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NYSTAGMUS RESPONSES DURING TRIANGULAR WAVEFORMS OF ANGULAR VELOCITY ABOUT THE Y- AND Z-AXES

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13. ABSTRACT

Nystagmus response parameters were estimated by a test procedure using short triangular waveforms of angular velocity. Mean estimates were determined as follows: Π/Δ = 15.5 seconds and K_n (θ/Δ) = 8.0 seconds for the horizontal semicircular canals, and Π/Δ = 6.8 seconds and K_n (θ/Δ) = 5.4 seconds for the vertical semicircular canals. The Π/Δ values are consistent with results obtained by other methods. Values of K_n (θ/Δ) have not been heretofore assessed. Determination of the effects of stimulus distortion on the values of the response parameters and estimates of intersubject and intrasubject variability are included. Also included are nomograms that permit a simple and accurate method for calculating Π/Δ and K_n (θ/Δ).

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SUMMARY PAGE

THE PROBLEM

In previous reports, parameters of the subjective semicircular canal reaction were estimated from responses to a series of test stimuli consisting of short triangular waveforms of angular velocity. In this report the feasibility of additional test procedures with short triangular waveforms that permit estimation of nystagmus response parameters is examined.

FINDINGS

Mean estimates of nystagmus response parameters were determined as follows: $\Pi/\Delta = 15.5$ seconds and $K_n\ (\theta/\Delta) = 8.0$ seconds for the horizontal semicircular canals, and $\Pi/\Delta = 6.8$ seconds and $K_n\ (\theta/\Delta) = 5.4$ seconds for the vertical semicircular canals.

These Π/Δ values are consistent with results obtained by other methods. Values of $K_n\ (\theta/\Delta)$ have not been heretofore assessed due to lack of a suitable method. Determination of the effects of stimulus distortion on the values of the response parameters and estimates of intersubject and intrasubject variability are included. Also included are nomograms that provide a simple method for calculating Π/Δ and $K_n\ (\theta/\Delta)$.

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INTRODUCTION

In previous reports parameters of the subjective reaction to semicircular canal stimulation were estimated from responses to a series of test stimuli consisting of short triangular waveforms of angular velocity (7,8,10). Essentially the same test procedures permit estimation of nystagmus response parameters of both the horizontal and vertical semicircular canals.

These procedures are based on a set of equations,derived from the torsion pendulum model, which has been used extensively by van Egmond, Groen, and Jongkees (3). The equations assume an ideal stimulus waveform, but in practice the waveform is often distorted due to performance limitations of the rotary device. Minor deviations from the ideal waveform are probably inconsequential, but the resulting errors may become significant when, for example, fine discriminations between individuals are made or when measurements from several laboratories are compared. Therefore, the effect of stimulus waveform distortion on parameter estimation was also examined in this report.

PROCEDURE

SUBJECTS

Twenty U. S. naval and marine officers served as subjects. These men ranged in age from 20 to 26 years. All had recently passed standard Navy flight physical examinations without signs of vestibular disorders.

APPARATUS

The rotation device was a Stille-Werner RS-3 rotator fitted with a rectangular platform and a removable chair. The device was controlled by an external command voltage generated by a low-frequency waveform generator. Stimulus angular acceleration was recorded from an accelerometer mounted on the rotation platform, and angular velocity was recorded from a tachometer attached to the drive motor.

Appropriately placed Beckman electrodes were used to record corneoretinal potentials from the subjects. These potentials were led through sliprings to a Sanborn 350 recording system and displayed on a chart recorder. The time constant of the amplification system was 2.5 seconds.

Stimulus angular acceleration and velocity were also recorded on the chart display, and angular acceleration was recorded on magnetic tape. The angular acceleration signal was later fed into an analog computer to generate a theoretical response curve for comparison with the one obtained from the prediction equations.

METHOD

Responses from both the horizontal and vertical semicircular canals were tested.

To stimulate the horizontal canals, the subject was seated upright in the chair so that his z-axis was aligned with the axis of rotation. To stimulate the vertical canals, the chair was removed, and the subject was positioned on his right side on the platform so that his y-axis was aligned with the axis of rotation. Half of the subjects were tested in the seated position first, and half were tested in the right-side-down position first.

The stimulus consisted of a triangular waveform of angular velocity formed by programming a 15 deg/sec^2 acceleration to last for 6 seconds, followed immediately by deceleration of the same magnitude and the same duration. This stimulus was administered ten times in each position with the direction of rotation alternated from trial to trial.

Subjects were tested in total darkness with their eyes open. Mental alertness was maintained by requiring the subjects to add a series of numbers read to them during stimulation and to answer after stimulation had ceased. Eye movements were calibrated before and after each stimulus presentation. The intertrial interval was 30 seconds.

The nystagmus records were scored with a device (6) that provides a readout, in both graphical and digital form, of slow phase eye velocity as a function of time. In addition, two measurements were obtained for calculation of parameter estimates. The first measure was the magnitude of peak slow phase eye velocity ($\dot{\psi}_{max}$), and the second was the time interval (t_r) from the end of the acceleration period (T_1) to response reversal. Figure 1 illustrates the way in which these two measures were obtained.

Calculations of parameter estimates were based on the assumption that the vestibular stimulus was a triangular waveform of angular velocity formed by a constant acceleration followed immediately by a constant deceleration of the same magnitude and duration. However, the actual stimulus waveform was distorted, as shown in Figure 1, particularly when the angular acceleration reversed direction. As a result, acceleration persisted beyond the point of initial change. Thus, for parameter estimation, the point at which acceleration passed through zero was chosen to mark the end of T_1, the beginning of t_r, and approximately when $\dot{\psi}_{max}$ should occur.

Two theoretical response curves were generated: one from the prediction equations (7) assuming an idealized acceleration waveform, and the other using the actual acceleration waveform on the analog computer programmed with the appropriate second-order differential equation. The latter response curve was obtained by manipulating the values of the program to achieve the same $\dot{\psi}_{max}$ and reversal point found in the actual nystagmus response. Both curves were then compared in order to assess the effects of stimulus waveform distortion.

RESULTS AND DISCUSSION

ESTIMATION OF RESPONSE PARAMETERS

Mean nystagmus responses for the group are shown in Figure 2. Significant

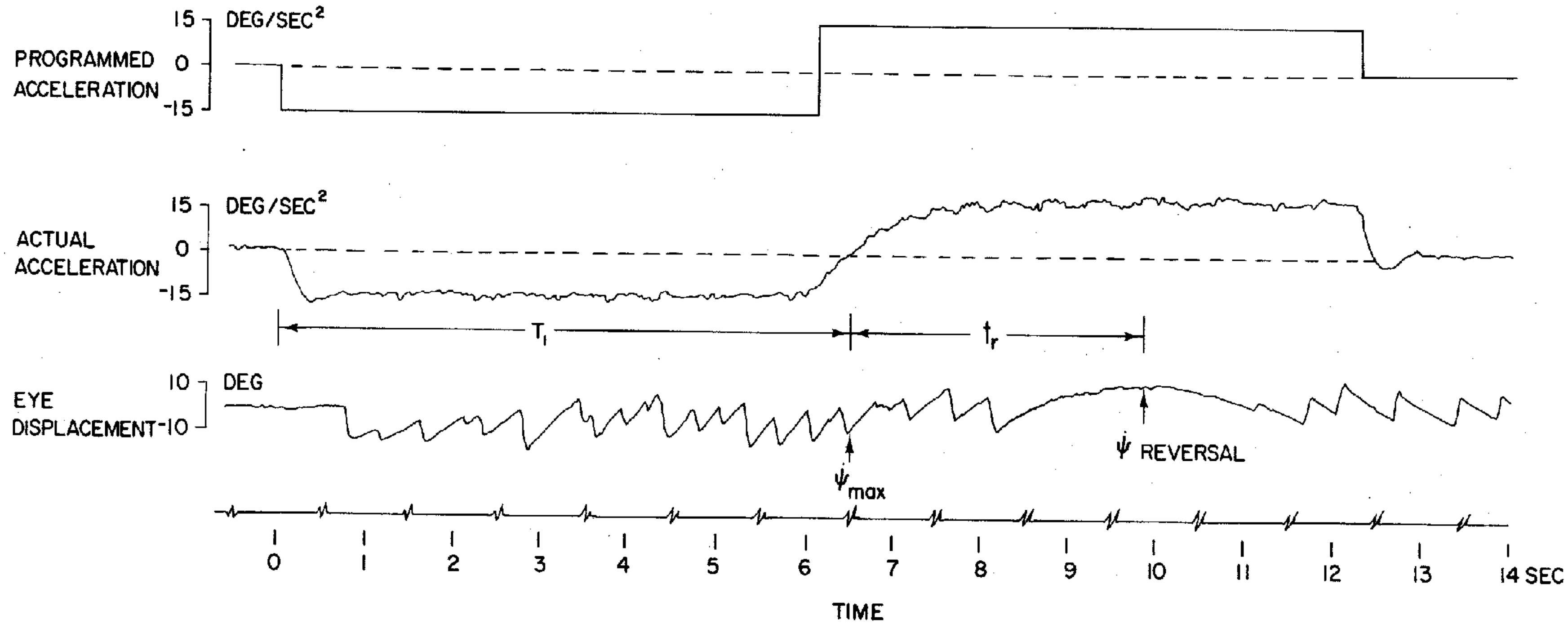

Figure 1

A sample record showing programmed acceleration, actual acceleration, and recorded eye displacement for stimulation of the vertical semicircular canals. Peak slow phase eye velocity ($\dot{\psi}_{max}$) is measured approximately at the end of the acceleration period (T_1), and the time interval (t_r) is measured from the end of T_1 to the point of response ($\dot{\psi}$) reversal.

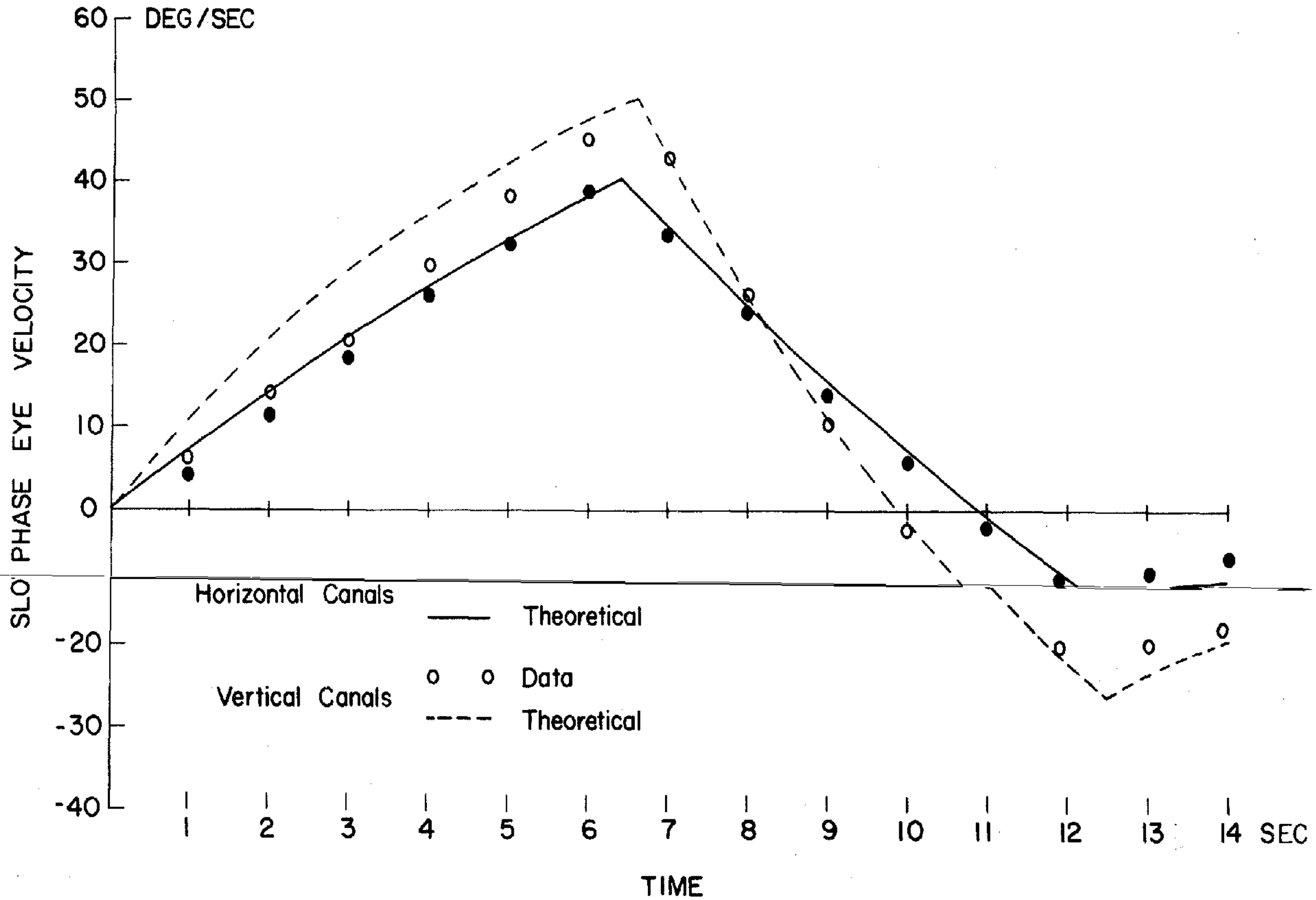

Figure 2

Nystagmus responses from stimulation of the horizontal and the vertical semicircular canals by a triangular waveform of angular velocity. Data points represent the mean of 20 subjects X 10 trials. Smooth curves represent theoretical responses calculated from the prediction equations.

differences were found between the responses of the horizontal canals (z-axis rotation) and those of the vertical canals (y-axis rotation). The total slow phase displacement of the two responses was approximately the same, but the peak magnitudes of both primary and secondary nystagmus were greater and the reversal occurred sooner for the vertical canal response. These differences were statistically significant ($p < .0005$).

According to the equations derived in previous reports (7,8), the nystagmus response can be specified if the values of two parameters, Π/Δ and $K_n\ (\theta/\Delta)$, are known. The value of Π/Δ can be determined from t_r, and once Π/Δ is known, the value of $K_n\ (\theta/\Delta)$ can be determined from $\dot{\psi}_{max}$. In practice, it is somewhat tedious to calculate these values from the equations. Therefore, nomograms were prepared, and are shown in Figures 3 and 4. The use of these nomograms is illustrated with the average values of t_r and $\dot{\psi}_{max}$ found in this study. For the horizontal canal response, t_r was 4.5 seconds and T_1 was 6.4 seconds. Thus, the value of Π/Δ, interpolated from Figure 3, is 15.5 seconds. These values of Π/Δ and T_1 used with Figure 4 give a value of $K_n\ (\theta/\Delta)/\dot{\psi}_{max}$ of 0.20 sec^2/deg which, when multiplied by the obtained $\dot{\psi}_{max}$ of 40.2 deg/sec, yields a $K_n\ (\theta/\Delta)$ value of 8.0 seconds.

For the vertical canal response, t_r was 3.3 seconds and T_1 was 6.6 seconds; therefore, Π/Δ is 6.8 seconds. A value of $K_n\ (\theta/\Delta)/\dot{\psi}_{max}$ of 0.11 sec^2/deg was then obtained from Figure 4 which, when multiplied by the $\dot{\psi}_{max}$ of 49.1 deg/sec, yields a $K_n\ (\theta/\Delta)$ of 5.4 seconds.

In the same way, parametric values can be obtained for other nystagmus data, once t_r and $\dot{\psi}_{max}$ have been measured. The nomograms were calculated for acceleration durations (T_1) of 5 to 7 seconds. Pilot studies indicated that this range is an optimum one when angular acceleration is 15 deg/sec^2 since the nystagmus response is difficult to score if the duration of acceleration is much less than 5 seconds, and the errors introduced by response adaptation (11) may become large if acceleration lasts much longer than 7 seconds.

The Π/Δ determinations from Figure 3 are independent of the magnitude of acceleration, but the $K_n\ (\theta/\Delta)$ values can be obtained from Figure 4 only for an acceleration rate of 15 deg/sec^2. For other acceleration rates, the correct $K_n\ (\theta/\Delta)$ value can be calculated from Figure 4 if the value of $K_n\ (\theta/\Delta)$ found from the figure is multiplied by 15 deg/sec^2 and then divided by the acceleration rate actually used.

The estimates obtained here for Π/Δ are generally consistent with those found by other investigators using various methods (1,7,9), thus supporting the validity of this procedure. Accurate estimates of $K_n\ (\theta/\Delta)$ have heretofore not been readily available, although calculation from data of Collins and Guedry (2), collected during prolonged angular acceleration, resulted in similar values. Further support for this procedure comes from the close fit to the data of the theoretical response curves generated by the prediction equation. Figure 2 shows that the equation accurately predicts the horizontal canal responses and for the most part, vertical canal responses. However, with vertical canal stimulation, there is a fairly pronounced departure of the rise in response during the initial acceleration from the theoretical rise curve. This may be attributable to difficulties in recording and scoring vertical nystagmus (1,4,9), but it may also be due to a real departure from the theoretical prediction. Nystagmus elicited by passive movement lacks the preparatory eyelid and brow movements which naturally accompany voluntary head rotations about the y-axis. The absence of these and other sensory data usually present in natural active movement may contribute to slow rise of the response, but, alternatively, the fact that the nystagmus velocity waveform approximates the shape of the stimulus velocity waveform more clearly than does its theoretical counterpart may reflect a need for restructuring some theoretical concepts.

EFFECTS OF STIMULUS WAVEFORM DISTORTION

It was shown in Figure 1 that the rotation device used here does not reproduce exactly the programmed stimulus waveform. Distortion was more severe during y-axis stimulation than during z-axis stimulation due to the greater rotational inertia that occurs when the subject's body is in the right-side-down position. Any amount of stimulus distortion is undesirable; nevertheless, it is a common problem with the rotary devices available in most vestibular laboratories, so an attempt was made to assess its effects on response prediction. In Figure 5 the theoretical response curve obtained from the equation (assuming a perfect triangular stimulus waveform) is compared with the theoretical response curve generated on an analog computer using the actual distorted stimulus waveform recorded during vertical canal (y-axis) stimulation. This amount of distortion had little effect, as indicated by the similarity of the two response curves. It introduced some errors when estimating response parameters from the equations, but these were within an acceptable margin for most purposes. Using the actual stimulus waveform, Π/Δ was estimated to be 7.3 seconds and K_n (θ/Δ) was 6.5 seconds, whereas using the equations, Π/Δ was 6.8 seconds and K_n (θ/Δ) was 5.4 seconds.

INDIVIDUAL DIFFERENCES

Parametric values were calculated in this study from the averaged responses of a group of subjects, but the procedure is applicable as well to the evaluation of individual responses. Large differences were found among the twenty subjects in this sample; estimates of Π/Δ ranged from 9.9 to 32.7 seconds for the horizontal canals and from 5.5 to 10.6 seconds for the vertical canals; K_n (θ/Δ) ranged from 4.9 to 11.2 seconds for the horizontal and from 4.2 to 8.2 seconds for the vertical canals.

These estimates appear to be reliable. From measures of intrasubject variability, the 95 per cent confidence interval for t_r was found to be ± 0.20 second for the horizontal canals and ± 0.23 second for the vertical canals. The 95 per cent confidence interval for $\dot{\psi}_{max}$ was ± 5.68 deg/sec for the horizontal canals and ± 8.05 deg/sec for the vertical canals. These confidence intervals were achieved from averages based on ten trials. Greater precision could be gained by using averages over more than ten trials, but the test procedure would be lengthened and its clinical usefulness diminished.

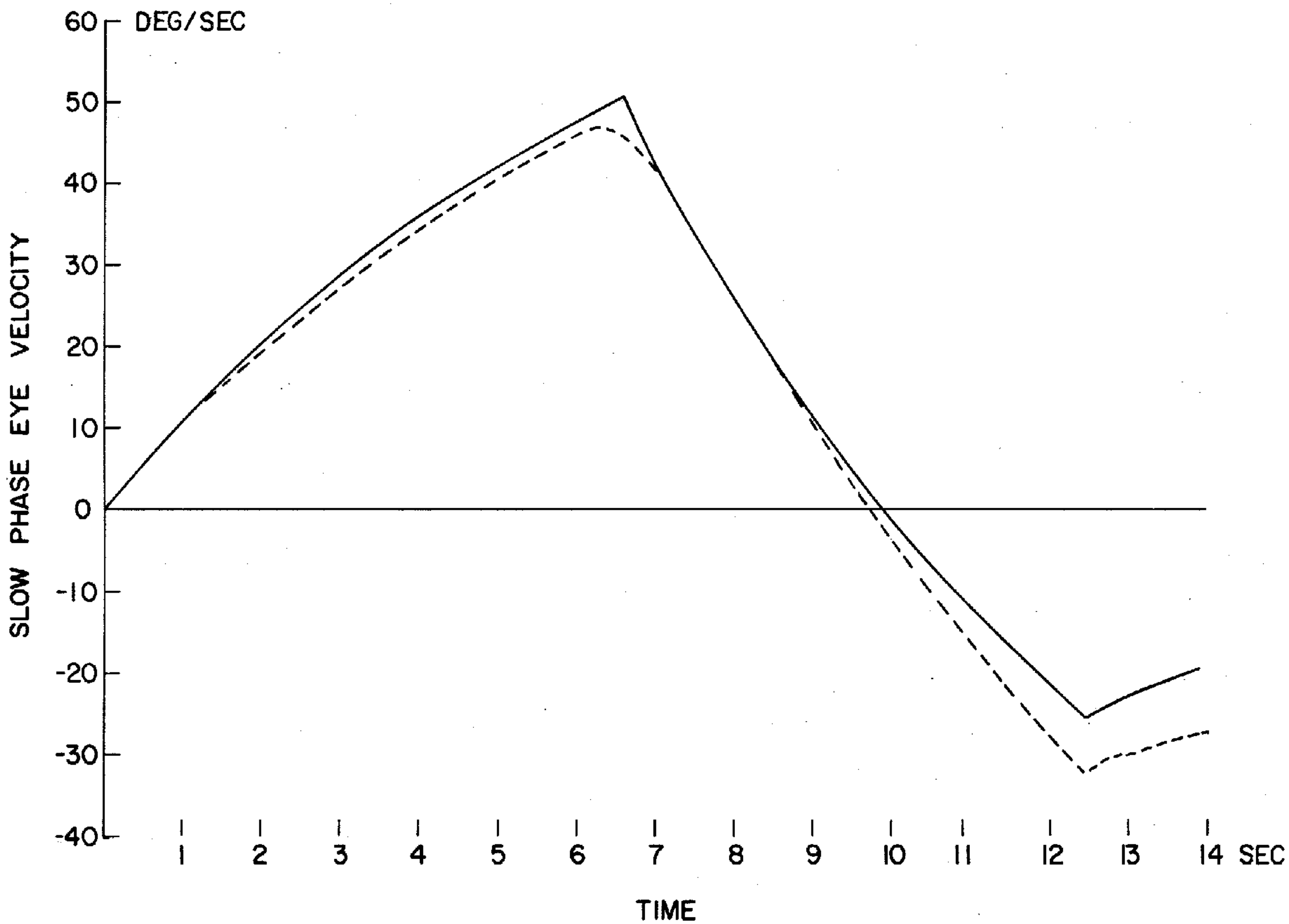

Figure 5

Effect of stimulus waveform distortion during vertical canal stimulation. The solid line represents the theoretical response curve generated by the prediction equation assuming a perfect triangular waveform stimulus. The dashed line represents the theoretical response curve generated by an analog computer from the actual stimulus used in this study.

Also, a significant decrease in the t_r measure was noted with repeated presentations of the stimulus. This decrease was only 0.2 to 0.3 second over the ten trials, but it would probably have been larger, and consequently more troublesome, if more trials had been presented. The reason for this decrease is not apparent, although Groen (5) has suggested a mechanism which may be involved. It is unlikely that the decrease was due to a decline in alertness over trials because the other response measure, $\dot{\psi}_{max}$, was not significantly affected.

CONCLUSIONS

The present and the preceding reports (7,8,10) have described procedures for estimating parameters associated with both nystagmus and subjective responses to semicircular canal stimulation. These tests appear to be both reliable and relatively simple to administer and score. In many situations, vestibular responses cannot be predicted without knowledge of canal and otolith involvement and other factors such as adaptation, alertness, and visual interaction. However, the procedures described here provide estimates of response parameters to two degrees of motion commonly encountered in flight, and these estimates may correlate well with vestibular sensitivity to this type of environment.

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