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TWO DEVICES FOR ANALYSIS OF NYSTAGMUS

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TWO DEVICES FOR ANALYSIS OF NYSTAGMUS*

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SUMMARY PAGE

THE PROBLEM

Development of methods and devices to facilitate measurement and analysis of nystagmus records.

FINDINGS

One of the two devices developed requires manual alignment of a crosshair with the nystagmus slope. This process is much faster than unaided manual scoring because 1) the mechanical aid in slope measurement is very effective, 2) time measurement is virtually automatic, and 3) all steps after the crosshair alignment, including tabulation of digital information and plotting of analog information, are accomplished automatically. The second device uses an area-summating electronic circuit combined with a timing switch for measuring average slow phase velocity. The main components are inexpensive plug-in units available for recording systems commonly used in electronystagmography. This device is less versatile but much faster than the first. Although not equivalent to a complex digital computer system, this device does provide immediate analog and digital display of analyzed nystagmus. Additional operations performed on the output of these devices can provide immediate estimates of the $\frac{\Pi}{\Delta}$ time constant and other parameters with potential clinical significance. Topics discussed include sources of error in several methods of scoring nystagmus and advantages of rapid nystagmus processing for experimental purposes, for aviator evaluation, and for clinical application.

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INTRODUCTION

The recording of vestibular nystagmus by electronystagmography and other methods is becoming a common practice in clinical (8, 18) and experimental (2-5) evaluation of the vestibular system. With adequate recording equipment, displacement of the pen is approximately proportional to angular displacement of the eyes, and paper speed determines the time base of the recordings. Several measurements of such records have been of primary interest: 1) duration of nystagmus, 2) total angular displacement of the eyes in the slow phase direction within some time interval, 3) angular velocity of the eyes in the slow phase direction at a number of points in time during the course of the response, and 4) number of nystagmus beats.

With the exception of duration, which requires a decision only about nystagmus termination, these different measures of nystagmus can be very time consuming when done manually. The present report describes two devices, one similar to a trace reader described by Benson and Stuart (2) and another complementary device, which facilitate measurement of nystagmus records and also facilitate the digital and analog presentation of the analyzed nystagmus data.

A. ELECTROMECHANICAL SLOPE COMPUTER

Measurement of Slow Phase Velocity and Time of Each Nystagmus Beat

In the experimental and clinical evaluation of nystagmus it is often desirable to obtain paired measures of 1) the slow phase velocity of each nystagmus beat and 2) the time of occurrence of the beat measured from some temporal starting point, e.g., the end of stimulation.

Although computer methods are available for stimulus-response patterns which are used a great number of times, measurement of new or occasionally used stimulus response patterns can be facilitated greatly by a device for "reading out" the slope and time of each nystagmus waveform. The device diagrammed in Figure 1 and pictured in Figure 2 serves to accomplish this task. It consists of:

1) A table with bearings and ways for a main carriage that moves laterally, i.e., along the x-axis, which is the time-axis. A potentiometer attached to the carriage provides voltage, proportional to lateral displacement, which is the time analog. The carriage contains bearings and ways permitting perpendicular movement of a polished plexiglass assembly along the y-axis. The plexiglass assembly contains a central transparent disc with crosshairs. Aligning one of the central crosshairs with a nystagmus slope turns the wiper of a potentiometer which provides a voltage proportional to angular displacement. The tangent of this angle is equal to nystagmus slope when the recording paper has been properly positioned on the table. The table is 66 inches (x-axis) by 24 inches (y-axis) to accommodate measurement of a convenient length of an 8-channel oscillograph record.

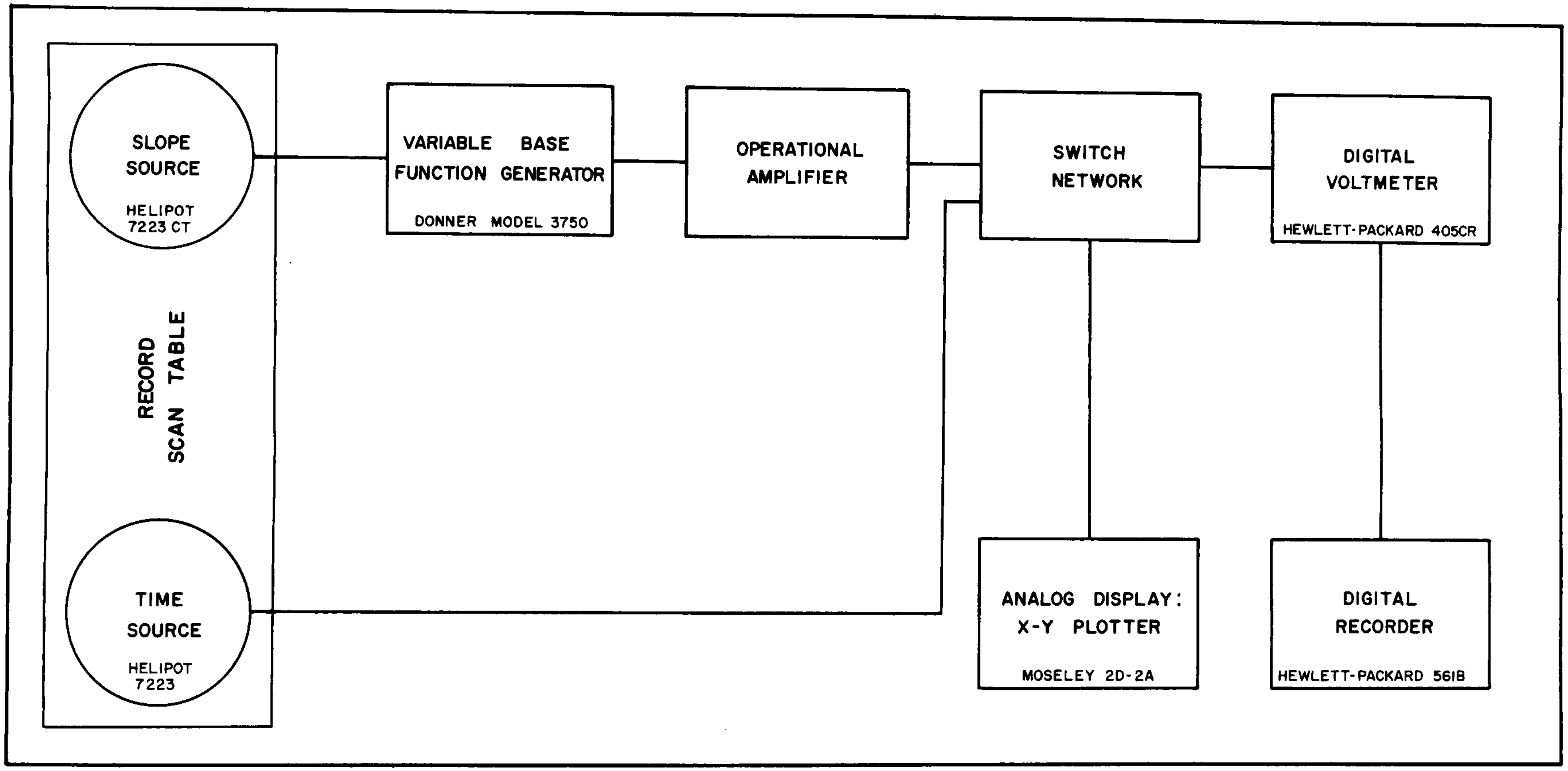

Figure 1

Diagram of Major Components in the Electromechanical Slope Computer

Figure 2

Photograph of the Electromechanical Slope Computer

Record scan table is on left; upright rack contains, in order from top: digital voltmeter, digital recorder, function generator, and operational amplifier; and the X-Y recorder is on right.

2) A variable base function generator converts the angular-displacement voltage into tangents of the angle. Tangents are in turn converted into angular velocity of the eyes in degrees per second by setting a dial on the operational amplifier. Appropriate dial settings are obtained from routine eye-movement calibration procedures.

3) An X-Y plotter produces the analog display of slow phase eye velocity plotted with respect to time.

4) A digital voltmeter and a digital recorder provide printed records of the time and angular velocity of each measured slope.

With this device, records can be scored, tabulated, and plotted in about one-tenth the time required for unaided manual completion of the job. The scorer's task of aligning the crosshair of the central disc with a nystagmus slope is illustrated in Figure 3. The intersection of the crosshairs is the time printed and plotted; thus, time printed for the beat measured in Figure 3 is at the midpoint of the beat. Because the device is properly machined, the alignment is accomplished quickly.

To compensate for baseline shifts, the outer disc can be rotated, thereby displacing the central disc and potentiometer together as a unit. This rotates the central hairline without changing the output of its potentiometer. In practice this adjustment has been used very little.*

A foot switch triggers printout of the time (T) and velocity (V) of each beat and also triggers the X-Y plotter. The type of information thus obtained is shown in Figure 4. The initial nystagmus recording is shown beneath the analog display (plotted graph); the tabulated digital readout is presented in the columns on the right in Figure 4. The extreme righthand column designates decimal positions for the middle column of three-digit number sets. Decimal points were inserted manually into these sets for illustrative purposes in this report. The plus and minus signs are printout designations of nystagmus direction. The lowermost pair of three-digit sets refers to the first nystagmus beat which has a slow phase velocity (V) of 4.10 deg/sec at a time of 0.733 seconds. The next pair of V and T scores above these refer to the second beat, et cetera. The graphic plot was made by the X-Y plotter; labeling of the coordinates was the only drafting work required before photographic reproduction of Figure 4.

Data available on other channels of the oscillograph record can also be included in the digital and analog display. For example, the time of the beginning and end of the stimulus, the magnitude of the stimulus, and points of subjective signals can all be displayed. In the analog display, other events can be indicated sufficiently above or below the x-axis to avoid confusion with the plotted eye velocity, while in the digital

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* Another potentiometer driven by the outer disc could be used to register baseline shifts on one channel while nystagmus relative to this baseline would be displayed on another channel. This feature has not been incorporated into the present device.

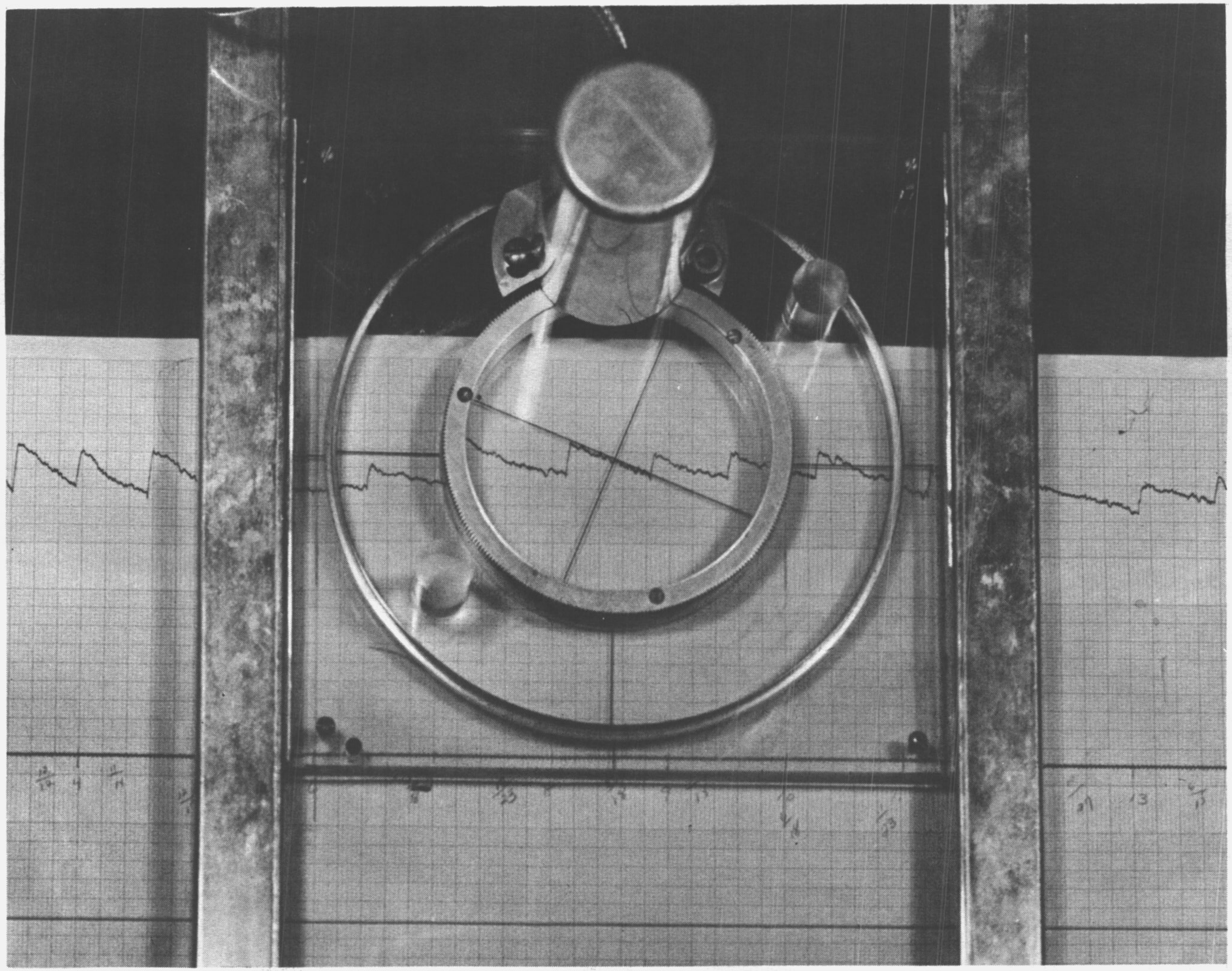
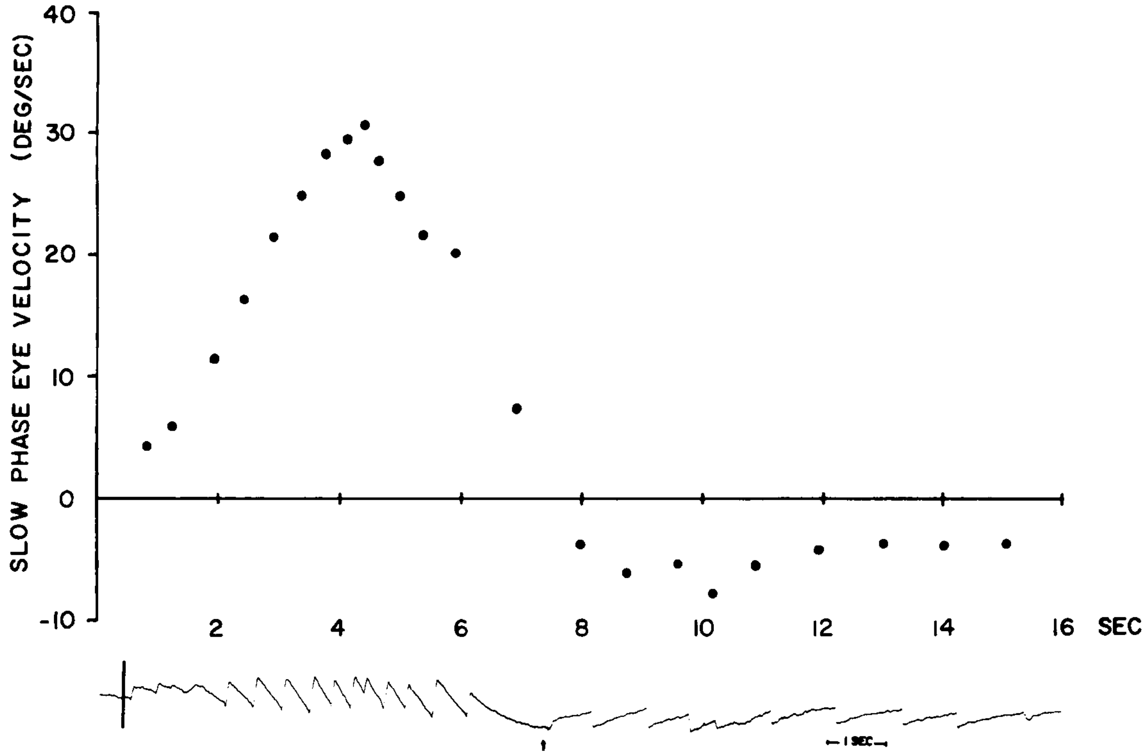


Figure 3

Close-up Photograph of Plexiglass Assembly and Potentiometer for Measuring Angular Displacement of the Inner Disc

Inner disc is rotated manually to align crosshair with nystagmus waveform.



Time	1 5.0		1
Velocity	4.4 8	-	2
T	1 4.0		1
V	4.4 6	-	2
T	1 3.0		1
V	4.3 7	-	2
T	1 1.9		1
V	4.8 9	-	2
T	1 0.8		1
V	6.3 1	-	2
T	1 0.1		1
V	8.6 0	-	2
T	9.5 3		2
V	6.0 8	-	2
T	8.6 9		2
V	6.8 6	-	2
T	7.9 2		2
V	4.4 2	-	2
T	6.8 6		2
V	7.2 3	+	2
T	5.8 4		2
V	2 0.6	+	1
T	5.2 9		2
V	2 2.3	+	1
T	4.9 1		2
V	2 5.5	+	1
T	4.5 6		2
V	2 8.6	+	1
T	4.3 1		2
V	3 1.8	+	1
T	4.0 4		2
V	3 0.6	+	1
T	3.6 9		2
V	2 9.3	+	1
T	3.2 9		2
V	2 5.8	+	1
T	2.8 1		2
V	2 2.1	+	1
T	2.3 3		2
V	1 6.7	+	1
T	1.8 3		2
V	1 1.5	+	1
T	1.1 4		2
V	5.8 3	+	2
T	.7 3 3		3
V	4.1 0	+	2

Figure 4

Analog Display (Graphic Plot) and Digital Display (Righthand Columns) of Measurements of the Original Nystagmus Record (Shown below Graphic Plot) readout they would be displayed in a particular sequence before or after the set of V and T measures of nystagmus.

This device is also convenient for analysis of cyclic events. For example, rotation about an Earth-horizontal axis produces prolonged nystagmus with a cyclic modulation regulated by position of the skull relative to gravity (5). Nystagmus velocity can be measured at selected points in the cycle, e.g., every 30 degrees. If desired, measures obtained from 10 or 20 cycles can be superimposed on one graph to show the average cyclic variation as well as the dispersion (Figure 5). Of course, the cycles can also be examined sequentially to ascertain temporal shifts in the cyclic modulation.

B. ELECTRONIC SUMMATION DEVICE

Measurement of Summed Slow Phase Displacement and Average Slow Phase Velocity

Total angular displacement of the eyes has been measured in many studies to obtain a single numerical score representing the magnitude of a nystagmus reaction (3). Fast phases are ignored, and slow-phase displacement is summed from one beat to the next throughout the preselected interval. If the interval selected is the entire duration of the primary vestibular nystagmus, then the measure gives the entire angular displacement of the eyes in the slow phase direction. Scores may range up to several thousand degrees, depending upon the magnitude and duration of the stimulus and the responsiveness of the subject. Dividing such a score by timed duration of the response provides another score, average slow phase velocity. Since responses may be either weak but long or strong but short, these two indicators may vary somewhat independently.

Integrating preamplifiers used in the area-summation mode are a means of summing successive nystagmus beats for the entire response or for successive intervals within a response. It should be noted that the operations involved are the inverse of electronic differentiators which have been used (14, 16, 17) to convert eye displacement to eye velocity measures. The quality of the final tracing with summating circuits is not degraded by electrical and biological noise which would be sufficient to make qualitatively unacceptable the final product of electronic differentiation. The quantitative result in either of these operations can be influenced by noise, but the occasional corrections thus necessitated do not outweigh the advantages of electronic summation.

The equipment diagrammed in Figure 6 was assembled from commercially available and relatively inexpensive components. It comprises a basic recording system with two plug-in units, an integrating preamplifier and a timing switch, and three auxiliary units. Only the integrating preamplifier and the basic recording system are required for the "total output" scores. This preamplifier must be used in the area-summation mode, and the Input Selector switch is set to the Single-Ended AC position. This gives a 10-cps low-frequency roll-off. The fast phase of nystagmus must step the recording pen in a positive direction to achieve acceptable accuracy. A switch for reversing signal polarity allows processing of either left- or right-beating nystagmus. The second plug-in unit, the timing switch, permits an analog display by the recording pen of

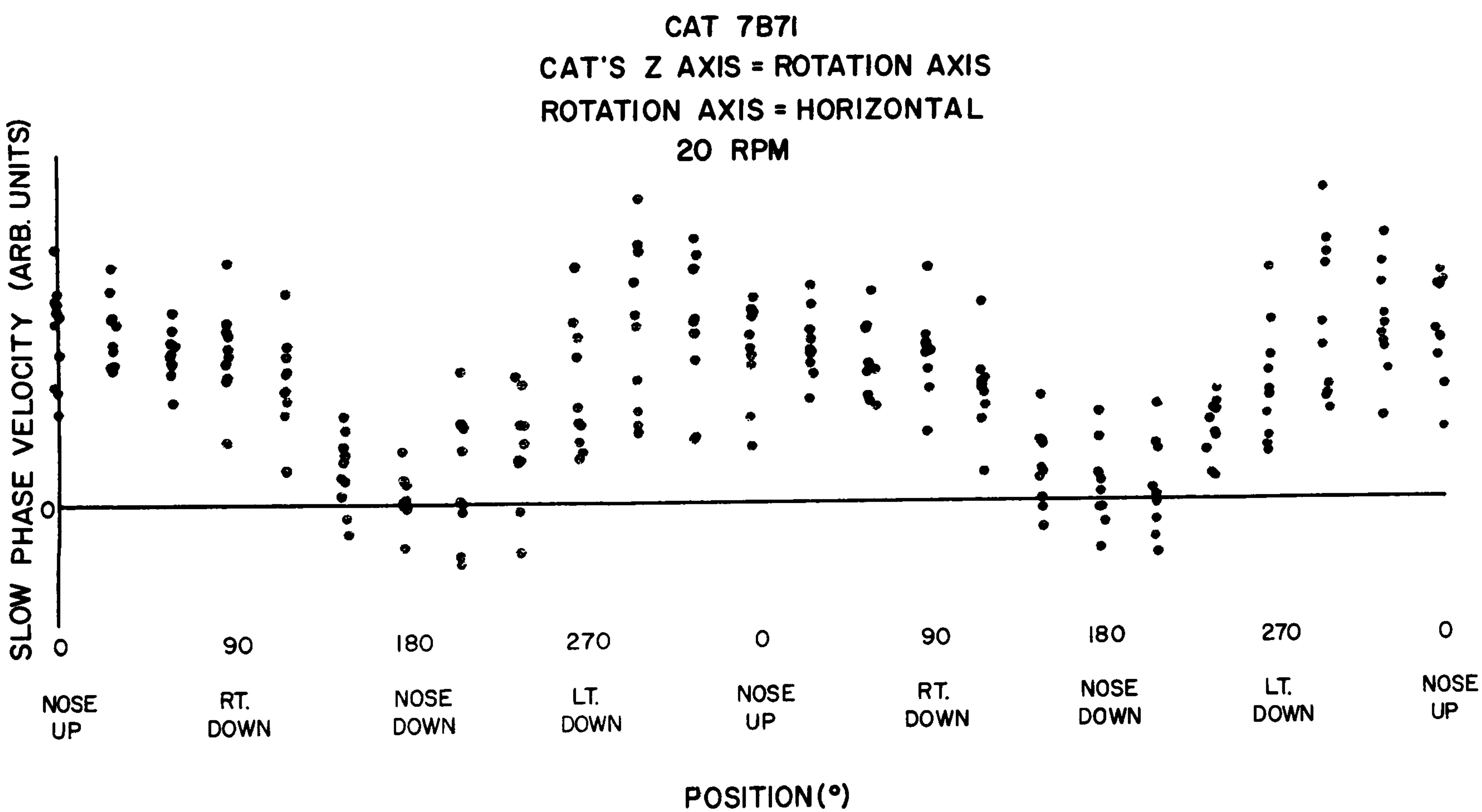


Figure 5

Cyclic Variation of Nystagmus Slow Phase Velocity during Rotation of a Cat about an Earth-Horizontal Axis

Plotted points from ten pairs of cycles were superimposed to derive the two-cycle plot shown above.

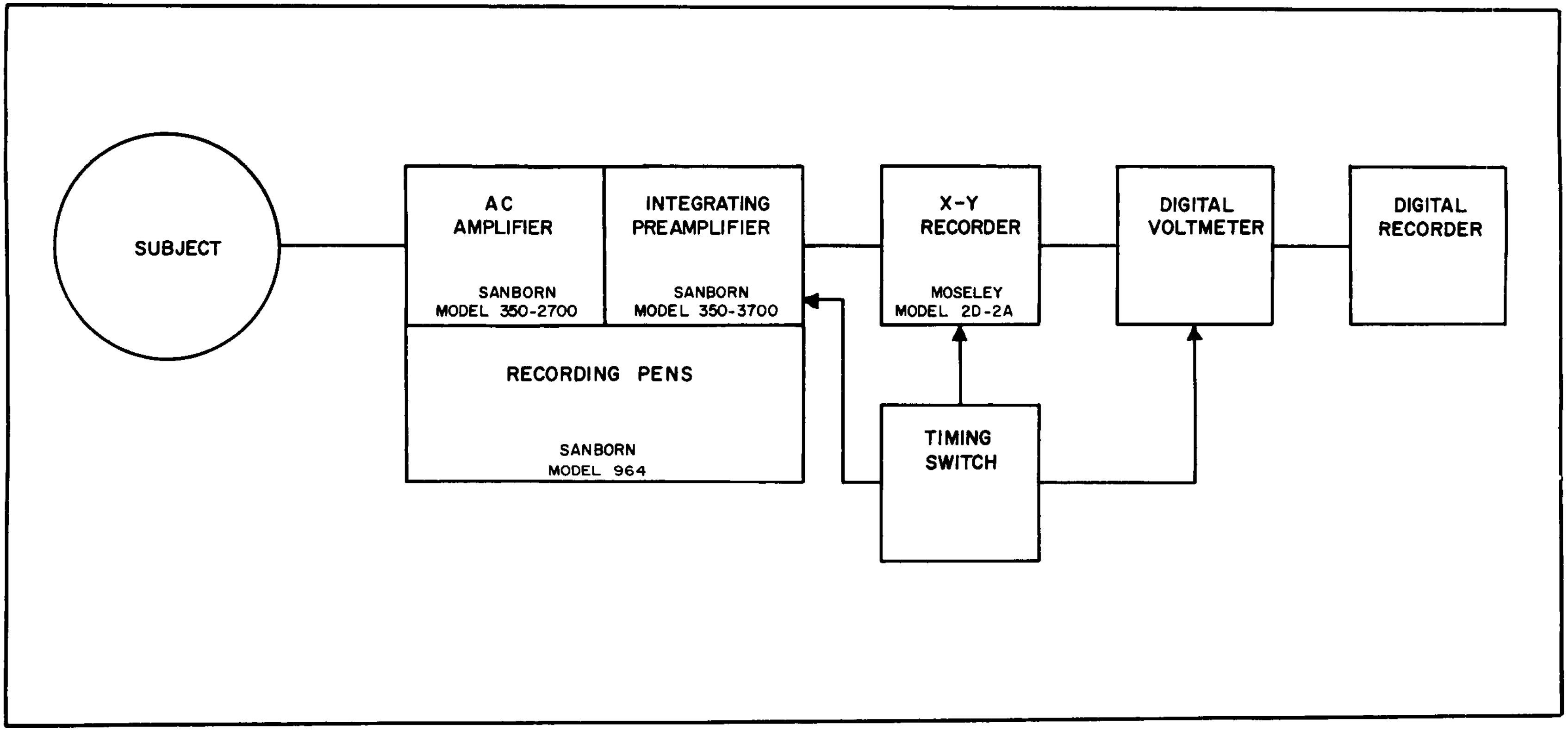


Figure 6

Diagram of Components for Obtaining Immediate Analog and Digital Display of Average Slow Phase Velocity

The integrating preamplifier and timing switch are plug-in units with the recording system.

average slow phase velocity in successive time samples of the response. The X-Y recorder merely provides an additional analog display, with minor qualitative advantages. The digital voltmeter and recorder* are required for digital printout.

Typical recordings are shown in Figure 7. Line A of Figure 7 is the usual displacement recording, and Line B is the summated displacement recording. Multiplying the total number of cycles in Line B by one calibrated cycle of the record provides the total slow phase output. For example, one cycle represents 150 degrees of slow phase eye displacement, and hence the 3.5 cycles shown represent 525 degrees, i.e., 3.5 x 150 degrees, of slow phase eye displacement. Noise and other sources of error noted in Line A can be subtracted from the total derived from Line B. The average slow phase velocity of any one cycle can be calculated by dividing the time required for the cycle into 150 degrees, or the average slow phase velocity for the entire response can be obtained by dividing total slow phase displacement by the total duration of the response. A sensitivity control can be used to change the rate of automatic recycling;# e.g., 5.25 cycles would have been produced in Line B if sensitivity had been increased so that 1 cycle = 100 degrees.

When the timing switch is used for recycling, eye displacement is summed within successive intervals of preselected length. Line C of Figure 7 shows results of timer recycling at two-second intervals. Pen displacement at the end of each interval is directly proportional to average slow phase velocity within the interval. Hence, an analog display of average slow phase velocity plotted for each two-second interval of the response is immediately available. An exception to this direct relationship occurs if very high velocity nystagmus produces recycling before the end of an interval. Prudent selection of sensitivity settings and interval duration will minimize these discrepancies, and any which still occur can be manually corrected by brief perusal of the tracings. Thus, the analog display of average slow phase velocity plotted with respect to time may be corrected by comparing Line A and B records which are obtained simultaneously. Two analog displays of the analysis of a nystagmus response by the Electronic Summation Device are presented in Figure 8 and compared with a hand-scored plot of the same response.

Figures 9 and 10 show relations between hand-scored records and records scored by this computer method. From such comparisons, it has been determined that the present method contains sources of error which can be corrected manually, but the errors in the uncorrected output appear no larger than errors made when large numbers of records are hand scored. Reliability on rescoring a record in this manner would far exceed reliability obtained when trained men score the same record independently.

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*The digital voltmeter and recorder must have fast response times; models indicated in Figure 1 are not adequate for this application.

#Sensitivity is set during calibration procedures involving controlled eye sweeps with visual targets.

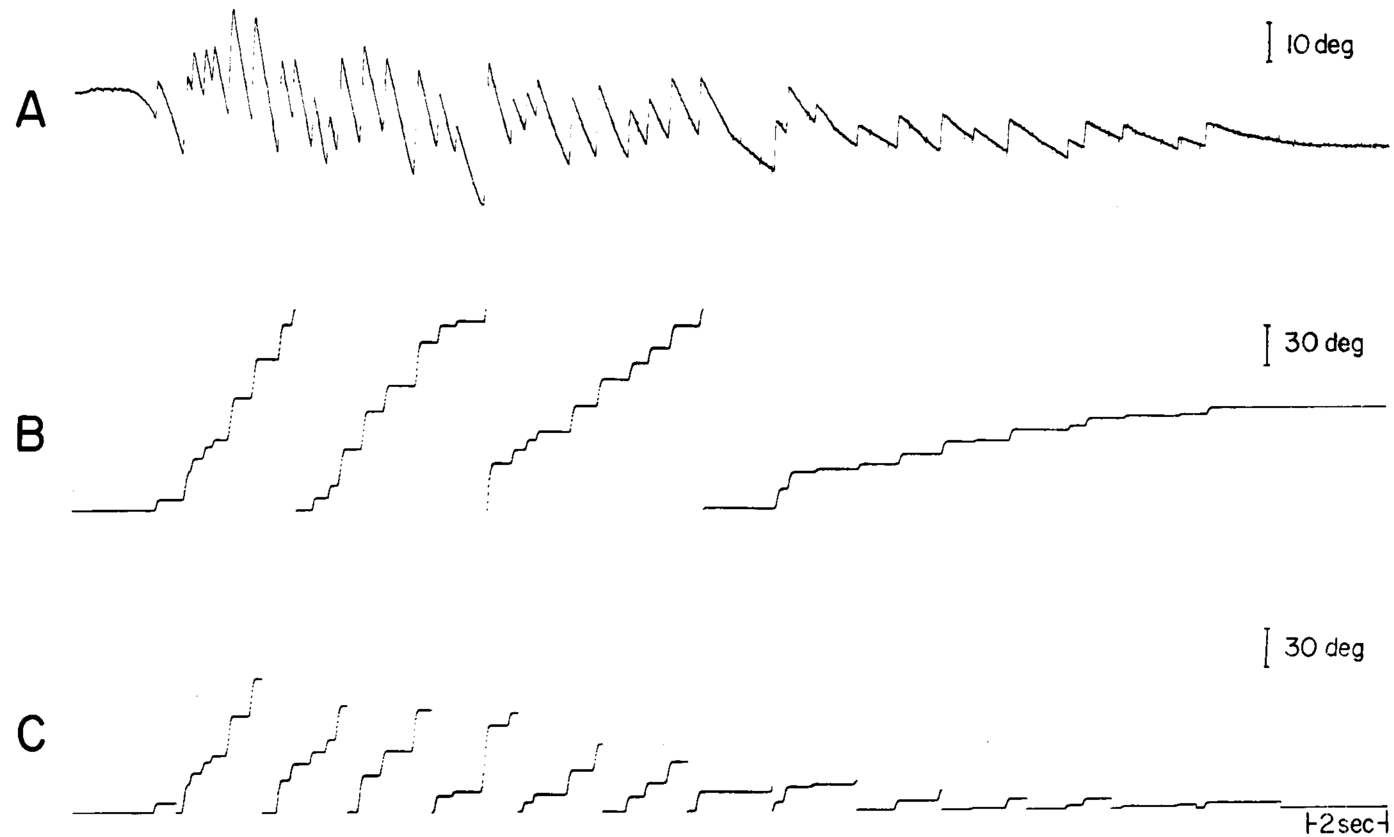

Figure 7

Nystagmus Recorded and Analyzed by ESD

Line A - A typical nystagmus record of eye displacement with respect to time.
Line B - Summated eye displacement (in one direction) with respect to time, with recycling set for 150 degrees of eye displacement.
Line C - Summated eye displacement in successive two-second intervals of the response. Height attained in each interval is proportional to average slow phase velocity of the interval.

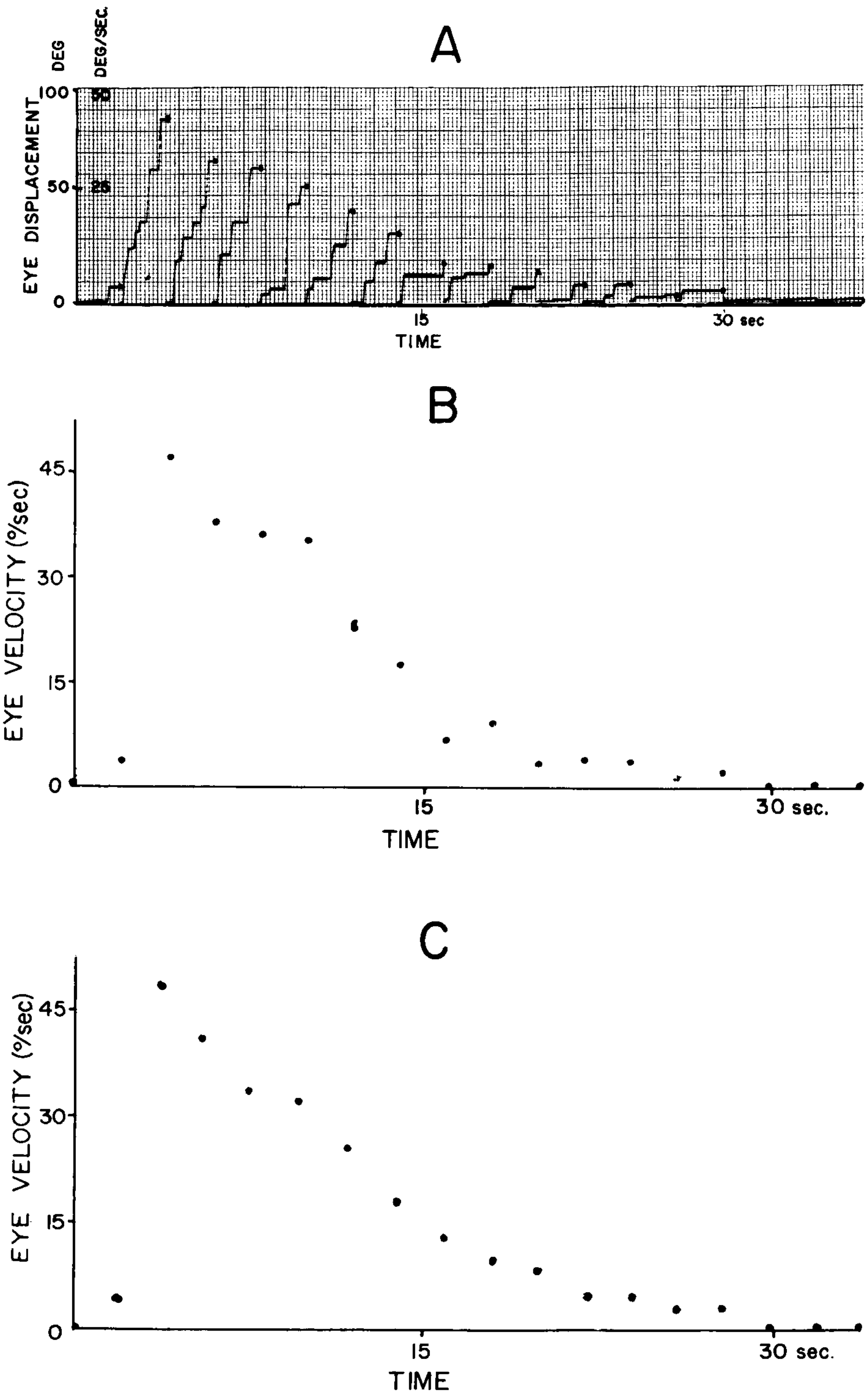

Figure 8

Displays of Average Slow Phase Velocity Per Two-Second Interval

A was obtained directly from the oscillograph pens. Dots were placed at the end of each cycle to aid visualization of the velocity curve.

B was produced by the X-Y plotter. Note: The eighth point is low; adjustment of timing relays can reduce such discrepancies.

C was calculated from hand measurement of slow phase displacement in each two-second interval of the record.

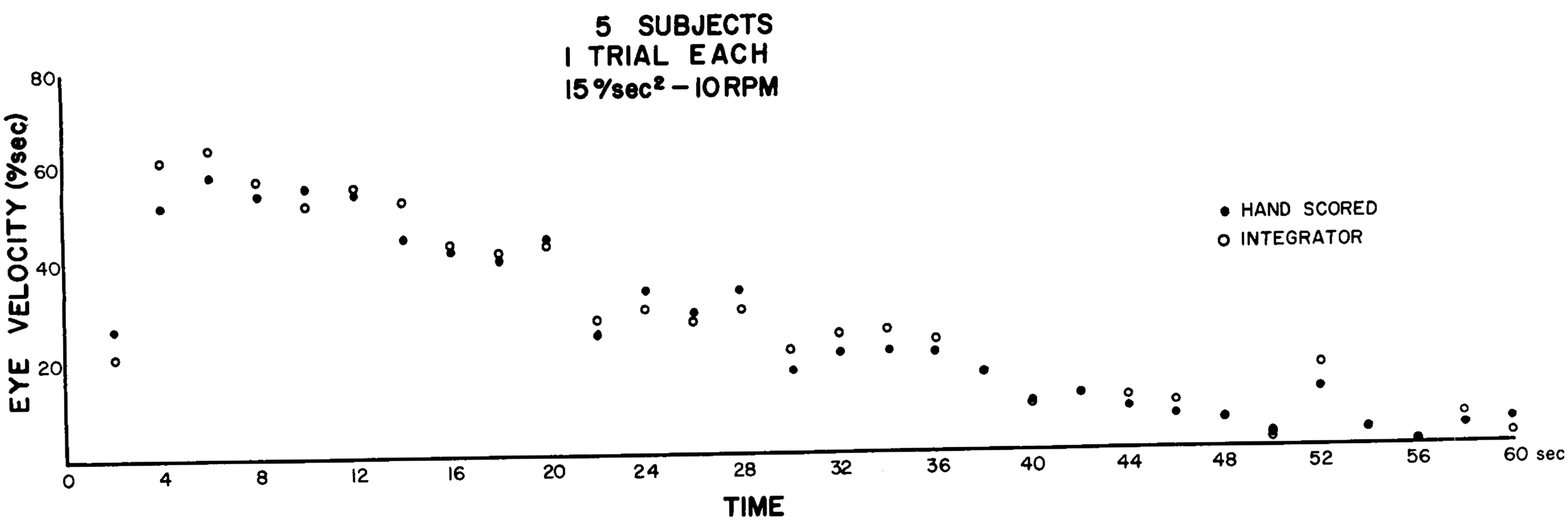

Figure 9

Average Slow Phase Velocity in Successive Two-Second Intervals Derived from Hand-Scored Records and from ESD Using Timer Recycling

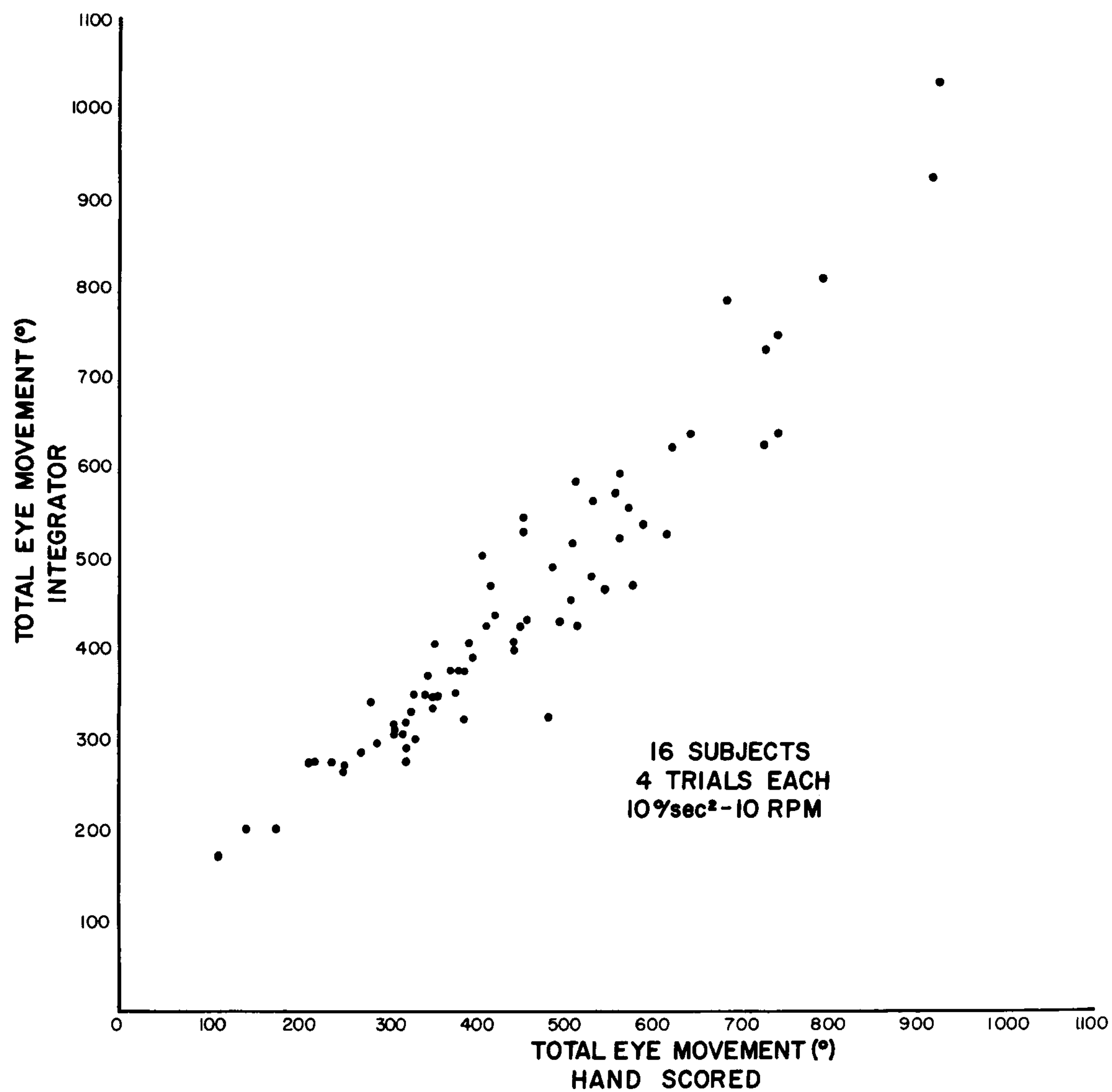

Figure 10

Scatter-Plot Showing Relationship between "Total Output" Scores Obtained from Hand-Scoring and "Total Output" Scores Obtained from ESD

C. ADDITIONAL OPERATIONS

Computation of the $\frac{\Pi}{\Delta}$ Time Constant

Additional operations can be performed on the measurements obtained from either of the devices described to derive other more abstract measures. These operations can be performed manually or by computers, but in either case the choice of operations depends upon a logical evaluation of theorized stimulus-response relationships and the intended use of the data.

Nystagmus cupulograms, for example, can be derived from the duration of nystagmus following impulse stops from various angular velocities or they can be obtained from the decay in nystagmus following a single stimulus (2, 10). From either of these procedures, the time constant of decay, $\frac{\Pi}{\Delta}$, can be calculated. This value has been assumed theoretically to represent the ratio of friction to spring action in an analogy which likens the cupula-endolymph system to an overcritically damped torsion pendulum (7). Although it is well recognized that neurological processes complicate this simple analogy, cupulograms have been used in the clinical evaluation of diseases of the vestibular system (6) and have been suggested for use in evaluating flight personnel (1).

Following an angular acceleration, nystagmus velocity (V) declines systematically. According to the torsion pendulum analog, LnV plotted against time forms a straight line. Paired values of V and T can be automatically converted into LnV and T pairs which can be programmed to generate an immediate estimate of $\frac{\Pi}{\Delta}$. The computer program required is a common one involving the Pearson Product-Moment Correlation formula. The ratio $\frac{\Pi}{\Delta}$ is the reciprocal of the slope of the straight line of best fit through the LnV, T points. Determination of the slope of the line of best fit by the method of least squares is part of the information obtained from the Pearson Product-Moment Correlation formula. Hence, the computer must be simply instructed to find the correlation between LnV and T. In addition to $\frac{\Pi}{\Delta}$ estimates, this basic program can easily provide the maximum slow phase velocity, i.e., the antilog of the LnV-intercept, the total number of beats, and the variance about the line of best fit. The latter parameter, variance, may be large due to a number of interruptions in the systematic decay of nystagmus or to a systematic departure from a straight line fit. Since clinical significance has been attributed to interruptions in systematic decay of nystagmus (15), programming a more detailed analysis of variance might be informative. Because of the potential importance of variance analysis, the output of the Electromechanical Slope Computer, which provides many V,T data points, would be desirable input for this additional operation.

DISCUSSION

The Electromechanical Slope Computer (ESC) aids in the analysis of any nystagmus record. Every individual beat and any segment of every beat can be scored. Selected beats, segments of beats at selected points in time or at selected portions of cycles can be analyzed and related to stimulus characteristics. Baseline shifts, changes in signal strength, blink artifacts, and other noise sources can be compensated. Much of this versatility derives from the fact that human judgment is an element in the operations that produce the final outcome. The same element which produces the versatility also slows the scoring process. However, the total process is much faster than unaided manual scoring because 1) the mechanical aid in the manual measurement of slope is very effective; 2) the measure of time is obtained simultaneously; and 3) all of the steps after the manual alignment, including tabulation and plotting of digital and analog information, respectively, are done automatically.

The Electronic Summation Device (ESD) provides much faster analysis than the ESC. However, the ability to analyze each beat and segments of beats is sacrificed. Scores which are close estimates of total slow phase displacement can be obtained quickly. These are valuable in habituation studies where it is sometimes desirable to have one number which serves to indicate the strength of the nystagmus reaction. Moreover, analog and digital displays of average slow phase velocity within successive time samples of the response are also immediately available with this method. The results of the electronic summation procedures may contain errors from unsystematic saccades, blinks, muscle discharge, et cetera. If noise from these sources is excessive, manual correction is required.

These same sources of error are problems with electronic differentiation circuits that are more or less the inverse of operations involved in electronic summation. Although electronic differentiation is the obvious logical procedure to obtain slow phase velocity, it also differentiates and amplifies many sources of noise. The final tracing has more "hash" than was initially present, and differentiated records frequently require time-consuming analysis to estimate average slow phase velocity of each individual beat. With electronic summation procedures, the output is clean, but sources of noise in the nystagmus recording may require manual correction as noted above. In more complex computer systems, these problems can be handled by programming logical decisions to discontinue analysis during artifact periods.

Rapid scoring of nystagmus and additional computer analysis of data will permit studies which have not been feasible with manual scoring and analysis. The ESC and ESD make rapid processing available to laboratories which do not have complex computer installations. However, there are several points which should be kept in mind as more advanced computation methods develop:

1) The speed of measurement and analysis will not lessen the need for control of conditions which influence the initial nystagmus record itself, such as arousal (3,4), visual stimulation (4), electrodes (9), repeated exposure (3), and stimulus control. The standardization of testing procedures is a fundamental necessity if meaning is to be attached to norms and correlations established within and between laboratories.

2) While it is valuable to find laborsaving automatic scoring methods, it is equally valuable to find stimulus-response patterns (including responses other than nystagmus) which will minimize scoring effort, maximize test-retest reliability, and also generate

more information content. Efforts in this direction have been suggested in the past (11, 13, 16) and are in progress (12). It is theoretically possible to estimate $\frac{\Pi}{\Delta}$ by several stimulus patterns in addition to those mentioned in Section C, and it would be valuable to determine whether the different estimates are in fact closely correlated. If they are, then the simplicity of the procedure and reliability of the test would dictate the choice of testing procedure. If they are not correlated, then the measures may have different clinical significance, or alternatively, one or more of the measures may be unreliable or invalid. Nystagmus decay curves generated by some procedures may not contain reliable information content irrespective of the elegance and speed of processing and analyzing nystagmus. However, logical application of computer methods should expedite elimination of unreliable procedures and also speed establishment of valid procedures.

Computation by complex digital computer facilities offers most of the advantages of both of the devices described herein and, of course, permits additional measurements and operations. However, the number of computer instructions which would be required for all of the decisions made during the use of the ESC suggests that its versatility will be difficult to match by a computer without a human component.*

Rapid analysis of nystagmus is of potential advantage to aviation medicine because ideas can be investigated by procedures which previously would have been far too time consuming. Many new measurements and correlations between tests and measurements can be evaluated. Very high correlations among several tests may result in elimination of all but the simplest. Test-retest reliability can be checked and norms can be established. Estimates of validity and probability statements can be put on a quantitative basis. All of these steps should be substantial aids in the diagnostic evaluation of clinical cases and of aviation personnel disturbed by problems of equilibration, vertigo, and motion sickness. Moreover, detailed analysis of individual responses, which has been too time consuming for routine clinical evaluation of flight personnel, is becoming feasible.

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*The process of instruction-writing may well produce explicit instructions for some judgments which heretofore have been relatively personal in manual scoring.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

Two devices are described which facilitate measurement and analysis of nystagmus. One device requires manual alignment of a crosshair with the nystagmus slope. This process is much faster than unaided manual scoring because 1) the mechanical aid in slope measurement is very effective, 2) time measurement is virtually automatic, and 3) all steps after the crosshair alignment, including tabulation of digital information and plotting of analog information, are accomplished automatically. The second device is a standard recorder with plug-in units for area-summation and timed switching. It is less versatile than the first device, and is not equivalent to advanced electronic computation, but it does provide an immediate analog display and (with a digital voltmeter-printer) an immediate digital display of analyzed nystagmus. Additional operations performed on the output of these devices can provide estimates of the $\frac{\Pi}{\Delta}$ time constant and other parameters. Topics discussed include sources of error in rapid processing of nystagmus and advantages of rapid processing for experimental purposes, for pilot evaluation, and for clinical application.

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