XXIV. NEUROLOGY[*]

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RESEARCH OBJECTIVES

The aim of our work is to apply the concepts of communication and control theory to an analysis of neurological mechanisms. Our group is composed of neurologists, mathematicians, and electrical engineers; and our research endeavors span a wide field that includes experiments on human control mechanisms, mathematical methods for analysis of nonlinear systems, clinical studies using on-line digital computer techniques, and neurophysiology of simple invertebrate receptors.

A. ENVIRONMENTAL CLAMPING OF BIOLOGICAL SYSTEMS

In order to study biological systems operating in their normal physiological range it is often necessary to use unanesthetized and intact animals — one very cooperative species is man. Under these conditions the variability, including both noise and adaptive changes, of the systems poses problems that must be met by averaging techniques such as small-signal steady-state analysis (1).

Another method is applicable when the biological system under study can be controlled by artificial physical systems with greater range and power. This method consists of "clamping" a particular variable or parameter in the mechanism that is to be studied. An example of this is the squid axon clamp of Marmont and Cole.

The experimental apparatus used in studying the pupil light servomechanism has means for forcing the light stimulus to be proportional to a given voltage, as well as means for producing a voltage that is proportional to the pupil area. If the pupil area voltage is fed back through a "clamping box" with adjustable gain and phase lag to the light control amplifier, a new loop composed of the pupil system and the "clamping box" in tandem is formed. (See Fig. XXIV-1 and ref. 2.)

When the gain of the clamping box is increased, the combined system should oscillate at the 180° phase crossover frequency of the pupil system. Further, if phase lag or lead is introduced in the clamping box the Nyquist curve of the open-loop pupil system is effectively rotated, and the frequency of oscillation is now the

new 180° phase crossover frequency. Figure XXIV-2 shows such an experiment.
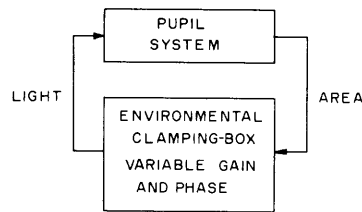

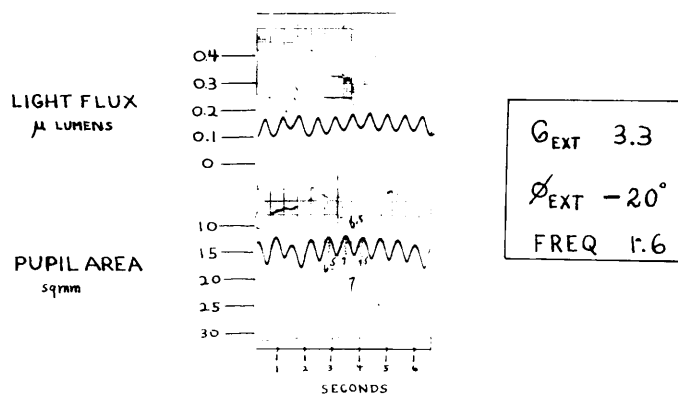Fig. XXIV-1. Environmental clamping operation method.

Fig. XXIV-2. High-gain instability oscillations under electronic feedback operating conditions.

Two other properties of this mode of operation should be commented upon. First, the resonant peak of the combined system acts as a filter to remove noise and harmonics at other frequencies; thus the sinusoidal appearance of the area and light changes shown in Fig. XXIV-2. Second, the linear properties of the system determine only the frequency of the oscillation. The amplitude is a function of non-linearities in the pupil mechanism. The inverse relation between frequency and amplitude demonstrates the strong velocity saturation characteristic of the pupil mechanism.

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References

1. L. Stark and P. M. Sherman, A servoanalytic study of the consensual pupil reflex to light, J. Neurophysiol. 20, 17 (1957).

2. L. Stark, Stability, oscillations, and noise in the human pupil servomechanism, Proc. IRE 47, 1925 (Nov. 1959).

B. DYNAMIC CHARACTERISTICS OF MOTOR COORDINATION

In this experiment our aim was to define human motor coordination by means of a transfer function and, of even more importance, to develop a model that includes anatomical, physiological, and neurological facts concerning this complex system. Human engineering studies have already approximately defined behavior in the useful range of human machine control (1), but in line with the above objective we pushed the system to higher frequencies, where the behavior often gives more information about the equivalent networks that are being studied.
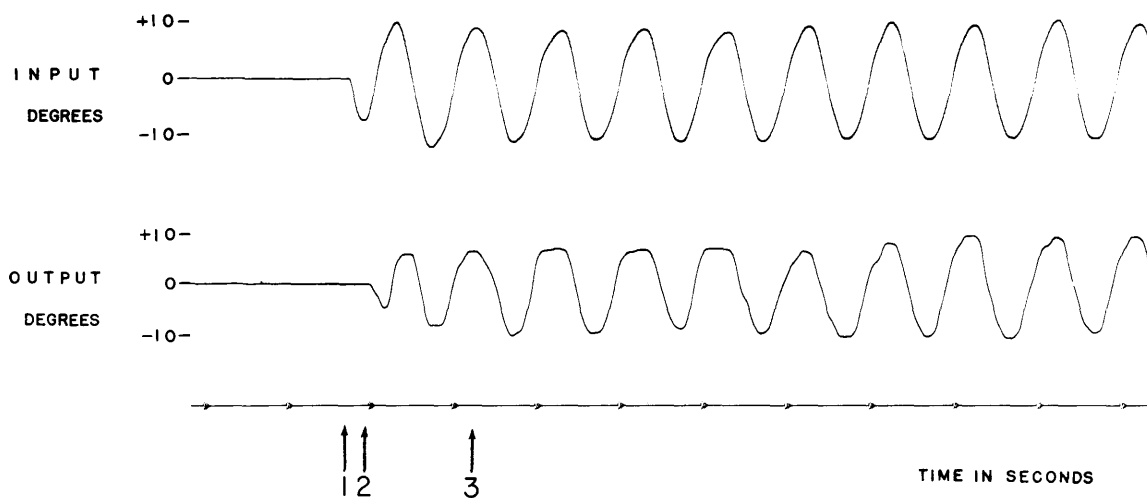

Fig. XXIV-3. Transient experiment.

For the purpose of this report we wish to stress an experimental technique for eliminating the predictive apparatus of the human subject. Figure XXIV-3 shows a recording of the input — a sinusoidal movement of the pointer — and the output — the following, or visual tracking guiding wrist rotation, of the subject. The response has three phases: (a) a reaction time delay; (b) a neurological response phase wherein the spinal cord reflexes, cerebellum, basal ganglia motor-coordination complex drives the system with phase lag and amplitude error; (c) a predicted response phase, when the "prediction apparatus" in the subject's brain has predicted the input signal and has corrected the response by adding phase advance and amplitude correction.

Figure XXIV-4 shows a method of prolonging the neurological response phase so that steady-state data can be obtained. The input consists of a mixture of relatively prime sinusoids, essentially unpredictable by the subject. The output then represents the desired steady-state neurological response. In order to eliminate the necessity for
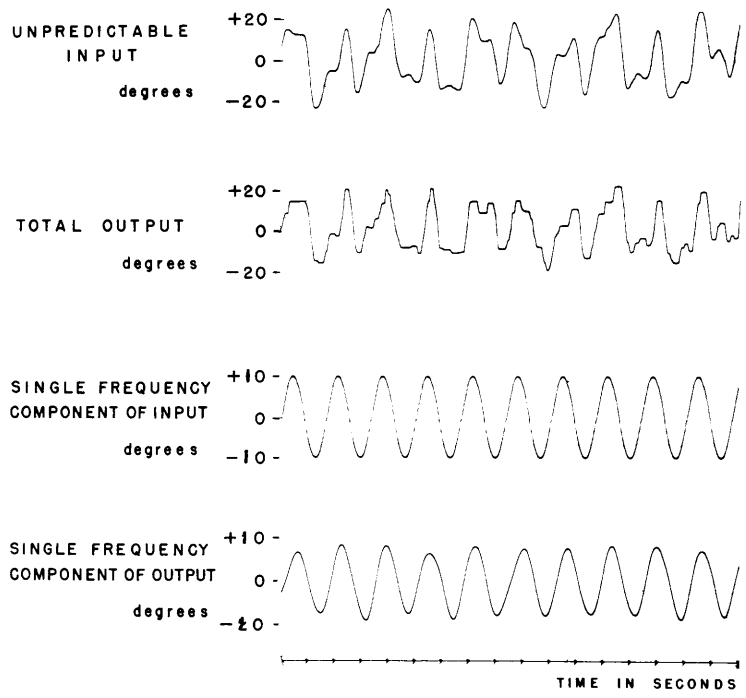
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UNPREDICTABLE INPUT
degrees

+20
0
−20

TOTAL OUTPUT
degrees

+20
0
−20

SINGLE FREQUENCY COMPONENT OF INPUT
degrees

+10
0
−10

SINGLE FREQUENCY COMPONENT OF OUTPUT
degrees

+10
0
−10

TIME IN SECONDS

Fig. XXIV-4. Unpredictable input experiment.

GAIN

2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0

o UNPREDICTABLE INPUT
   Amplitude of central frequency $\pm 5°$
□ PREDICTABLE INPUT
× FREE WHEELING

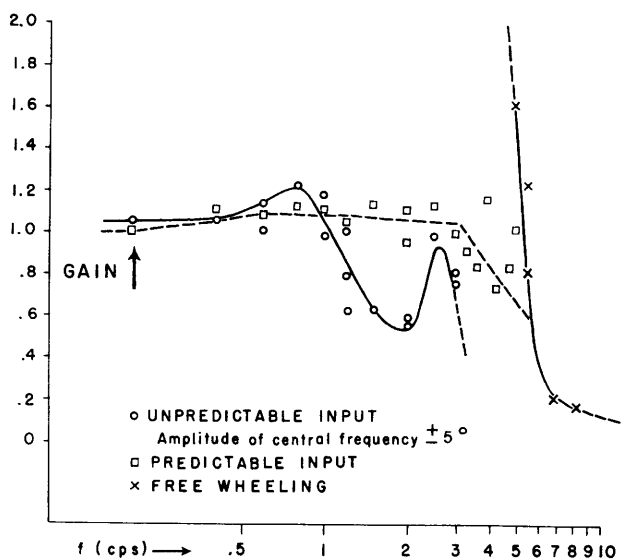f (cps) ⟶   .5   I   2   3   4 5 6 7 8 9 10
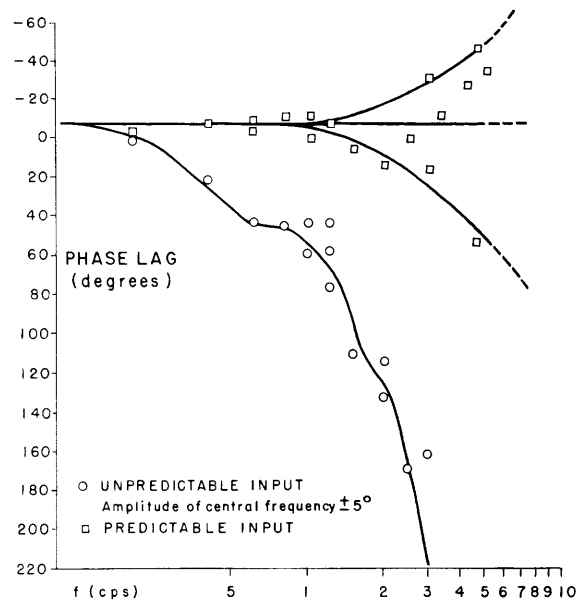
Fig. XXIV-5. Frequency response gain data.

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Fig. XXIV-6. Frequency response phase data.

computational machinery in the analysis we abstracted a single-frequency component of the input, and passed the output through a narrow bandpass filter set at the same frequency. These simplified input and output recordings are also shown in Fig. XXIV-4.

In Figs. XXIV-5 and XXIV-6 are shown frequency response data obtained with and without the prediction apparatus; that is, the predicted response and the neurological response. It can be seen that the predicted response has a gain of 1 and zero phase lag until the end of the response range, where scattering of the data becomes great. The neurological response demonstrates steadily increasing phase lag (with both minimum and nonminimum phase elements) and peaks and notches in the gain curve. These two response curves are clearly different.

In summary, a method of overcoming the predictive adaptation of the human control system is explained, and examples are shown to illustrate this aspect of our experiments.

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References

1. D. T. McRuer and E. S. Krendel, The human operator as a servo-system element, J. Franklin Inst. 267, 1 (1959).