A. ACCOMMODATION TRACKING

Accommodation is most often seen in association with convergence, and it is well known that a variety of clues, particularly binocular fusion, drives convergence. Is there a monocular accommodation reflex, and if so, what is its stimulus? It is important to try to understand such a physiological error mechanism—a widely distributed, unlearned, involuntary mechanism present in restricted monocular viewing without complex perceptual clues—which might drive the lens control system. It is also of interest to understand the mechanism for sensing not only the magnitude of the error signal but its directional sense because blur is rather similar in both directions of error.

Several suggestions, with rather incomplete experimental evidence to support them, have been put forward. These include astigmatic asymmetry and spherical aberration,\(^1\) chromatic aberration and the Stiles-Crawford effect, secondary to small fixation movements (monocular parallax).\(^2\) There is also a trial-and-error mechanism in the 2-cps oscillation of the lens which could act as a phase-sensitive detector.\(^3\)

1. Experiment

The experimental arrangement used in our tracking experiment is described in Fig. XVII-1, which is essentially the same as Campbell and Westheimer’s.\(^1\) The subject looks at a target through a convergent lens \(L_2\) that is placed so that its second principal focal plane is at the plane of the pupil of the subject (second principal focal plane method). This geometrical disposition eliminates the dependence of the size of the target on its position. The luminance of the target is also kept unchanged by means of lens \(L_1\) that collimates the illuminating light beam. The subject’s eye is instilled with 1 per cent homatropine, which paralyzes the ciliary muscle; thus he can see the target clearly only when its distance from the eye is at a certain value. (We have carried out experiments both for drugged and undrugged subjects.) The target is moved back and forth by successive steps of various amplitudes (measured in diopters) of either positive or negative spherical aberration.

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negative sign which are chosen with equal probability but quite randomly. As the target moves from the original position of clear vision, the subject is told to bring the target back into focus by turning the knob of a potentiometer. The target position is servo-controlled so that it is proportional to the sum of the random-step input and the potentiometer output.

The random-step input and the voltage of the potentiometer are recorded on a Sanborn pen recorder. An example of such a recording is shown in Fig. XVII-2.

Campbell and Westheimer studied the initial direction in which the subject moved the target in tracking to determine whether or not a directionally sensitive error detector is present in the subject's lens control system. They tried this tracking experiment for four subjects and reported that all of them could track the target movement correctly after a few trials under normal conditions. One subject experienced difficulty when monochromatic light was used, but soon learned to overcome this and thereafter tracked without error. When spherical aberration is removed by means of an annular pupil, Campbell and Westheimer's four subjects were "not always correct" in their tracking task. This error followed completely correct tracking with a normal pupil, perhaps after some learning. Fincham, however, showed no effect of an annular pupil.

Our experimental evidence indicates that even with a normal pupil, no error-free initial tracking or learning of tracking occurs. We feel that the main difference between
Campbell and Westheimer's and our results is that we controlled the randomness of the target more carefully.

2. Experimental Findings

Figure XVII-3 shows one of the results of our experiment. The number of failed initial-tracking moves in each successive 10 trials is plotted against the number of succeeding sets of 10 trials. There is no obvious decreasing initial-error tendency, in contrast with the almost perfect responses mentioned by Campbell and Westheimer.

We have performed the experiment for several subjects with their eyes either homatropinized or not. Fixing the subject's eye lens by the drug does not always seem to be necessary as long as the subject turns the potentiometer quickly after target moves.
Fig. XVII-3. Number of erroneous initial tracking attempts (ordinate) in successive 10 trials vs sequence of sets of 10 trials (abscissa).

Fig. XVII-4. Probability density of successive correct trackings. (a) Data obtained for the first 100 trials. (b) Data for last 100 trials of 290 trials. The solid line is the theoretical probability distribution for purely random events.
because the time required for the subject to decide which way he should turn the potentiometer is obviously much shorter than the time lag of accommodation. As a matter of fact, the results are not very different in either case.

Quantitatively, to confirm the randomness of our results, the distribution of the number of intervals between successive failed trackings was investigated. Figure XVII-4 shows the distributions obtained for the first and the last hundred trials in a total of 290 trials. It is clear that there is no significant difference between the two distributions.

By assuming that the occurrence of false tracking is random (Poisson distribution) and that its average occurrence is \( a \), the probability that the time interval between two successive occurrences of the false tracking is \( T \) is given by

\[
P(T) = ae^{-aT}.
\]

The straight lines in Fig. XVII-4 represent this equation. The coincidence of the data to this line suggests that the tracking occurred randomly.

Three necessary features in the control of the experimental stimulus condition must be stressed. First, the size and intensity of the target should be constant as it is moved nearer and farther away. This can be accomplished by placing a second principal focus of the target image at the plane of the pupil. Second, lateral movement of the target will occur if any of the optics are slightly off axis. The target will move in opposite lateral directions with near and far movement. As soon as this happens, a subject may

![Graph](image-url)

**Fig. XVII-5.** Number of erroneous initial tracking in successive 10 trials vs sequence of set of 10 trials. After 160 trials the subject apparently noticed either lateral movement or size change resulting from imperfect arrangement of optics. Ordinate and abscissa scales same as in Fig. XVII-3.
quickly learn to appreciate this clue and to track a random target correctly. The experiments shown in Fig. XVII-5 furnish an example. In the seventeenth group of 10 trials, the subject evidently quickly learned to track correctly, and on inquiry was about to point out a lateral movement present as a clue. Different published experiments may be judged on the following basis: the least demonstrated ability to track a random target should be the most accurate and carefully controlled experiment, since any error in apparatus will provide unwanted clues. The third important factor of control is the randomness of input step changes of target position.

3. Discussion

Astigmatic affects can certainly be used as clues for voluntary accommodative tracking. In addition to a usual asymmetrical blur that is due to common astigmatic faults in most persons’ lenses, these effects can be exaggerated with the use of cylindrical lenses. However, we feel that it is not a good candidate for the physiological sensor, since it is such a variable factor, and possibly is absent in many normal persons. Its effect is, of course, quite dependent upon image characteristics. A bright self-illuminated target will accentuate this effect, whereas an opaque, less brightly lit target such as we have used will decrease this effect. Fincham has shown that small targets often remove whatever clues have been previously used for accommodative responses.

Fixation movement was found to be necessary by Fincham for four of the subjects who were experienced enough to subjectively control their eye fixation. The effect of small fixation movements would be to increase the contrast of the image’s light distribution on the retina because the spatial differentiation that occurs with movement counteracts the smear of the image’s light distribution (produced by convolving the object’s light distribution with the quasi-Gaussian spread function of the optics of the eye). A fixation movement also has the effect of removing adaptation to a stationary target which

![Graph](image-url)

**Fig. XVII-6.** Record of random target motion and the tracking by a subject whose eye is not drugged. Ordinate, number of errors in 10 successive trials; abscissa, number of trials. Change of target lighting from white to monochromatic has no obvious effect.
causes disappearance of a stabilized image.\textsuperscript{7,8}

The lens control system is remarkably insensitive to chromatic aberation. The inability of our subjects to track in initial direction better than randomly was unaffected by their having or not having chromatic aberation information (Fig. XVII-6). It thus seems doubtful whether or not chromatic aberation can be the physiological stimulus to an accommodative reflex.

The 2-cps oscillation might act as a trial-and-error phase-sensitive direction device for the accommodative stimulus.\textsuperscript{9} In operating conditions of low-amplitude error signal, as in a stationary state driven by noise alone, the lens servo is unstable or highly undamped,\textsuperscript{10} and 2-cps oscillations are produced. Nonlinearities stabilize the system, however, for large input signals.\textsuperscript{10} These oscillations are just below the correct amplitude range for threshold sensitivity.\textsuperscript{11} However, it still requires an effective utilization of the appreciated blur at a level of 0.2 diopter which is below amplitudes of 0.3 diopter, where we have shown that no nonrandom tracking occurs if careful attention is paid to the three experimental control conditions. It is possible to appreciate blur consciously and be unable to use it to track.\textsuperscript{2}

4. Conclusion

We began these experiments to confirm published suggestions concerning the physiological image operating mechanism which acts as a stimulus to the accommodative response. We were interested in obtaining evidence to decide between an odd error function such as chromatic aberation and a phase-sensitive detection scheme such as the 2-cps oscillation as a trial-and-error method. After several runs of tracking experiments of the type described here, with careful re-evaluation of published data, we have arrived at the tentative position that no physiological mechanism for monocularly driving accommodation has been clearly demonstrated to act at an unlearned reflex-stimulus level of neural function. However, a variety of perceptual clues voluntarily learned or appreciated may be used to track targets or correct for blur. However, if care is taken to eliminate gross perceptual clues, such as lateral movements of a target in off-axis optical system, size and intensity clues often present in experimental systems constructed without use of the second principal focus method, and nonrandom predictable target movements, and furthermore, if no additional clues are supplied by cylindrical lenses emphasizing astigmatic asymmetries, brightly illuminated targets emphasizing other lens asymmetries, and large target movements, then the ability to track targets seems to be rather meager and, in fact, closely approaches random tracking.

L. Stark, Y. Takahashi

References

(XVII. NEUROLOGY)


5. We wish to thank Professor G. Westheimer for calling our attention to reference 4.


B. DEPENDENCE OF ACCURACY OF EYE MOVEMENTS ON PREDICTION

Measurements of the horizontal eye movements of subjects following square-wave patterns of target position reveal that after several cycles the subjects begin to predict the target movement. The normal minimum reaction time of approximately 130 msec is decreased and often becomes negative during such prediction of the time, direction, and magnitude of the next target step.\(^1\)

In observing the rapid saccadic responses to a square wave of target position it was noticed that, for predictions, the amplitude of the initial saccadic response was often in error by a considerable angle, and a large corrective saccade was required later to position the eye on the new target angle. This error was in contrast to the accuracy of the responses that occurred after a normal reaction time, for which the amplitude of the initial saccade was generally accurate within better than 5 per cent of the angle of the target step. Examples of these responses are shown in Fig. XVII-7a. Notice that the accurate corrective saccade does not occur until 130 msec after the target has reached its new position. One interpretation of this observation is that in the nonpredictive case the input to the control system is the new target position, whereas in the predictive saccade case the input is the remembered target position, and the accuracy of this remembered position is low.

To test this observation in a controlled manner, a series of experiments were run
with constant-amplitude 0.4-cps square waves — a target function that has yielded a high percentage of predictions, as well as normal delayed responses.\(^1\) Figure XVII-7b is a typical plot of the percentage of error of the initial saccadic movement versus response time. The frequency of errors greater than 5 per cent increases sharply for predictive movements \( (\chi^2 = 21.9, p<0.001) \). Of particular interest are saccadic responses occurring from 0-130 msec after the target step. Since this is less than a minimum reaction time, the decision to make the saccadic jump must have been initiated before the target step, and its intended magnitude based on the remembered angle of the alternate

---

**Fig. XVII-7.** (a) Normal and predictive saccadic responses. (b) Percentage of initial error vs response time.
target position. Before the response actually took place, however, the target switched to its new position and visual information was available to modify the amplitude of the intended saccade. The data indicate that no such modification takes place. The frequency of percentage errors greater than 5 per cent in response is significantly higher for all responses occurring earlier than 130 msec before the target step than for those occurring after 130 msec ($\chi^2 = 7.08, p<0.01$). The significance of this result is that once a decision to make a saccadic movement has been initiated, no new visual information can affect the course of this movement.2

L. R. Young, L. Stark

References


C. PHOTOTUBE GLASSES FOR MEASURING EYE MOVEMENTS

The eye-position monitor described previously1 is of limited use for some investigations because of the slow rise time of its Clairex CdS photosensors. This problem is further complicated by the influence of the intensity of illumination on the frequency response. To avoid these effects, a new eye-position monitor has been built which employs RCA 1P42 miniature vacuum phototubes.

This monitor operates on the scleral reflection principle, as does the Clairex device, but has an added degree of flexibility afforded by the adjustable optometrist's eye-glass frames on which the elements are mounted. This frame serves as a support for the

![Fig. XVII-8. Schematic diagram of phototube glasses.](image-url)
Fig. XVII-9. Recordings of eye movement taken with phototube glasses. (a) Optokinetic nystagmus response to target moving laterally in visual field, with derivative of eye motion. (b) Response to ±5° steps, with derivative of eye motion.
two GE 224 bulbs and 1P42 phototubes and may be easily adjusted to fit any subject. Figure XVII-8 shows the schematic diagram of these glasses.

Since the output level from the phototubes is quite low, special care must be exercised to avoid noise pickup. At present, the peak-to-peak amplitude of 60-cps pickup has been reduced to a level corresponding to an eye-deflection arc of less than 20', a quite satisfactory level.

Calibration is made by recording the output of the monitor as the subject shifts his gaze from one small fixation point through a known visual angle to another fixation point. The calibration is linear for an angle of eye deflection of ±6°.

Figure XVII-9 shows samples of two records taken with these glasses. In Fig. XVII-9a the subject is exhibiting optokinetic nystagmus. Figure XVII-9b shows the subject response to 5° steps as recorded by these glasses. A simultaneous record of the time derivative of eye position is also shown in each figure.

G. P. Nelson, L. Stark, L. R. Young

References


D. FINGER TREMOR

For some time finger tremor has been studied with the hopes of applying the information so obtained to the analysis of the nature of the control system for human movement and for possible use as a diagnostic test. Some examples of finger tremor in Parkinson's disease have been previously recorded.¹ Recent published reports have suggested that the ballistocardiographic impulsive force plays a role in the generation of physiological finger tremor.²

We have developed an apparatus for the measurement of finger tremor which uses the optical lever principle and is sensitive and reliable. Figure XVII-10 shows a schematic diagram of this apparatus, and Fig. XVII-11 shows a calibration curve obtained with a micrometer movement. Some examples of data obtained under different weight and tension conditions are shown in Figs. XVII-12 and XVII-13. It can be seen that there is some variability from subject to subject. Of interest is the effect of load in altering the spectra of the tremor. Voluntary tension seems to yield a greater low-frequency portion of the spectra, and weighting the finger appears to sharpen the spectra.
Fig. XVII-10. Schematic diagram of optical tremor measuring device.

Fig. XVII-11. Calibration curve of optical tremor measuring device.
Fig. XVII-12. Finger tremor from Subject A with finger (a) relaxed, (b) tense, and (c) weighted (50 grams); Subject B with finger (d) relaxed, (e) tense, and (f) weighted (50 grams); and Subject C with finger (g) relaxed, (h) tense, and (i) weighted (50 grams).
Fig. XVII-13. Finger tremor for (a) Subject A, finger relaxed; (b) Subject B, finger relaxed; (c) Subject C, finger relaxed; (d) Subject A, finger tense; (e) Subject B, finger tense; (f) Subject C, finger tense; (g) Subject A, finger weighted (50 grams); (h) Subject B, finger weighted (50 grams); and (i) Subject C, finger weighted (50 grams).
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Of course, it is necessary to apply spectral analysis to these data in order to make quantitative statements, and such studies are under way; one example is found in Section XVII-G.

E. Mudama, P. A. Willis, L. Stark

References

1. L. Stark and M. Iida, Dynamical response of the movement coordination system of patients with Parkinson syndrome, Quarterly Progress Report No. 63, Research Laboratory of Electronics, M.I.T., October 15, 1961, pp. 204-213.


E. SAMPLED-DATA PROPERTIES OF THE HUMAN MOTOR COORDINATION SYSTEM

Recent studies have suggested that both the eye-movement tracking system and the hand-movement tracking system can be treated as sampled-data control systems.¹⁻³ This report will present some data that may be used in support of this analysis of the human motor coordination system.

When slowly moving ramps are used as input target signals, and the subject is tracking this input with a device that offers very small mechanical impedance, a response that is similar to that of Fig. XVII-14 is seen. The output response consists of step-like changes of position which occur with irregular intervals and amplitudes. The output signal rotary motion transducer had an effectively infinite resolution, and neither friction

![Fig. XVII-14. Response to slow ramp input signals.](image-url)
nor any other component of the mechanical impedance of the transducer was of sufficient magnitude to play an important role in the dynamics of the system. Early studies utilizing this input suggested the possibility that the known sampled-data properties of the eye-tracking system were possibly related to these steplike responses, but recent experiments have failed to confirm this conjecture.4

When pulses of varying width are used as input target signals and are presented irregularly in time, a response that is similar to that shown in Fig. XVII-15a is obtained. There are delays of approximately 150-250 msec before the rapid response motions occur for both leading and trailing edges of the input target motion. This delay in response has several components in addition to nerve conduction time and is sometimes called the psychological refractory time. When a pulse of extremely narrow width is supplied unpredictably as an input target motion, a normal delay occurs before the response movement to the leading edge of the input motion, as shown in Fig. XVII-15b.

Fig. XVII-15. Response to unpredictable pulse inputs. (a) Typical long pulse response. (b) Typical impulse response.
However, the response motion to the trailing edge of the input motion has a much pro-
longed delay, 400 msec in the case illustrated in Fig. XVII-15b. This prolonged delay
can be accounted for as a normal refractory period that starts with the initial response
motion, rather than being triggered by the trailing edge of the input target. This behav-
ior would be characteristic of a sampled-data system. Similar evidence has been shown
for the eye-movement control system, in which, because of the relative power of the
eye musculature compared with the low mechanical impedance of the eyeball, the load
and muscle dynamics are negligible compared to the shaping of the response waveform
by the sampled-data control dynamics.

For a motor coordination sampled-data system with the transient responses shown
in Figs. XVII-14 and XVII-15, the frequency response to wide bandwidth inputs would
demonstrate a peak at one-half the sampling frequency, or at approximately 2-3 cps,
as well as an absence of coherent tracking characteristics at frequencies greater
than this peaking frequency. The eye-movement system has been more fully treated
experimentally and theoretically by Young. For the manual tracking control sys-
tem, however, there exists very little experimental data that clearly support the
occurrence of this suggested peaking frequency, since most of these experiments
have used input bandwidths with either much lower frequencies than 3 cps or else
too little power at these higher frequencies to obtain effective responses necessary
to demonstrate the peak. Stark, Iida, and Willis have described steady-state
frequency response experiments that were not limited by these undesirable input
spectrum characteristics (see Fig. XVII-16).

This clearly defined peak in the response spectrum supports the transient data and the idea that the human motor coordination system can be treated as a sampled-data control system.

L. Stark, Y. Okabe, P. A. Willis

References


F. FREQUENCY RESPONSE OF A SPINDLE RECEPTOR

To establish a firmer basis for the model of a spindle receptor which was presented in Quarterly Progress Report No. 66 (pp. 384-389), a sinusoidal analysis of the stretch receptors in the frog's extensor longitus digitus IV muscle was undertaken. This preparation contains 3-7 spindle bags with as many as 3 occurring on a single intrafusal fiber. No attempt was made to obtain single-unit responses; rather the average response of all of the units associated with this unifunctional muscle were judged to be more useful for justifying a model of this transducer which is suitable for simulating motor coordination.1,2

Fig. XVII-17. Response of spindle receptor to sinusoidal drive. Length of vertical lines in top record is proportional to interval between successive nerve pulses from spindle; peak-to-peak change in instantaneous frequency, ~40 pps. Bottom record shows sinusoidal component of spindle stretch, the input (frequency, ≈0.03 cps).
1. Procedure

The preparation was stretched sinusoidally in position about a dc level that was chosen to eliminate saturations at either maximum frequency of nerve pulses or a minimum frequency of no pulses. The peak-to-peak stretch was 0.4 mm which should correspond to a small-signal input to this 17-mm long muscle. The nerve impulses triggered a linear sweep circuit; a trace whose length was proportional to the pulse interval resulted. The record was calibrated in pulses per second so that the results might be evaluated in terms of instantaneous frequency of firing. A sample record is shown in Fig. XVII-17.

2. Results

Figure XVII-18 shows that the phase vs frequency plot is only roughly proportional to the slope of the amplitude vs frequency plot, an exact proportionality being required of a linear system. Figure XVII-19 shows a step response of this preparation. As another check on linearity it was desired to compare this step response with that predicted from the sinusoidal analysis. The break frequencies of rough asymptotes drawn on the gain plot of Fig. XVII-18 were used to form the transfer function

![Graph showing frequency response of a frog spindle receptor. Rough asymptotes have been drawn on the gain curve.](image-url)
H(s) = \frac{K(30s+1)}{(5s+1)(0.35s+1)}.
\hspace{1cm} (1)

K was evaluated from the lowest frequency point of Fig. XVII-18 to be $K = 27$ (pps/mm stretch). The unit step response was calculated

$$S(t) = 27 + 143 e^{-0.2t} - 170 e^{-3t}$$
\hspace{1cm} (2)

and is superimposed on the record in Fig. XVII-19. The rise time is rather slow, but decay is approximately correct.

Fig. XVII-19. Step response of a frog spindle receptor. The step response predicted from the frequency response data is shown by the solid line. The step input occurred at $t = 0$.

It is interesting to see what constraints are placed on the parameters of the model developed in (1) and shown in Fig. XVII-20 by the values of the time constants

Fig. XVII-20. Mechanical model of a spindle receptor. Inputs are $X_m$ (length of the muscle) and $X_Y$ (artificial length caused by an input to the intrafusal fiber); the output is $X_{SB}$ (length of the nuclear bag).
in \( H(s) \). The equations that relate the time constants to the physical parameters are

\[
T_1 = \frac{B_f}{K_f} \quad T_2 = \frac{B_f + B_b}{K_f + K_b} \quad T_3 = \frac{B_f B_b}{K_t (B_f + B_b)}. \tag{3}
\]

\( K \) is not included, since part of its value is contributed by the unknown gain of the transducer that converts stretch of the nuclear bag to nerve pulses.

Even though the \( K \)'s and \( B \)'s represent five unknowns in the three equations (3), interesting relations may be obtained by demanding that these mechanical parameters be positive. If \( B_b > 0 \), then \( K_b > 4.7 K_f \). If we allow the equality, then \( B_b = 0 \) and \( K_t \) must approach infinity. Instead, assuming \( K_b = 4.8 K_f \) leads to \( B_b = 0.5, \) (force-time/length) independently of units of measure. Also, \( K_t = 3 K_f/(2K_f + 0.035) \), and if we assume that \( 2 K_f \gg 0.035 \), then \( K_t \approx 3/2 \) (force/length). But the tendon should have a much larger spring constant than the intrafusal fiber. \( K_t \gg 10 K_f \).

All of these requirements would be satisfied if

\[
K_f = 0.1 \text{ kg/m}, \quad K_b = 0.48 \text{ kg/m}, \quad K_t = 1.3 \text{ kg/m},
\]

\[
B_b = 0.5 \text{ kg-sec/m}, \quad \text{and} \quad B_f = 2.9 \text{ kg-sec/m}.
\]

3. Conclusions

Three factors prevent us from drawing any strong conclusions. First, the analysis was conducted with only two preparations, and the range of frequencies used was barely sufficient. More experimental work should be done. Second, underlying all of our mathematical analysis was the assumption of linearity. Both the failure of correct correspondence between gain and phase Bode plots and an error in the rise time of step response as computed from the transfer function indicate nonlinearities, even for the small signal inputs that were used. Third, values of the mechanical parameters of the spindle receptor were suggested without strong justification for the model to which these parameters apply. Nevertheless, these findings add support to the model presented in Quarterly Progress Report No. 66 (pp. 384-389) and provide some feeling for the functional significance of the anatomical structure of spindle receptors.

We wish to thank Dr. José del Castillo for his valuable suggestions and for making his facilities at the University of Puerto Rico, School of Tropical Medicine, available to us.

J. C. Houk, Jr., V. Sanchez, P. Wells

References

G. ON-LINE USE OF A GENERAL-PURPOSE DIGITAL COMPUTER FOR BIOLOGICAL EXPERIMENTS

The use of computers in attempting to assimilate large amounts of information concerning biological systems has been widely stressed. A useful development has been the application of on-line digital computers that rapidly present digestive, analytical results of a complex, perhaps statistically designed, experiment to the experimenter while the experiment is in progress or shortly afterward. This reduction of feedback time in experiments is one important advantage of the utilization of a digital computer in this fashion. Examples of these on-line computers include the special-purpose Average Response Computer, the Analog Electronic Averager, and the TX-0 computer, all of which are used in the Research Laboratory of Electronics.

We have previously described our use of a digital computer for the generation of comb spectra input functions and for gain- and phase-shift analysis of the experimental system response. Three other types of data analysis methods have been programmed for the GE 225; these are the average response program, the impulse response program, and the autocorrelation and power spectrum programs.

1. Average Response Program

A digital-computer program has been written and successfully used which accepts on-line response data evoked by repetitive excitation and automatically computes the average response as an analog voltage output. The program is fully specified by the following three parameters: (a) Input sampling rate - max value, 4.7 kcps; (b) Output sampling rate - max value, 4.7 kcps; (c) Number of points in response - max value, 7,000.

Separate specification of an input and output sampling rate enables the computer to time-scale in order to suit auxiliary equipment, for instance, the X-Y recorder. At present, the number of responses averaged must be less than 256, although the precise number does not have to be specified at the beginning of an experiment. In a typical experiment responses to a particular input are obtained repeatedly until various experimental factors prohibit the taking of more data, for instance, subject fatigue, at which time the experimenter signals the computer that the experiment has been completed.

Previously, analytic studies of the deterministic portion of the pupil servomechanism have been delayed with respect to transient data because of a lack of adequate signal-to-noise ratio and variability in single responses. This is now less of a barrier, as can
Fig. XVII-21. Average pupil responses (solid line) and model response (dashed line) to (a) Positive pulse of light and (b) Positive ramp of light.

Fig. XVII-22. Typical single pupil responses. (a) Pulse responses. (b) Ramp responses.
be seen by comparing Figs. XVII-21 and XVII-22.

The averager program has been used to obtain reliable and consistent pupil response data to use in formulating models for the human pupil reflex to light. Figure XVII-21 shows examples of averaged responses. Typical single pupil responses are shown in Fig. XVII-22 for comparison.

2. Impulse Response Program

A general second-order model is stored in the GE 225, and the coefficients and parameters of this model are adjusted by the program to give a second-order fit to the input time record. Figure XVII-23 shows an example of the mechanical impulse response of the human motor coordination system and also the second-order fit obtained by the computer. Higher-order fits, which are obviously necessary, are under development.

3. Autocorrelation and Power Spectrum Program

An autocorrelation program that allows a maximum τ shift of 650 and will take an infinite string of input data has been written. The computation time is $T = (.02 \text{ sec})$ (total points) ($\tau_{\text{max}}$). Figure XVII-24a shows the autocorrelation function obtained from a finger tremor record, a section of which is shown in Fig. XVII-24b.

The cosine transform program accepts this autocorrelation as input and yields both unsmoothed and smoothed power density spectra as an output. Both the autocorrelation and the power spectra are obtained as output plots on an X-Y plotter.
Fig. XVII-24. (a) Autocorrelation of the section of finger tremor time record shown in (b).

Fig. XVII-25. Power density spectra obtained from Fig. XVII-28a. (a) Unsmoothed spectrum. (b) Smoothed spectrum.
Figure XVII-25 shows the unsmoothed and smoothed power density spectra obtained from the autocorrelation function of Fig. XVII-24a.

Julia R. Bristol, R. C. Payne, P. R. Samson
A. A. Sandberg, L. Stark, P. A. Willis

References


5. Y. Okabe, R. C. Payne, H. Rhodes, L. Stark, and P. A. Willis, Use of on-line digital computer for measurement of a neurological control system, Quarterly Progress Report No. 61, Research Laboratory of Electronics, M.I.T., April 15, 1961, pp. 219-222.

H. EFFECT OF PHARMACOLOGICAL AGENTS ON CONTROL OF EYE MOVEMENTS

Our program of research into neurological control systems has partly relied upon an input-output, black-box analysis, with several variants, such as experimental manipulation of input signal characteristics and artificial environmental clamping of feedback gain, to aid in this analysis. The dissection of the black box of a neurological control system is made possible by means of studying patients with different neurological syndromes (defective subsystems) and also the use of pharmacological agents that have differential effects on the loops and mechanisms in the system under study. This report represents initial application of the latter method to the eye movement control system.

1. Pharmacological Agents

Barbiturates are common sedatives widely used as sleeping pills. We used seco-barbital (35 mg intravenously) in smaller doses than employed in normal sedation since it has been known that certain features of eye movements are very sensitive to these
barbiturates. Another drug, methamphetamine (10 mg intravenously), is a stimulant and is related to drugs commonly taken to resist sleepiness. At times it is given for its effect of reducing appetite. These drugs were administered by a licensed physician under carefully supervised medical conditions to normal, healthy subjects.

2. Measurement and Target Techniques

The subject was positioned with his head fixed in a catcher's mask and a set of photocell goggles, which have been described, for measuring eye position in various directions of horizontal gaze. The target was either a vertical bar of light or a series of stripes moving across a television screen that was behind the fixation point. Calibration and recording have also been previously described.4-7

3. Performance Tasks

A rather varied set of tasks was required to be performed by the subjects in order to survey drug effects on many aspects of the complex sampled-data multiloop system that controls normal human eye movements. These included (a) Directed gaze in darkness – lateral and forward, (b) Compensatory movements to passive head rotation, (c) Gaze directed at fixation point, (d) Conjugate eye movements following moving targets of (i) steps, (ii) constant velocity, (iii) constant acceleration, and (iv) sinusoids; and (e) Optokinetic nystagmus.

These tasks are designed to elucidate the various types of eye movements – saccades, pursuit, fixation stability, and nystagmus.

4. Results

Normal tracking of a sinusoidal target movement generally results in a rather smooth eye position recording similar to that shown in the middle trace of Fig. XVII-26. Occasionally, discontinuous changes of position occur which can be more clearly seen in the rate or derivative recording shown in the top trace of Fig. XVII-26. These discontinuous spikes of velocity were found to occur at a rate of 2.8 saccades per cycle when the input signal is a 0.5-cps sinusoid. The same subject under the influence of 35 mg of secobarbital administered intravenously shows a very scalloped eye position recording (middle trace of Fig. XVII-27). This is produced by an increased saccadic rate of 6.4 saccades per cycle, which is clearly shown in the top trace of Fig. XVII-27 as a frequent series of velocity spikes. It is clear that the pursuit control loop8,9 has been grossly affected by the drug, yet at the same time the subject is obviously alert enough to perform fairly accurate tracking and, indeed, to have his saccadic position-control loop operate at greater than normal rates in order to compensate for the affected pursuit system.

The normal response to a series of moving stripes when the subject is attempting
Eye rate and eye position when tracking 0.5-cps sinusoid in top and middle trace. Bottom trace, eye position in response to a moving pattern of stripes behind the fixation point. (Time, 25 mm = 1 sec.)

Fig. XVII-26.

Same subject as in Fig. XVII-25, under 35 mm secobarbital.

Fig. XVII-27.

To maintain fixation on a stationary point is a pattern of optokinetic nystagmus. This is shown in the bottom trace of Fig. XVII-26, in which approximately 1.2 jumps per second occur to produce an irregular saw-tooth waveform. The constant-velocity slower portion of the saw tooth represents the action of the pursuit system, which is involuntarily influenced by the moving stripes. The eye drifts produced by the moving stripe pattern are compensated for by the saccadic fixation system. The effect of barbiturates is striking, removing almost all trace of the optokinetic nystagmus, as shown in the bottom trace of Fig. XVII-27.

In agreement with this evidence of the resistance of the saccadic system to barbiturates is the response to unpredictable steps shown in Fig. XVII-28. Here, we see that when the subject has been administered barbiturates no significant changes occur in the accuracy of large saccades. In fact, there is only a suggestive decrease in accuracy shown in the middle trace of Fig. XVII-28, as compared with the top trace of Fig. XVII-28. The result is the same for the subject following unpredictable steps after having had methamphetamine administered. When statistical analysis is applied to the data, however, it is found that methamphetamine decreases and secobarbital increases.
the normal response latent time of 250 msec by 10 per cent.

When the subject is placed in complete darkness and is instructed to direct his gaze at a fixation point, which is extinguished at the beginning of the run, another interesting set of effects is noted, as shown in Fig. XVII-29. Two characteristics of the record were measured and analyzed: Average saccadic frequency and average saccade angle. These quantities should represent the instability of the eye control system in maintaining fixation in darkness. Barbiturates were found to increase the average frequency from 1.1 to 3.0 saccades per second, whereas methamphetamine decreased the average saccade angle from 1.6° to 0.8°.

Discussion

It is felt that these results, although preliminary, suggest the power of combining an input-output analysis with a pharmacological dissection method.

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References


