XVIII. NEUROLOGY*

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A. WORK COMPLETED

1. A MARKOV ANALYSIS OF ADAPTIVE TRACKING BEHAVIOR

A thesis with this title was presented by John W. Billheimer to the Department of Electrical Engineering, M.I.T., in partial fulfillment of the requirements for the degree of Electrical Engineer, August 1963. A brief summary of the thesis research follows.

Modeling techniques are proposed for the purpose of representing the complex, memory-dependent process of adaptive human behavior within the constraints of a simple Markov model. In essence, these techniques involve the development of partitioning schemes that order stage-oriented substates in patterns that are capable of incorporating the past history of adaptive systems in a form that is amenable to Markov analysis.

The proposed partitioning techniques are discussed and evaluated in the light of both theoretical and practical considerations. On the theoretical level, the mathematical basis for stage partitioning is explored and extended to the definition of dummy holding states that provide the systems analyst additional degrees of freedom in the construction of stochastic learning models. On the practical level, these techniques are applied to the mathematical analysis of adaptive tracking behavior. Pursuit-tracking experiments are described in which the sequential behavior patterns followed by human operators in adapting their responses to predictable target signals are isolated, studied, and simulated. Results indicate that the proposed partitioning techniques provide a mathematical framework that is fully capable of supporting the analysis of adaptive behavior traits.

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B. VISUAL SUPPRESSION DURING VOLUNTARY SACCADIC EYE MOVEMENTS

1. Introduction

Visual suppression, or the elevation of visual threshold, during voluntary saccadic eye movements has been demonstrated by numerous investigators.[1-5] As a preliminary step in the investigation of the possibility of an intermittency operator

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in the eye-movement control system, we set out to reproduce the results of Latour.[1] This was done for two reasons: (i) his results were presented in a manner that seemed compatible with the future course of our experiments, and (ii) relatively little information about his experimental conditions was published.

2. Methods

A dark-adapted subject sat before two fixation lights that were mounted on a visual perimeter at a distance of approximately 5 feet and were separated by an angle of 20°. The movements of his left eye were monitored with a pair of glasses like those previously described.[6,7] The sensing elements in these glasses were semiconductor light sensors (Texas Instruments, LS-400) which were used primarily because of their short time constant and their sensitivity to infrared light.

One of the fixation lights was on at any given time, and the subject was instructed to maintain fixation on that light. One stimulus presentation consisted of extinguishing one fixation light while simultaneously turning the other on. After the normal latency the subject made a voluntary saccadic eye movement. The switch that was used to interchange fixation lights also triggered an Argonaut pulse generator with a built-in variable delay. The delayed pulse from the Argonaut triggered a General Radio Company Strobotac, thereby providing a test flash to the subject.

The intensity of the test flash was adjusted so that it was just suprathreshold when its image was approximately 10° off the fovea. This test flash was positioned midway between the two fixation lights.

Perception of the test flash by the subject was indicated by his depressing a push button. This event was recorded on a Sanborn recorder. Also recorded were the subject's eye movements, the change in fixation lights, and the trigger pulse to the strobe. Hence, a test flash of approximately 10-μsec duration could be presented to the subject any time before, during or after his eye movement. An experimental run consisted of approximately 200 of these stimulus presentations. During the course of a run the Argonaut delay was varied in order to present the test flash at different times with respect to the eye movement.

Analysis of the records consisted of noting (i) the interval between the beginning of the eye movement and the test flash (10-msec resolution), and (ii) the presence or absence of the subject's indication of perception of the test flash. Thus we could determine the chance of perception of the test flash at any given time of its occurrence with respect to the beginning of the eye movement.

3. Results

The results of a typical experiment are presented in Fig. XVIII-1. The center ordinate represents the chance of perception of the flash and the abscissa represents

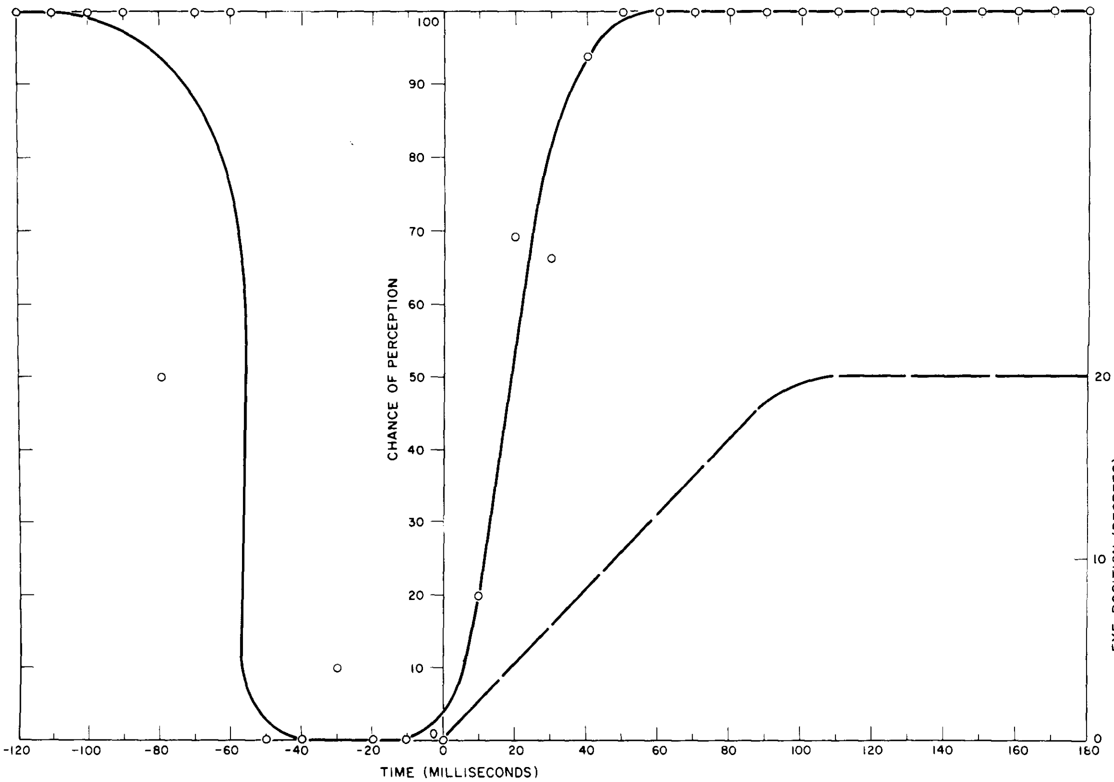

Fig. XVIII-1. Visual suppression during voluntary saccadic eye movements.

the time in milliseconds between the beginning of the eye movement and the presentation of the test flash. Superimposed on this plot is a plot of eye position against time. Eye position in degrees is found at the extreme right of the plot.

Briefly, the results may be summarized as follows: Suppression of vision normally begins approximately 50-80 msec before the eye begins to move; vision then remains suppressed until approximately 30-50 msec after the beginning of the eye movement. The suppression effect is maximal for a period of approximately 20-40 msec before the beginning of the eye movement. The degree of suppression achieved is a function of the intensity of the test flash.

It is implied from the manner in which the curve of suppression vs time is drawn in Fig. XVIII-1 that the point at -80 msec is aberrant. Latour[8] has noted a secondary dip in one of his experiments, and speculates about a "whole train of holes in visual perception." We have not consistently observed such phenomena, but this is perhaps indicative of such a secondary dip.

4. Discussion

Our results roughly confirm those published by Latour. The only possible discrepancy lies in the fact that visual suppression in our experiments seems to begin somewhat earlier and does not seem to extend quite as far into the eye movement as does the suppression effect in Latour's work. It is possible that these discrepancies could be resolved by a more complete comparison of Latour's and our experimental arrangements.

Two interesting aspects of all of the suppression effects observed are (i) a distinct elevation of visual threshold is clearly demonstrable well before the eye begins to move, and (ii) this elevation of threshold is apparent only during approximately one-half of the fast phase of the eye movement.

It is interesting to speculate about the relationship between visual suppression effects and what has been called the intermittency operator.[9] This operator has been postulated as a result of servomechanical approaches to the visual tracking system. Studies by Young and Stark[10] brought out two important features of the eye-tracking system. The first is that the system as a whole is composed of two separable systems, the smooth pursuit system behaving primarily as a velocity-tracking system, and the rapid saccadic system serving as a position servomechanism. Second, a sampled-data model is required to adequately describe the discrete nature of nonpredictable tracking which, with some inputs, is composed of a series of corrective saccades separated by an interval of approximately 0.2 sec.

Young and Stark make no predictions about the actual location of the sampler in their modeling process. In our future experiments we shall attempt to define the relationship between visual suppression and this "intermittency operator," and also to locate the site of the observed intermittency.

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C. VISUAL SUPPRESSION DURING THE FAST PHASE OF VESTIBULAR NYSTAGMUS

Visual suppression during voluntary saccadic eye movements is described and discussed in Section XVIII-B. It is of interest to determine whether or not such a suppression phenomenon exists in association with involuntarily initiated saccadic eye movements, as it does with those which are voluntarily initiated. With this in mind, an experiment was carried out in which vestibular nystagmus could be induced in human subjects. The experimental apparatus and some preliminary results will be described here.

1. Experimental Apparatus

The subject is seated on a swivel stool that can be manually rotated by a second person. The subject's eye movements are continuously monitored by using the special glasses described in Section XVIII-B. It should be pointed out that the subject wears

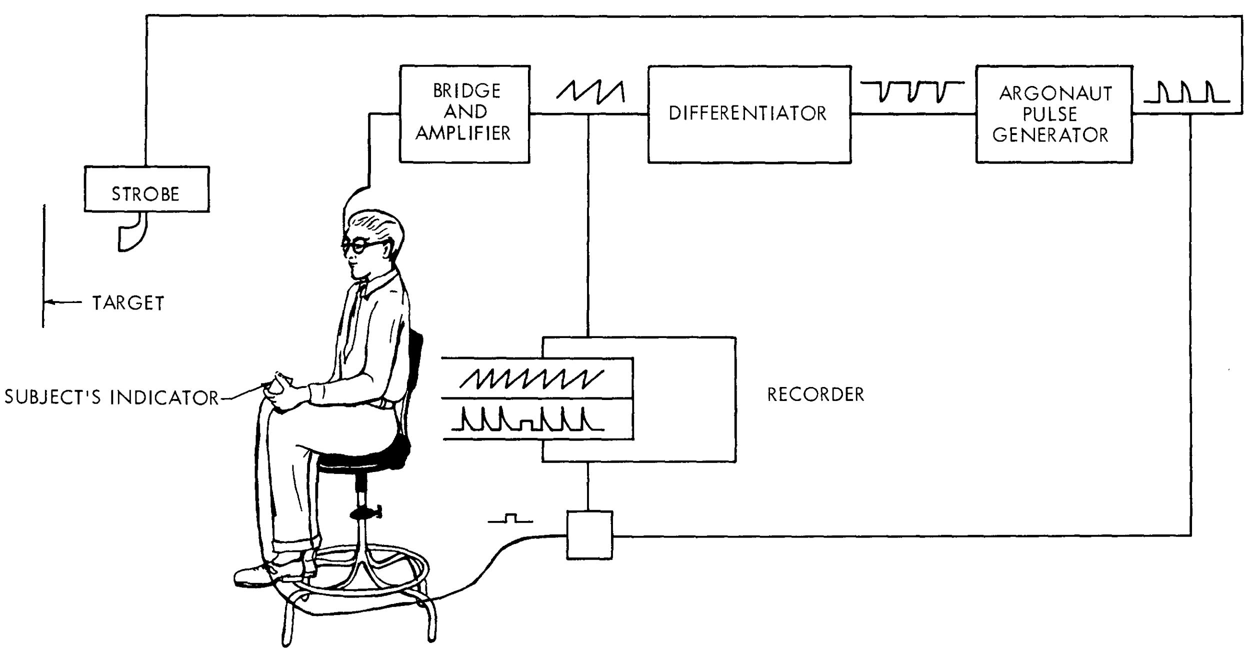

Fig. XVIII-2. Schematic representation of experimental apparatus.

these glasses at all times while seated on the stool.

A schematic representation of the electronic equipment used in this experiment appears in Fig. XVIII-2. The amplified signal that is proportional to eye position is differentiated. Differentiation of the fast phase of the vestibular nystagmus results in an impulse that is then used to trigger an Argonaut pulse generator. The Argonaut generator provides a standard pulse, which can be delayed if desired and is used to trigger the General Radio Company Strobotac. Thus a test flash can be presented to the subject at any time during or after his fast phase by incorporating a suitable delay into the Argonaut.

The test flash illuminates an 8.5 in. × 11 in. sheet of white paper at a distance of approximately 5.5 feet. In the horizontal plane this subtends a visual angle of ~8°.

2. Method

Test-flash intensity is determined as described in Section XVIII-B. The subject is rotated on the stool while the experimenter monitors his eye movements on the Sanborn recorder. When a clear nystagmus is no longer present (thereby indicating that the subject is being rotated at nearly constant velocity), the person rotating the subject is instructed to stop him. The subject is stopped abruptly while facing in the direction of the test flash, and his postrotary nystagmus commences. The fast phases of this nystagmus cause the presentation of the test flash.

If the subject sees a test flash, he indicates his perception thereof by activating the subject's indicator as described in Section XVIII-B. This indication, along with the pulse that triggers the test flash, is recorded on one channel of the Sanborn recorder, while the subject's eye position is recorded on a second channel.

3. Results

Figure XVIII-3a shows a sample taken from a run in which the test flash was presented at an average of 25 msec after the beginning of the fast phase. Of 53 test-flash presentations, the subject indicated that he saw only one (not shown). Note that the subject's indication of perception would normally occur on the same trace as the trigger pulse (lower trace). These results are quite repeatable, as long as the test-flash intensity is properly adjusted. Figure XVIII-3b is a sample from a run made under conditions identical to those in Fig. XVIII-3a, except that the test flash was brighter. That the subject saw every test flash is indicated by the broad pulse appearing after every trigger pulse (lower trace).

4. Discussion

From these preliminary results it seems possible to conclude that an elevation of visual threshold occurs during the early part of the fast phase of vestibular nystagmus.

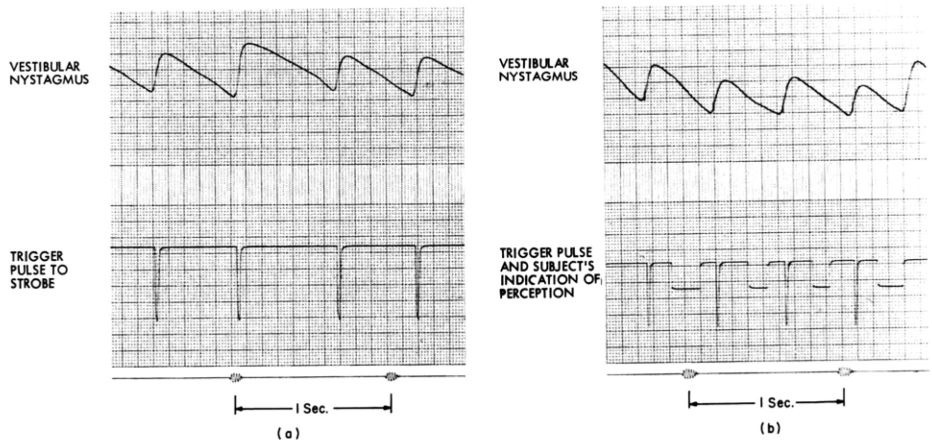

Fig. XVIII-3. (a) Sample from an experimental run showing total lack of perception of the test flash. (b) Sample taken under same conditions as (a) except that a brighter test flash was used. Broad pulses between trigger pulses indicate that subject saw all test flashes.

This is perhaps the first indication that such a suppression phenomenon is associated with saccadic eye movements that are reflexively initiated.

In future experiments more data will be taken at different times of flash presentation so that the suppression phenomenon associated with involuntary saccades may be compared with that already collected for voluntary saccades.

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D. THE SCIENTIFIC TRANSLATING SYSTEM

The Scientific Translating System (STS) was developed by us in the spring of 1963 to meet the laboratory's requirement for an expandable programming and monitoring system.

Its use has considerably reduced the time necessary for development of the laboratory's computer programs. The system itself consists of three computer programs: the assembler, the loader, and the monitor.

1. The assembler, SCRAM

The SCientific Relocatable AsseMbly program can perform assemblies to provide a variety of outputs. One may also make an assembly in order to detect programming errors. Facilities, similar to those available in CTSS,[1] are provided for on-line editing of the source input.

2. LINK

The linking loader loads the relocatable output from several SCRAM assemblies into one large program. It follows the definition of symbols at load time and provides a complete set of diagnostics and listings that facilitate debugging.

3. The MONITOR

The operator can use the monitor to expedite the rapid execution of programs that are stored on magnetic tape. The monitor also allows the operator to save the state of a program, and to restore and continue executing a saved program. These facilities speed up the debugging and operation of the laboratory's programs.

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E. DYNAMIC PROCESS IDENTIFICATION OF POSTURAL CONTROL SYSTEM

1. Introduction

A method for determining the parameters of the postural control system under sinusoidal tracking conditions was developed by using impulse-response analysis. The impulse applied had a duration considerably less than the minimum significant time constant of the biological system. The performance of the system could thus be monitored under dynamic conditions with minimum disturbance. Results indicate that the system is input-adaptive, and the parameters vary while the subject is tracking a sinusoidal input.

2. Impulse Excitation to the Postural Control System

The postural control system was excited by impulses from a torque motor coupled to the shaft of a handle. The subject tracked a sinusoidal signal on the screen, and torque impulses were applied randomly at various handle positions. The resulting responses can then be interpreted to identify the dynamic process of the postural control system.

The torque motor has a linear torque curve up to 0.85 ft-lb for various armature currents. The problem, however, was to produce torque impulses of predictable magnitudes. A convenient method for doing this was to apply impulses of fixed amplitude and accurately controlled duration. Calibration was achieved by measuring the initial slope of the handle response (unloaded) for excitations of various impulse widths.

The torque impulse produced was found to be proportional to the impulse duration in calibration runs.

A number of impulse responses of a subject was obtained under static conditions. The half-period of the responses varied between 60 msec and 150 msec and is in reasonable agreement with previous results.[1] Hence, for this experiment a torque impulse of 10 msec was well below the time duration for the significant change of the impulse response.

3. Experimental Procedures

The dead load of the mechanical system was first calibrated. A spring in the form of a torque wrench was attached to the handle to produce a second-order mechanical system. The three parameters are specified as moment of inertia J, viscous damping B, and spring constant K. From measurements of the natural frequency and rate of decay and the calibration data of the torque wrench, the parameters were computed to be $J_d = 4.0 \times 10^{-4}$ ft-lb-sec^2/radian; $B_d = 6.2 \times 10^{-3}$ ft-lb-sec/radian; and K_d = 0.96 ft-lb-sec/radian, where d represents the dead load of the mechanical system.

The impulse responses from the torque motor were superimposed on the

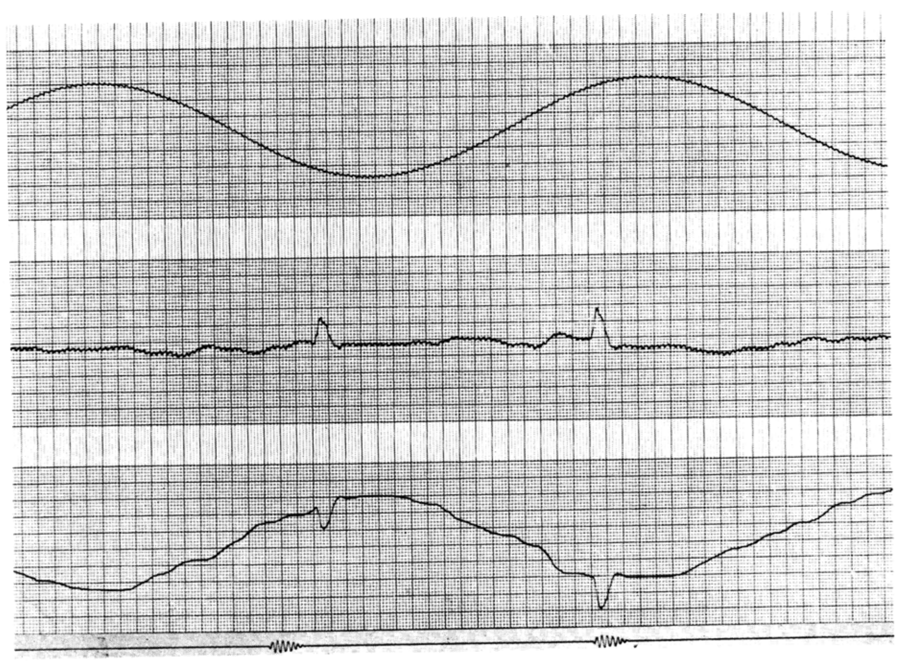

Fig. XVIII-4. Experiment results of dynamic process identification of the postural control system. Upper, input; lower, tracking signal on which is superimposed the impulse response; middle, difference of the two. The paper is running at 100 mm/sec; vibration of the needle is clearly shown at this speed.

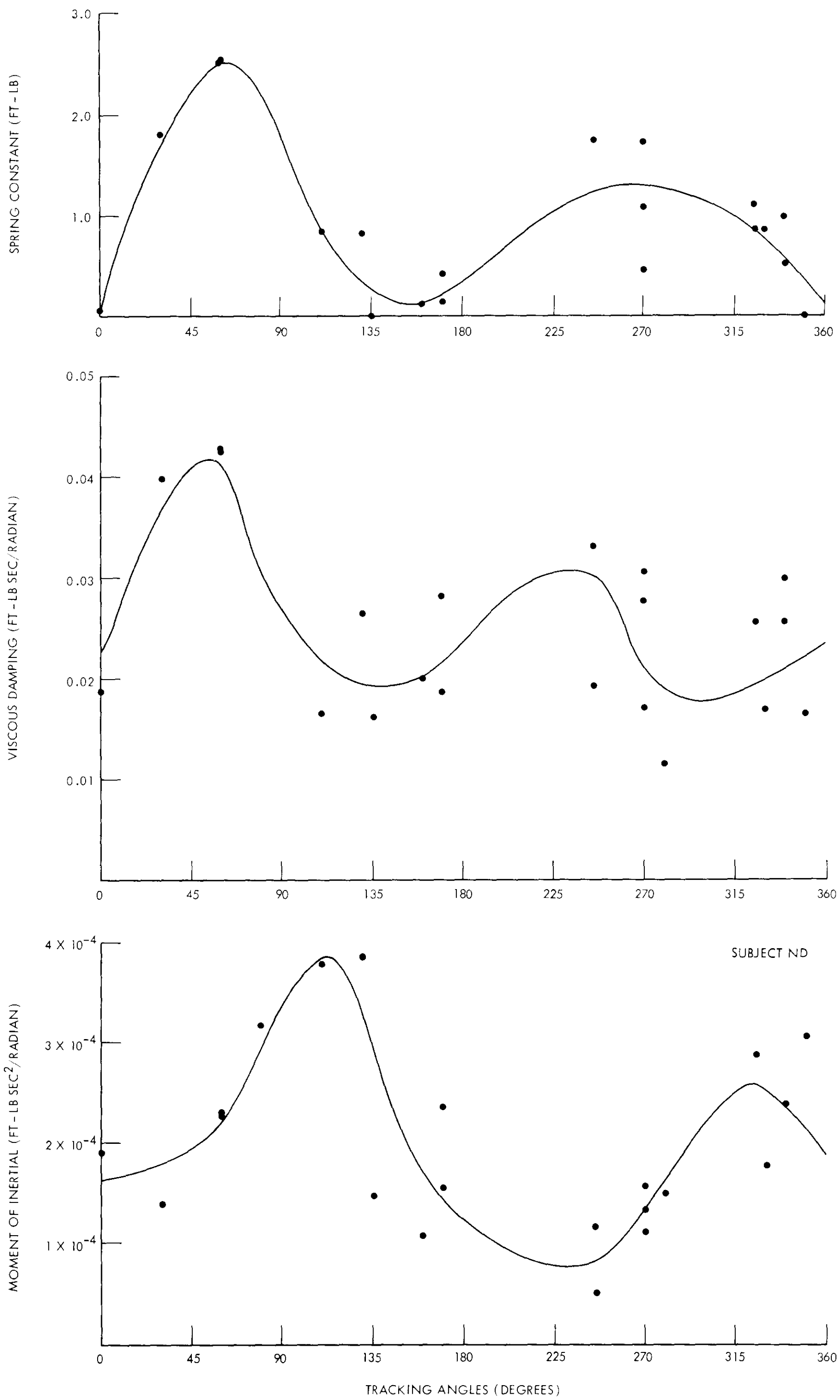

Fig. XVIII-5. Performance characteristics of hand-motor-coordination system under sinusoidal tracking conditions.

handle-position record that is the response of the subject following the target position. The computation of the system parameters under this condition is difficult because of the nonuniform time reference. This difficulty can be partially eliminated by monitoring the difference between the handle output and the visual input to give a relatively constant reference for the duration of the impulse response. Figure XVIII-4 shows typical impulse-response records with sinusoidal tracking.

4. Experimental Results

Impulse-response characteristics of the second-order approximation of the postural control system were obtained at various tracking angles of the handle position. The parametric contributions resulting from the dead load of the mechanical system were then subtracted from values computed from the over-all response characteristics. The results are plotted in Fig. XVIII-5. The system parameters found in the dynamic case do not vary appreciably from those found in the static case.[1]

5. Conclusions

The second-order approximation to the postural control system[2] is the simplest mathematical description that can be made, but it contains most of the relevant features of the system. Figure XVIII-5 shows that the system becomes sluggish near the tracking instant when the handle position crosses the zero reference. It gives more oscillations during the tracking instant when the handle position is at its maximum or minimum angle. Thus the system progressively exchanges sluggishness for tightness, or smoothness of operation for precision. It is therefore input-adaptive, since the system monitors its own performance and adjusts its parameters in the direction of better performance.

H. H. Sun, N. Durboraw, L. Stark

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F. TOPICAL CORTICOSTEROIDS AND PUPIL DIAMETER

The present study is a portion of a large study in which the effect of topical corticosteroids on many functions of the anterior segment of the eye was investigated. The study was prompted by the reports that local and systemic corticosteroids induce an elevation of intraocular pressure.[1,2]

Eight healthy female subjects between the ages of 20 and 26, and two healthy male subjects of ages 30 and 48 were given a corticosteroid preparation (3 subjects received 0.1 per cent dexamethasone; 7 subjects received 0.4 per cent prednisolone) to be administered to one eye four times a day for 6-11 weeks. The experimenter did not know which eye was treated until the conclusion of the study. Pupillary measurements were recorded with the Lowenstein type of pupillograph daily at approximately the same time. The pupillary responses were either averaged by hand or by the G.E. 225 digital computer equipped with an analog-to-digital converter. Three weeks after the conclusion of the steroid study all signs of corticosteroid effect had disappeared and five subjects were given the drug vehicle (containing sodium chloride, polysorbate, chlorobutanol, and distilled water) without prednisolone to apply to their control eye four times a day for two weeks.

All 10 subjects showed an enlargement of the pupil in the eye receiving the steroid as compared with the contralateral control eye. Figure XVIII-6 shows typical responses for the difference in pupil diameter as seen in two subjects. Seven subjects

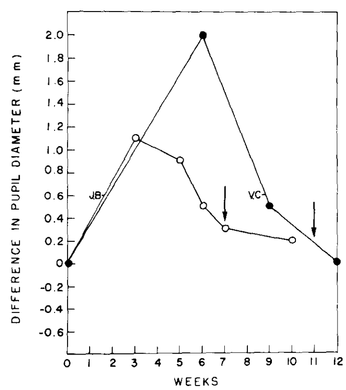

Fig. XVIII-6. Differences in pupil diameter between control and treated eyes for 2 subjects. Arrows indicate cessation of medication.

demonstrated a peak difference between the third and fifth week on medication and then began to return to baseline values although the steroids were still being administered. Maximum differences in pupil diameter ranged from 0.5 mm to 2.0 mm. The vehicle alone did not affect the diameter of the pupil.

The appearance of pupillary dilation in the treated eye of all 10 subjects was striking in contrast with the negative results of a previous study.[3] The return of pupil size to baseline levels in 7 subjects before the drug was stopped suggested an adaptive phenomenon. Qualitative inspection of pupillographic records indicated that the dilated pupil appeared to respond to a light stimulus in a relatively normal manner. This fact, plus the presence of ptosis (lid droop) in the treated eye, seems to rule out sympathetic nervous system stimulation as a cause of the dilation. Alternate possible mechanisms are weakening of the muscular elements of the sphincter or interference with the cholinergic innervation to the sphincter.

As for the possibility of a muscular weakening factor, it has been reported that corticosteroids administered systemically have produced functional weakness in human skeletal muscle and necrosis or loss of mass in the skeletal muscles of laboratory animals.[4] Similar effects have been observed in animal cardiac muscle in vivo and in vitro.

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