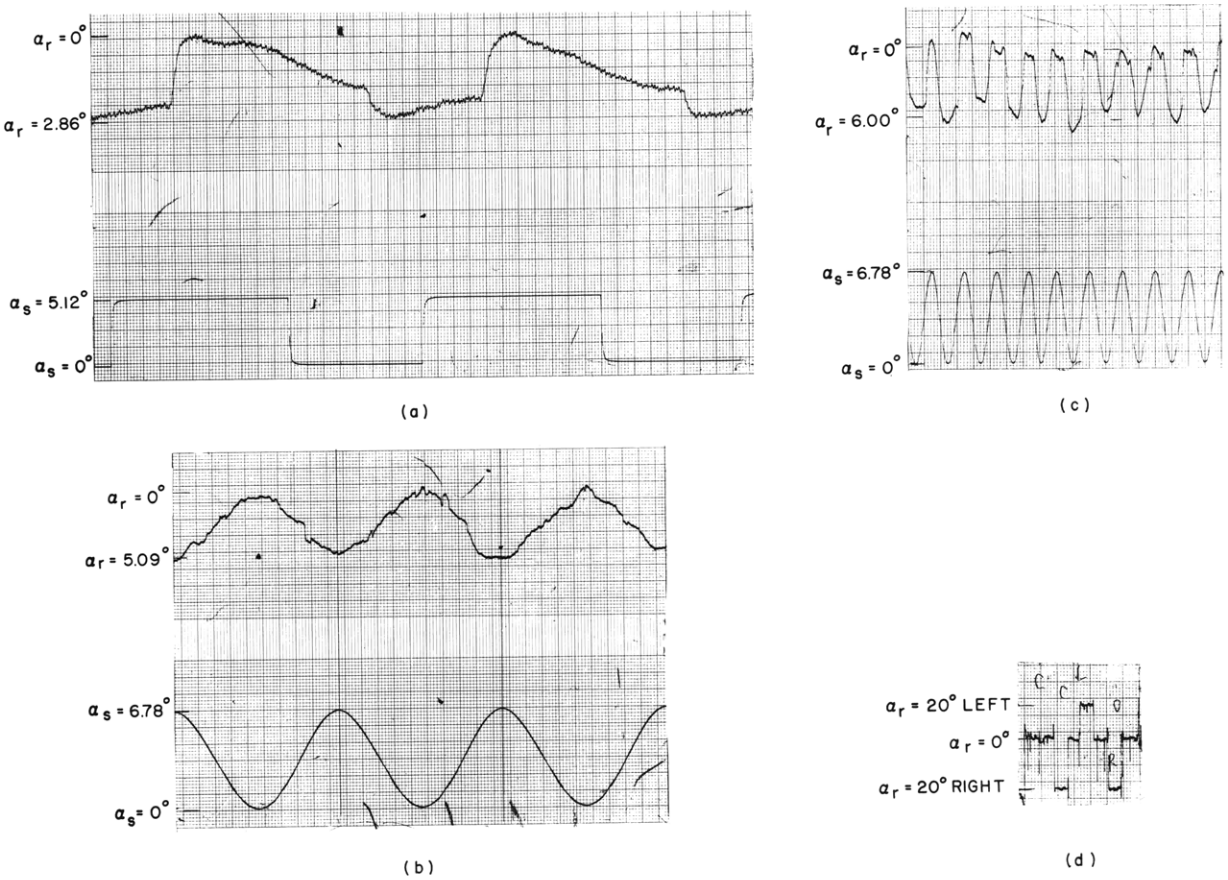


Fig. XXV-3. (a) Step response, f = 1.0 cps.
(b) Sinusoidal response, f = 0.1 cps.
(c) Sinusoidal response, f = 1.0 cps.
(d) Typical calibration, α_s = stimulus angle; α_r = response angle (average value shown).

mixed computer-produced sinusoidal stimuli used. Finally, the dynamics of the system when the feedback loop has been opened will be investigated.

B. L. Zuber, L. Stark

References

1. C. Rashbass and G. Westheimer, Disjunctive eye movements, J. Physiol. 159, 339-360 (1961).

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.

C. PUPILLARY NOISE

In an attempt to discover possible sources of pupillary unrest (noise), a crosscorrelation program has been written for the GE 225 computer. With the aid of this program

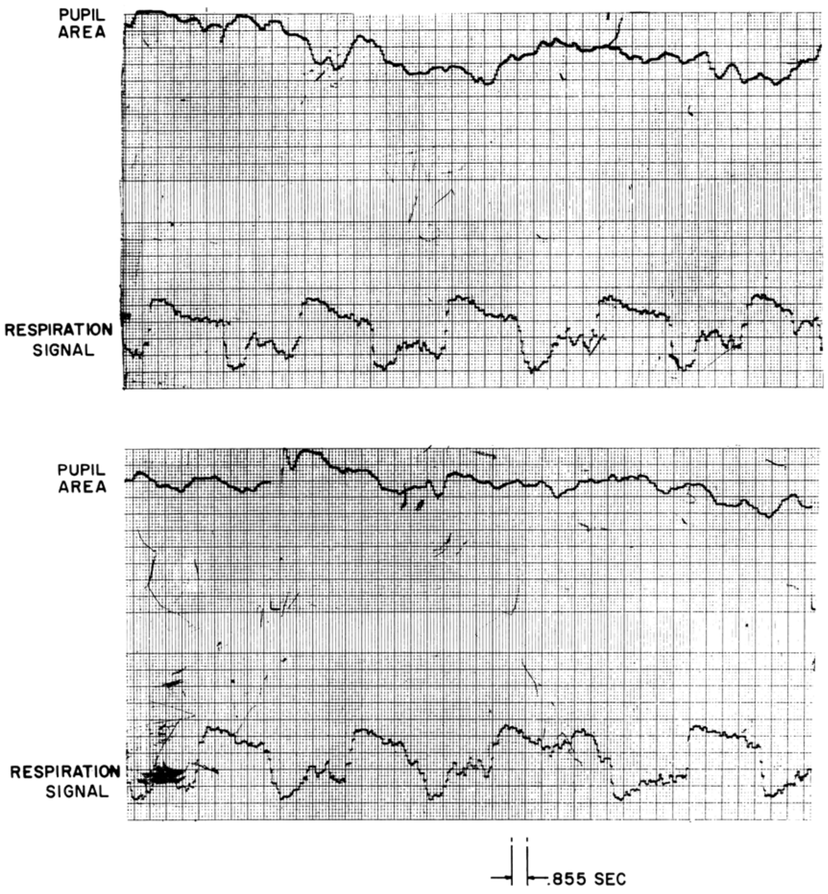


Fig. XXV-4. Digitalized records of pupil area and respiration signal.

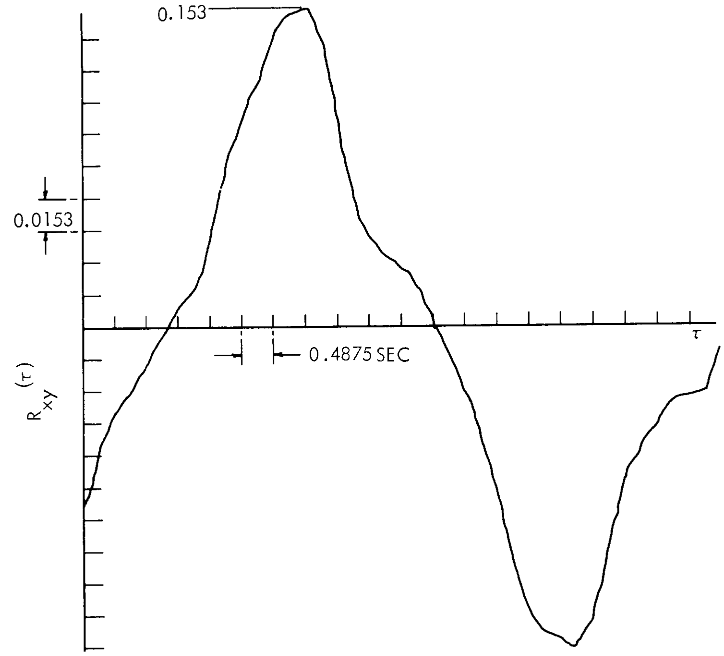


Fig. XXV-5. Crosscorrelation between pupil noise and respiration.

pupil noise can be compared with other biological signals to determine whether or not correlation exists.

As a first attempt, the pupil noise was crosscorrelated with a respiration signal. This respiration signal was obtained from a device that consisted of a thermistor (Fenwal Type BC32L1) placed inside a hollow plastic tube, which, in turn, was inserted into the nostril of the subject. As the subject inhaled and exhaled, the temperature in the environment of the thermistor changed and thus the resistance of the thermistor changed. The thermistor was used as one arm of a resistance bridge, and the signal obtained indicated, in some sense, the respiration of the subject.

The respiration was crosscorrelated with the pupil area under constant illumination conditions. Three cases were tried: (a) slow breathing, (b) regular breathing, and (c) fast breathing.

Figure XXV-4 shows a typical area and respiration signal for the slow-breathing case after digitalization, and Fig. XXV-5 shows its crosscorrelation function. The crosscorrelation function is

$$R_{xy}(\tau) = \frac{\overline{(\overline{x}(t)-\overline{x})(y(t+\tau)-\overline{y})}}{\overline{\sigma_x \sigma_y}}$$

Here, the bar denotes time average, x is the pupil area, y is the respiration signal, $\overline{x}$ and $\overline{y}$ are the respective time-average values, and σ_x and σ_y are the respective rms values of the signal. We see from Fig. XXV-5 that the correlation peak goes as high as 15 per cent. For regular breathing the correlation peak was approximately 11 per cent, and for fast breathing a peak of approximately 2 per cent was obtained.

No definite conclusions will be drawn now, due to the fact that the experiment was performed only once, and there is the possibility of head movement during breathing, which could add correlation.

S. F. Stanten, L. Stark

D. EYE-MOVEMENT EXPERIMENTATION

Equipment for our eye-movement experiment has been set up at the Massachusetts Eye and Ear Infirmary of the Massachusetts General Hospital. It is very similar to the experimental arrangement used for the study of the effect of pharmacological agents on

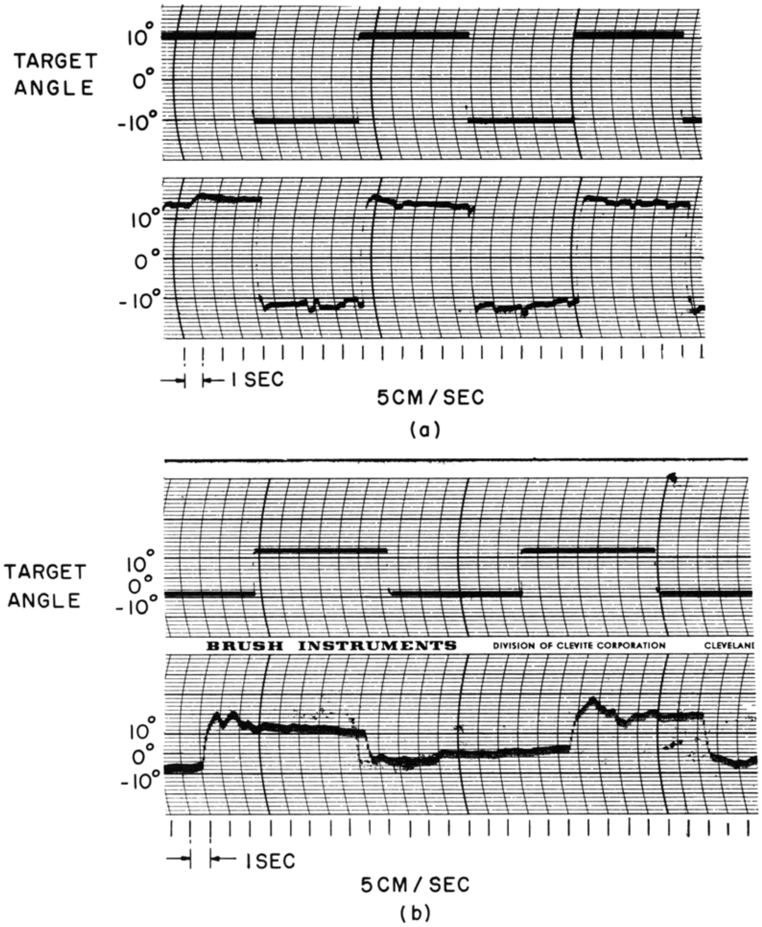


Fig. XXV-6. Response to step changes in target angle recorded from (a) normal subject, and (b) young child with possible brain tumor.

control of eye movements.[1] We are studying patients with various eye-movement disorders who sit with head fixed in a "catcher's" mask. They wear a pair of photocell goggles that measure eye movement as a moving spot of light on an oscilloscope screen is tracked.

The patient performs a varied set of tasks: (a) directed gaze in darkness — lateral and forward; (b) compensatory movements to passive head rotation; (c) directed gaze at fixation point; and (d) conjugate eye movements following moving targets of steps, constant velocity, constant acceleration, and sinusoids. These are designed to measure certain types of eye movements — saccades, pursuit, fixation, stability, and nystagmus.

Figure XXV-6a shows the response of a normal subject to step changes in target angle. Note the rapid response without much overshoot. Figure XXV-6b shows the response of a young child with a possible brain tumor. His record shows considerable oscillatory overshoot that was not seen in ordinary clinical examination.

Gabriella W. Smith, D. G. Cogan, L. Stark

(Dr. D. G. Cogan is Chief of Ophthalmology, Massachusetts Eye and Ear Infirmary.)

References

1. H. T. Hermann, G. P. Nelson, L. Stark, and L. R. Young, Effect of pharmacological agents on control of eye movements, Quarterly Progress Report No. 67, Research Laboratory of Electronics, M.I.T., October 15, 1962, pp. 231-232.

E. MODEL OF PUPIL REFLEX TO LIGHT

Work continues in an attempt to refine our model of the human pupillary response to light. Extensive use has been made of the GE 225 computer as an integral part of a hybrid analog-digital pupil model, and to obtain reliable results by the use of on-line averaging of experimental data.

From Fig. XXV-7, and from previous work[1, 2] it is apparent that some form of scale compression is present early in the signal processing by the system. Figure XXV-8 illustrates the existence of a nonlinearity with memory.[1] Note the small effect of the pulsewidth on the height of the response.

The model presented previously is shown in Fig. XXV-9. The revised model shown in Fig. XXV-10 differs from the previous model in the following respects.

(i) A logarithmic scale-compression factor has been added, the results of which are shown in Fig. XXV-11.

(ii) An extra and faster time constant has been added to the transfer function of $\overline{I}$. This addition will aid in reducing the effect on response height of pulsewidths from 10 msec to 2 seconds. However, this addition decreases the dependence of time to peak on the pulsewidth in contradiction with experimental results.

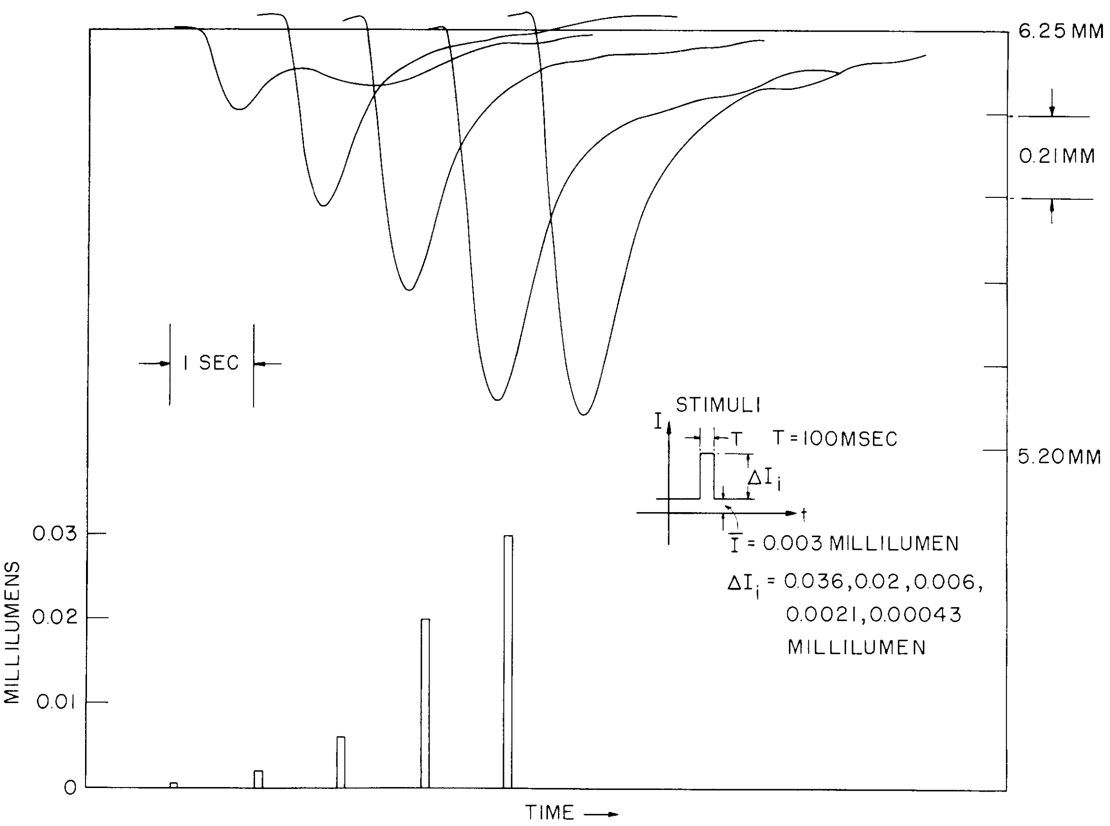


Fig. XXV-7. Pupil response to light pulses of different heights.

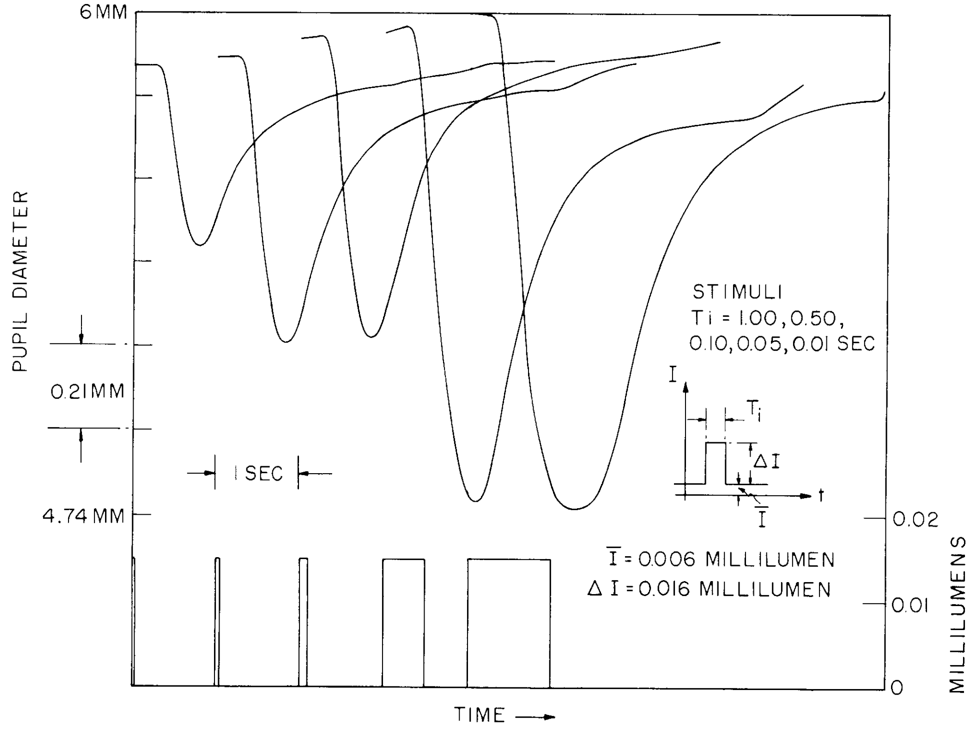


Fig. XXV-8. Average response of pupil to light pulses of decreasing width.

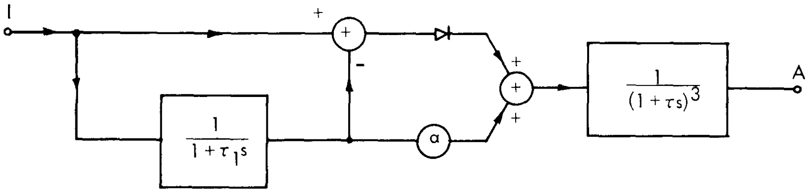
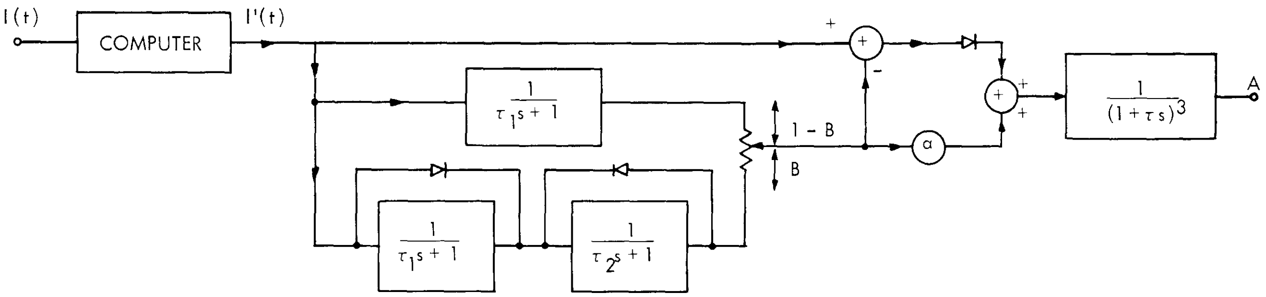


Fig. XXV-9. Old pupil model. $\tau_1 \approx 1.5$ sec; $\tau \approx 0.15$ sec; $\alpha = 0.1$.



$I'(t) = LOG_2\ [K\ I(t-T)+1]$

$K=6,\ \tau_1=1.5$ SEC, $\tau_2=0.2,\ \tau=0.2$ SEC

$\alpha=0.05,\ \beta=0.8,\ T=0.2$ SEC

Fig. XXV-10. New pupil model.

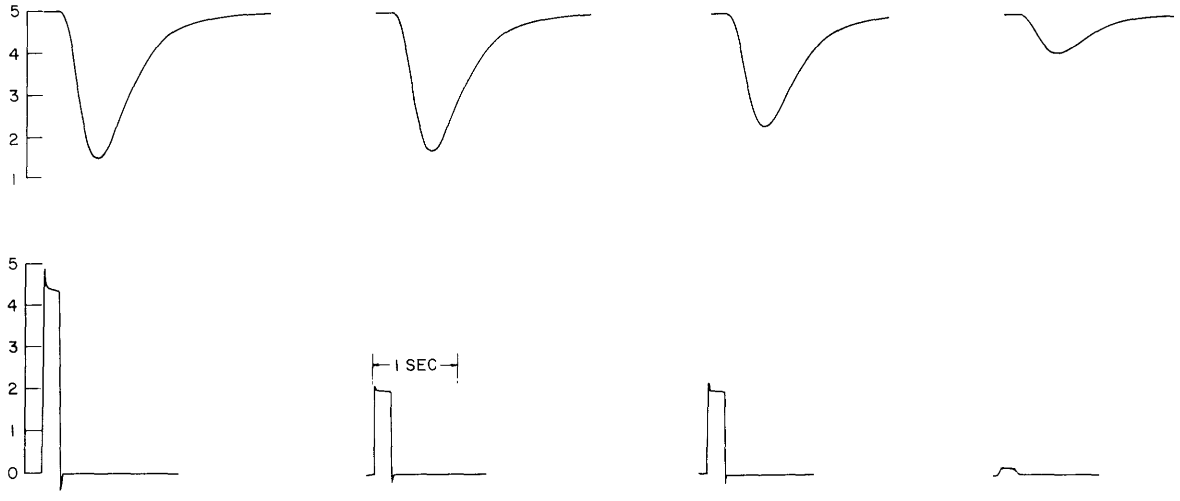


Fig. XXV-11. Response (top) of pupil model to positive pulses (bottom) of greatly varying amplitude. Note scale compression of log function. (Overshoot of the simulated stimuli is due to X-Y recorder inertia.)

(iii) The lower diodes have been introduced to make the recently introduced rapid light adaptation ineffective during dark adaptation.

A. A. Sandberg, L. Stark

References

1. L. Stark, Julia H. Redhead, and H. Van der Tweel, Pulse response of the pupil, Acta Physiol. Pharmacol. Neerl. (in press).

2. F. H. Baker, Pupil response to short-duration pulses, Quarterly Progress Report No. 65, Research Laboratory of Electronics, M.I.T., April 15, 1962, pp. 251-257.

F. HUMAN PREDICTION OF FILTERED RANDOM SEQUENCES

An experiment has been designed to investigate a human subject's strategy in predicting successive numbers in a nonindependent sequence of random numbers. The experiment is implemented in the form of a digital-computer program that interacts with the subject and the experimenter by means of typewriters. This program has been written and checked out, and the first carefully controlled experiments are now in progress.

The subject is presented with a sequence of positive and negative decimal integers, which are formed by taking a weighted sum of (a) a number obtained by an independent sampling of a uniform distribution of zero mean and (b) a linear combination of previous numbers in the output sequence.

After each number is presented, the subject is asked to predict what the next number in the sequence will be. It is apparent, and, indeed, can be proved, that he may minimize his mean-square error by setting his prediction just equal to the quantity (b) above. This is then his "optimum policy."

Figure XXV-12 gives a block diagram of the experimental configuration. The quantities shown have the following meanings:

R	Random-number generator
Fi	Filter
D_1	Delay of one discrete time unit
S	Subject
E	Experimenter
i	Discrete time variable
X(i)	Independent sample from a uniform distribution
Y(i)	Constrained random number
Q(i)	Subject's optimum prediction for Y(i)
Y(i-1)	The number presented to the subject just before he gives P(i)

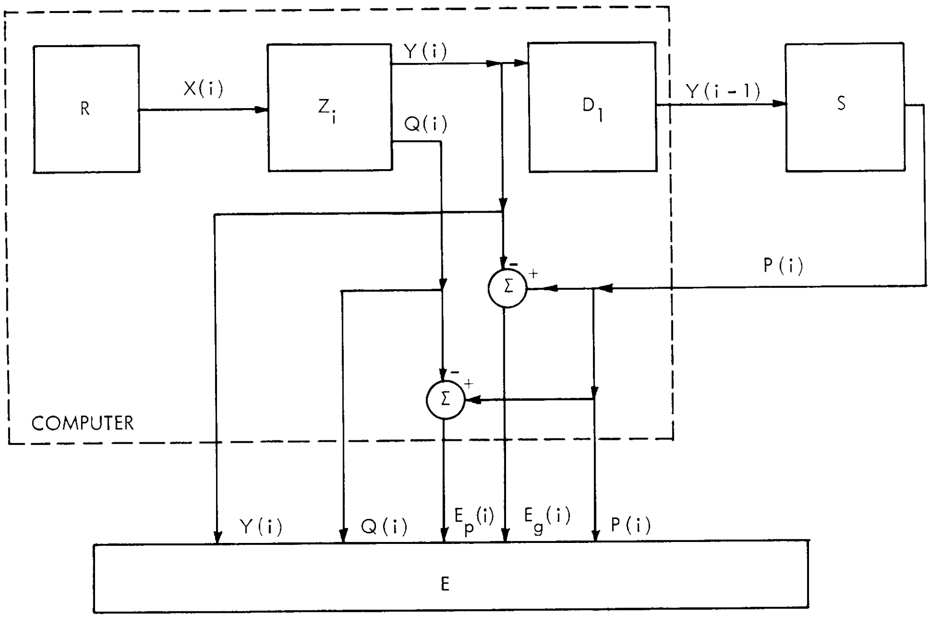


Fig. XXV-12. Experimental configuration.

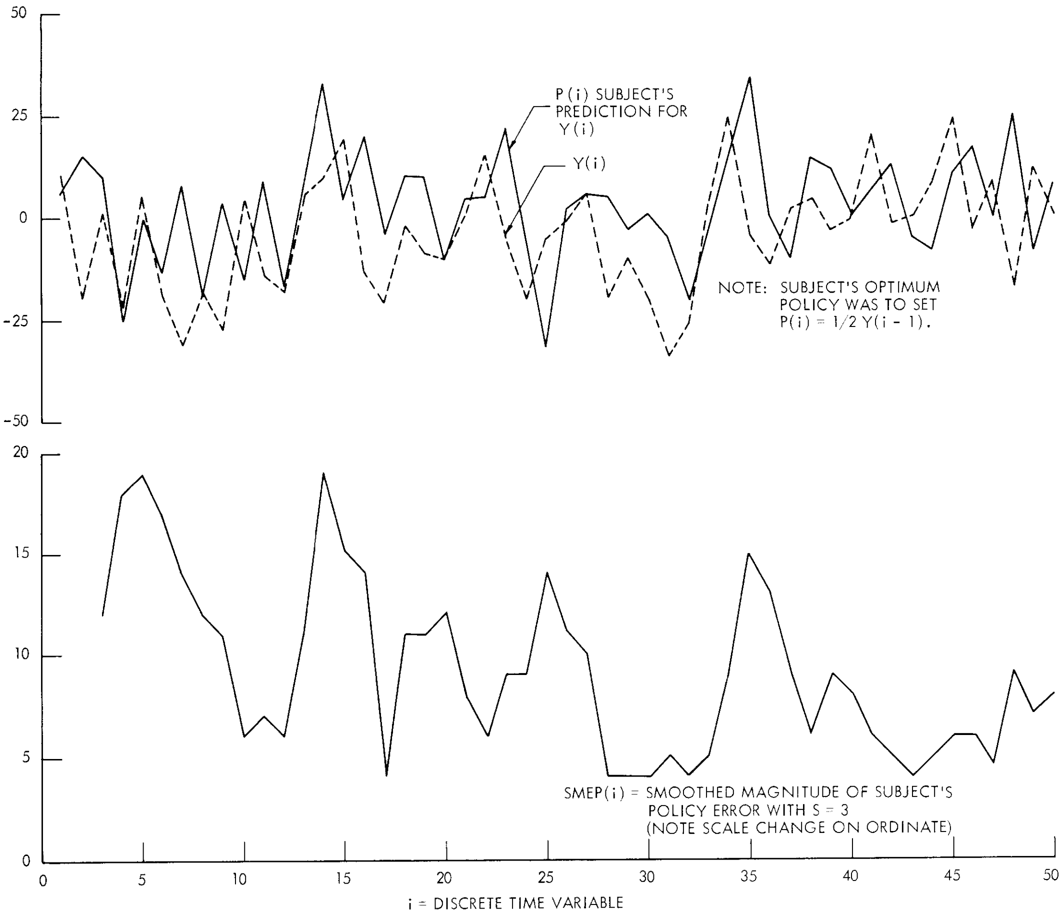


Fig. XXV-13. Results of one human prediction experiment.

$P(i)$	Subject's prediction for $Y(i)$
$Eg(i)$	Subject's guess error $(=P(i)-Y(i))$
$Ep(i)$	Subject's policy error $(=P(i)-Q(i))$.

Another quantity that is not shown in Fig. XXV-11 and is also calculated by the computer is

$$SMEP(i) = \frac{1}{S} \sum_{j=1}^{S} \left| Ep(i-j) \right| .$$

Here, SMEP stands for "smoothed magnitude of policy error." We have found it convenient to set $S = 3$ for most of our experiments.

Figure XXV-13 is a graph of $P(i)$, $Y(i)$, and $SMEP(i)$ (with $S=3$) plotted against i for a representative sum of 50 predictions.

The hypothesis has been set forth that the subject will gradually learn to behave well with respect to the optimum policy, but that the random character of the Y's will cause him to eventually become dissatisfied with his performance. He will then make a drastic change in his policy, which, of course, will cause his policy error to increase in magnitude. He will then gradually return to the optimum policy, only to become dissatisfied again later on. Our experimentation has not progressed far enough to enable us to confirm or deny this hypothesis.

E. C. Van Horn, Jr., L. Stark