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16. Abstract

Recent CAMI-USNAMRL studies have shown that alcohol ingestion interferes with visual control of vestibular eye movements and thereby produces significant decrements in performance at a compensatory tracking task during oscillation about the yaw axis; significant or consistent decrements in performance in the absence of motion were not obtained. The present study was designed to extend knowledge about these effects to pitch-plane stimulation. Twenty-four young men, equally divided into alcohol and control (no alcohol) groups, performed a compensatory tracking task while stationary and while oscillating about their pitch and their yaw axes in the USN Human Disorientation Device. Alcohol doses were 2.0 ml of Smirnoff vodka per kg of body weight and tests were conducted before drinking and 1, 2, and 4 hours after drinking. In the absence of motion, there was no difference between the groups in tracking error while subjects were in the pitch position; significantly more errors occurred for alcohol subjects in the yaw position one and four hours (but not two hours) after drinking. During motion, one and two hours after drinking, alcohol subjects performed significantly poorer than the non-drinkers and had significantly less control of their eye movements for both axes of stimulation. Absolute error was greater during all sessions for pitch-plane stimulation as compared with yaw-plane stimulation. These degrading effects of alcohol on performance, particularly evident during motion, are discussed from the viewpoint of aviation safety.

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ALCOHOL AND DISORIENTATION-RELATED RESPONSES. VI. EFFECTS OF ALCOHOL ON EYE MOVEMENTS AND TRACKING PERFORMANCE DURING LABORATORY ANGULAR ACCELERATIONS ABOUT THE YAW AND PITCH AXES

I. Introduction.

Adequate pilot flight performance, especially under IFR conditions, requires good visual acuity and legibility of cockpit instruments. Among the possible sources of interference with good vision during flight are nystagmic eye movements which occur as a result of vestibular stimulation. Under normal conditions these eye movements are suppressed by visual fixation. However, two recent CAMI-USNAMRL studies[2,4] showed that alcohol ingestion interfered with such fixation and, concomitantly, degraded performance (compensatory tracking) requiring eye-hand coordination during angular motion in yaw (Z axis); interestingly, the alcohol produced no consistent changes in tracking performance when no angular motion was involved. These alcohol-induced changes in eye-hand coordination during motion lasted for as long as four hours and were evident at blood alcohol levels as low as .027%.[4]

However, much of the motion of an aircraft involves pitch (Y axis) or roll (X axis). Several studies[1,5,6,8] have shown that under normal conditions visual suppression of ocular nystagmus is not equal for motion about the three axes (X, Y, and Z). For example, while visual suppression is equally effective during either direction of motion in Z-axis stimulation, its effect is asymmetrical during Y-axis stimulation. Specifically, nystagmic eye movements arising from "pitch-forward" motion are more frequent and of greater amplitude than those occurring during "pitch-backward" motion. These differences in eye movement patterns results in differences in tracking performance; tracking error during "pitch-forward" motion is significantly greater than during "pitch-backward" motion. Another difference in response between Y- and Z-axis stimulation is the greater tendency for Y-axis motion to produce motion sickness even though stimulus rates might be identical.[1]

The present study was designed (a) to examine some effects of alcohol on performance at an eye-hand coordination task during angular motion about the Y axis, (b) to compare those results with data obtained during Z-axis stimulation, and (c) to compare results from Y- and Z-axis stimulation with performance in the absence of motion. In order to reduce the probability of motion sickness during Y-axis stimulation, the angular stimulus rate ($\pm 60°$/sec) used in this investigation was considerably lower than the rate ($\pm 120°$/sec) used in our previous alcohol studies.[2,4]

II. Method.

Subjects. Twenty-four young male volunteers from the Naval Air Station at Pensacola served as subjects. All were in good health and without any history of vestibular disorders. One group of 12 volunteers was tested under the influence of alcohol; the other group of 12 served as a control. The latter received a non-alcoholic beverage but were led to believe that it contained alcohol.

Apparatus. The USNAMI Human Disorientation Device (HDD),[7] a multi-axis rotator, was programmed to provide sinusoidal oscillation with a peak velocity of $\pm 60°$/sec and a period of 25 sec. Motion about the Z axis (stimulation of the horizontal semicircular canals) was accomplished with the subject seated upright, over the center of rotation. For Y-axis stimulation (i.e., of the vertical semicircular canals), the capsule was rotated 90° about the horizontal axis so that, with the subject's right side down, a line drawn between the two ears was co-linear with

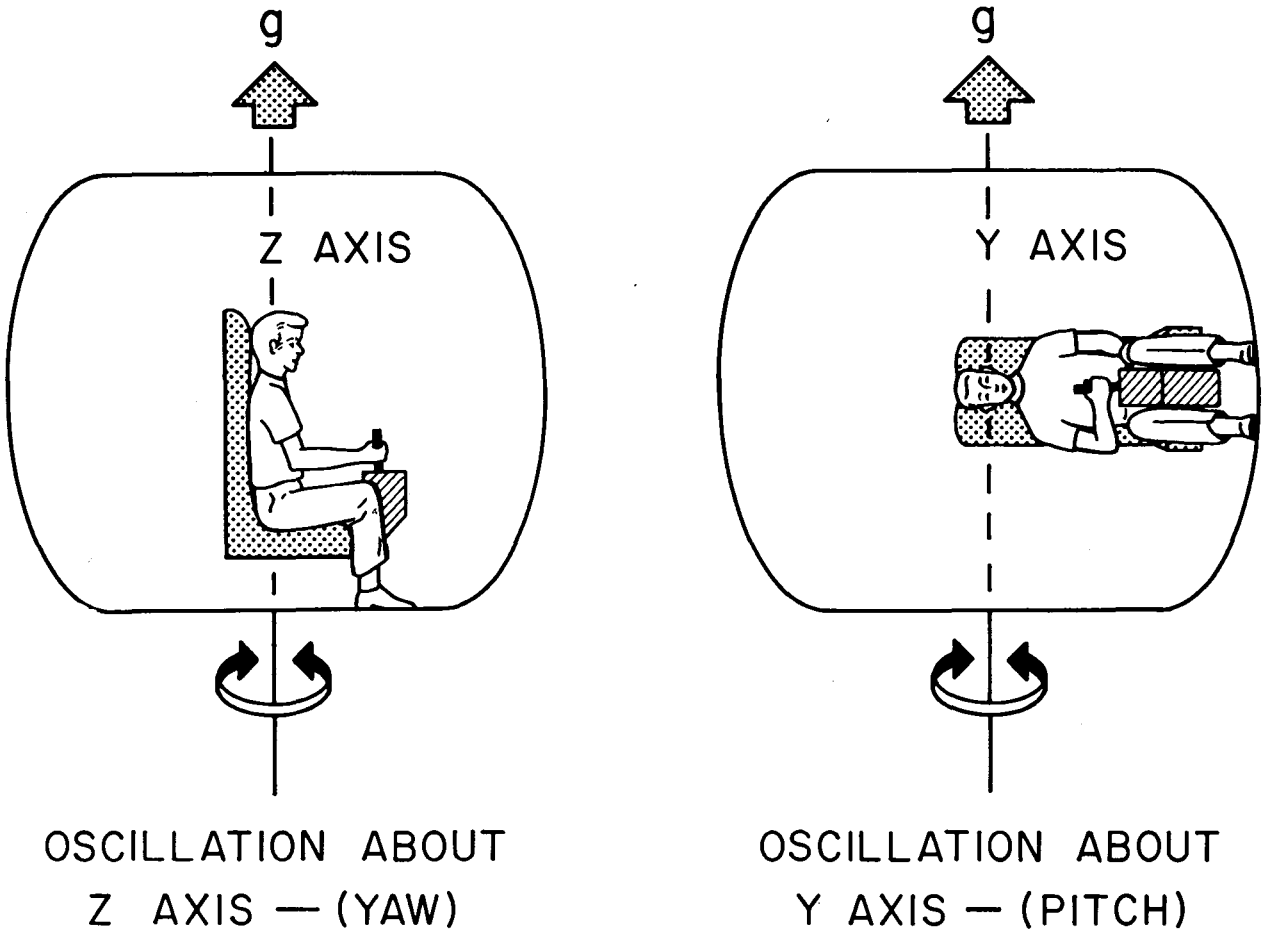

FIGURE 1. Illustration of how subjects were positioned in the Human Disorientation Device for Y- and Z-axis stimulation.

the axis of rotation. An illustration of the two positions is presented in Figure 1.

The compensatory tracking device, which is described in more detail elsewhere,[3] consisted of a joy stick and an aircraft localizer/glide-slope instrument. The subject was instructed to keep the instrument's needle display in the center or null position by compensatory movements of the joy stick located between his legs. A sinusoidal forcing function with a period of .071 Hz was used to deflect the needle; all deflections were recorded. The needle's null position was always aligned with true vertical and was parallel to the axis of rotation; thus, the needle movement was approximately in the same plane as the subject's oscillation-induced eye movements. The interior of the HDD was in total darkness with the exception of 0.1 ft. L. of illumination on the tracking instrument.

Procedure. The subject was seated and strapped in the HDD after electrodes had been attached beside the outer canthus of each eye to record horizontal eye movements. Another pair of electrodes was located above and below the left eye to record vertical eye movements. Following an instruction period, the subjects were given 2.5 min of tracking practice in each of the two body positions while the HDD was stationary (static tracking). The pre-drinking session was then begun. Static tracking performance was first recorded for one min with the subject either upright or in the right-side-down position. The subject was then oscillated in the HDD. For the first min of the oscillation, involving two cycles, the subject's eye movements were recorded in total darkness with alertness being maintained by a mental multiplication task; this assured adequate recording. A 2.5 min period

of oscillation (five cycles) followed, during which the localizer/glide-slope instrument was illuminated and the subject tracked (dynamic tracking). The same procedure was then repeated for the other axis. The order of stimulus presentation of the Y and Z axes was counterbalanced among subjects.

Following the pre-drinking session, the subjects were taken to a nearby room where they consumed either orange juice (control group) or a mixture of orange juice and vodka (alcohol group). The alcoholic mixture contained 2 ml of 100-proof Smirnoff vodka per kg of body weight. All subjects were allowed 30 min to drink their respective beverages.

Three post-drinking sessions were spaced at 1, 2, and 4 hours after drinking was completed. Each session involved: (a) one min of static tracking, (b) one min of oscillation in the dark, and (c) 2.5 min of dynamic tracking each for the Y and the Z axes.

A venous blood sample was drawn from those in the alcohol group prior to each of the experimental sessions. Only a pre-drinking blood sample was drawn from the control subjects. Blood ethanol levels were determined by use of gas chromatography.

III. Results and Discussion.

Blood Ethanol Levels

There was no evidence of any ethanol in the pre-drinking blood samples for either group. The mean blood ethanol levels for the alcohol

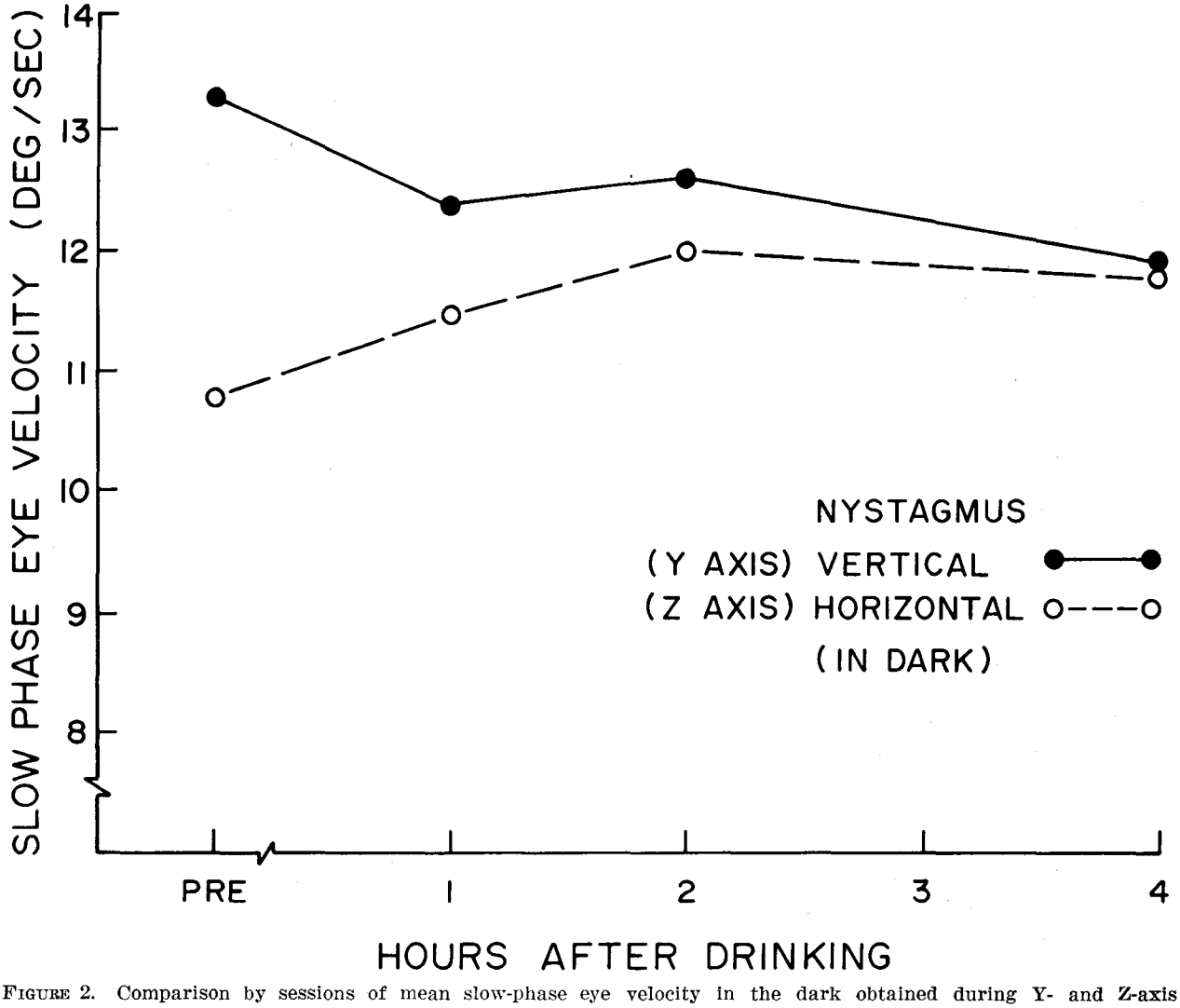

FIGURE 2. Comparison by sessions of mean slow-phase eye velocity in the dark obtained during Y- and Z-axis stimulation of the alcohol subjects.

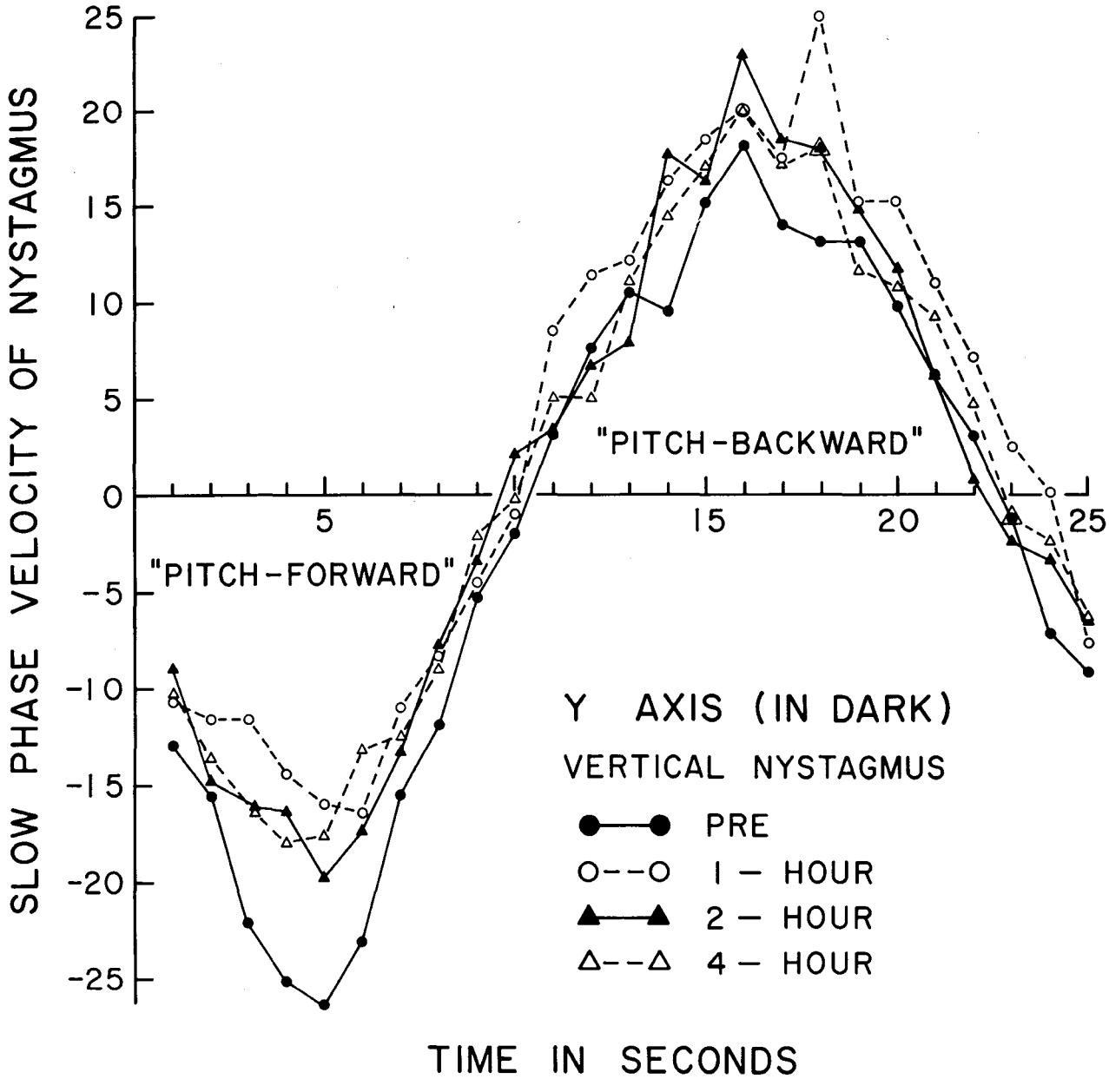

FIGURE 3. Second-by-second plots of slow-phase eye velocity in the dark for Y-axis stimulation of the alcohol subjects.

subjects at the 1-, 2-, and 4-hour testing sessions were: .081%, .075%, and .047%, respectively.

Alcohol Group

Nystagmus in the Dark. Average slow-phase eye velocities for the pre- and post-drinking sessions are plotted in Figure 2. Although the mean values for Y-axis stimulation were always above the values for Z-axis stimulation, the difference was significant ($p<.05$) only during the pre-drinking session. Since the direction of the eye movement is dependent upon the direction of the oscillation, average slow-phase velocities of the nystagmic eye movements were plotted for each sec of an oscillation cycle (Figures 3 and 4). These plots show that nystagmus was nearly symmetrical for both halves of the cycle, for both Y and Z axes.

While there was a general pre- to post-drinking increase (7–11%) in slow-phase eye velocity for Z-axis stimulation, post-drinking values for

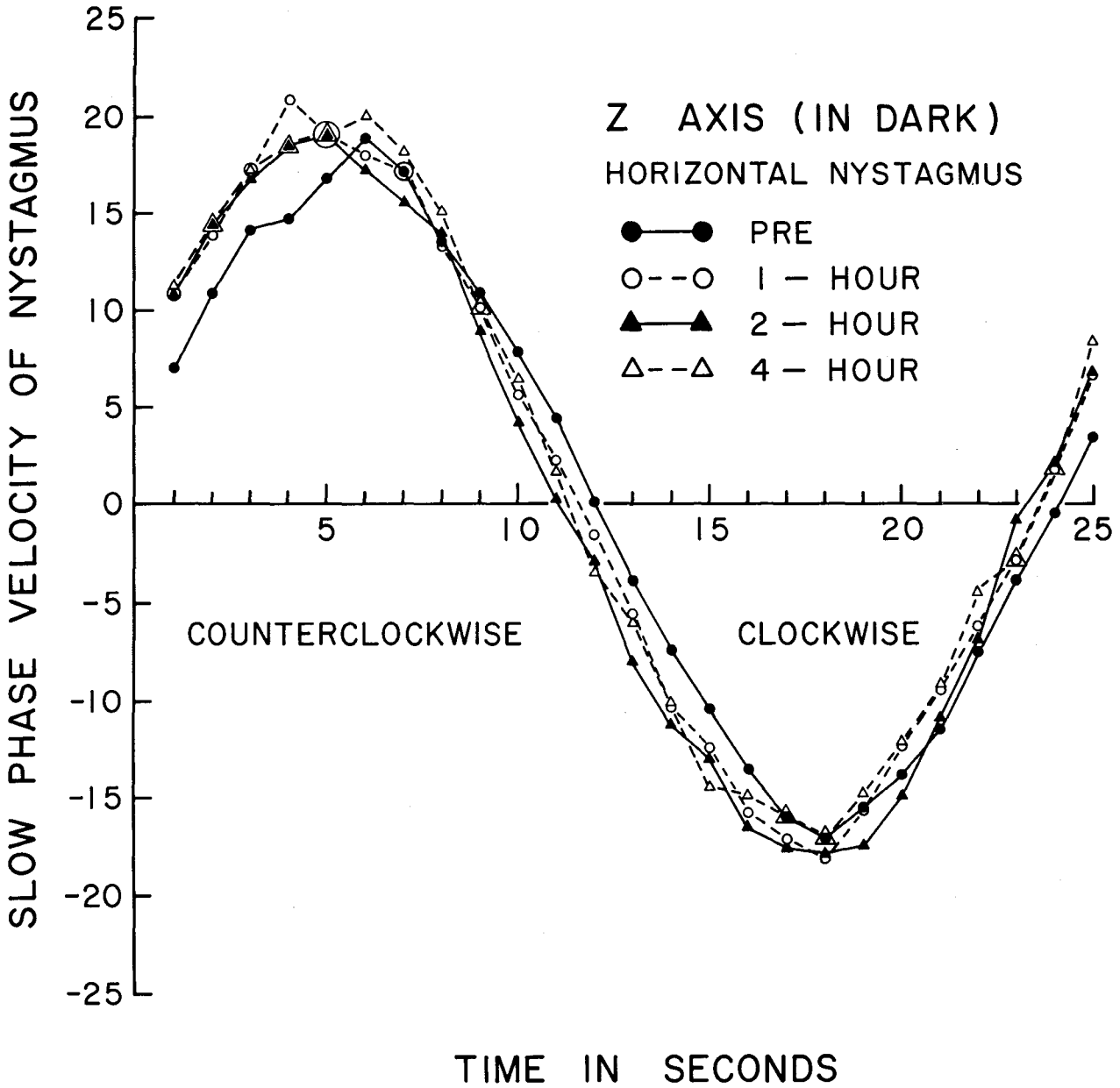

FIGURE 4. Second-by-second plots of slow-phase eye velocity in the dark for Z-axis stimulation of the alcohol subjects.

Y-axis stimulation were 5–10% below their pre-drinking level. However, none of these pre- to post-drinking changes was statistically significant.

Nystagmus in the Light. As noted above, during oscillation about both the Y and Z axes, nystagmus in the dark was nearly symmetrical for both halves of the oscillation cycles. There was, however, considerable visual suppression of these eye movements during angular stimulation with the tracking task illuminated. Mean slow-phase eye velocities during tracking for each axis of stimulation appear in Figure 5. Mean values for Y-axis stimulation were nearly double those for Z-axis stimulation for all sessions; these differences were statistically significant ($p<.05$–$.001$). The higher values for the Y axis were due primarily to the velocity of the nystagmic eye movements occurring during the "pitch-forward" period of the Y-axis stimulation (com-

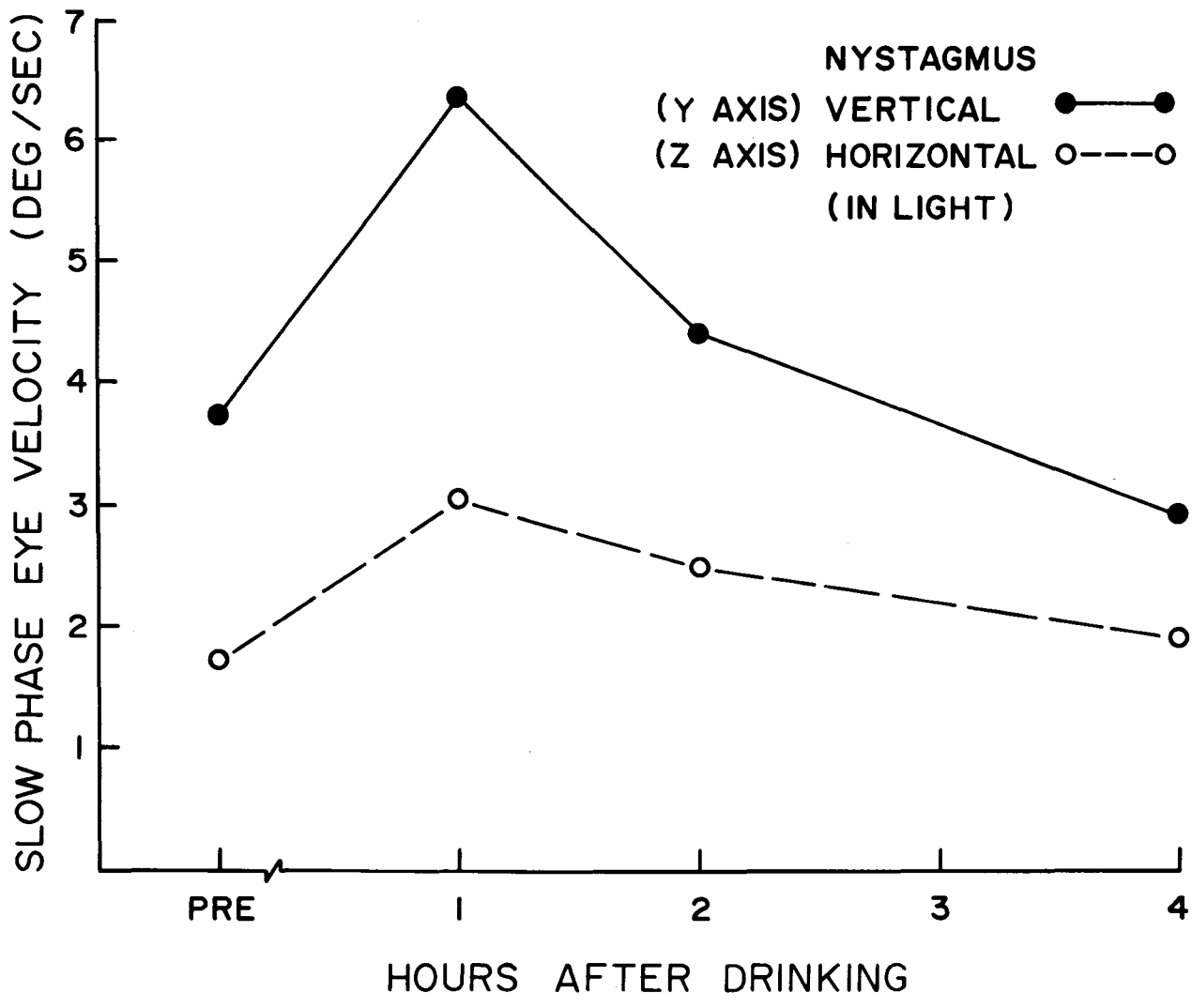

FIGURE 5. Comparison by sessions of slow-phase eye velocity in the light obtained during Y- and Z-axis stimulation of the alcohol subjects.

pare Figures 6 and 7). While slow-phase eye velocity was nearly symmetrical for the clockwise and counterclockwise directions of Z-axis oscillation, the eye velocity during the "pitch-forward" period of Y-axis oscillation was significantly higher ($p<.001$) than during the "pitch-backward" segment of the cycle. This differential suppression of nystagmic eye movements during Y-axis oscillation with vision permitted supports findings in previous studies[1 5 6 8] and has been attributed to an asymmetrical habituation of the eye movements.[5]

The results of alcohol ingestion were particularly evident in the large and statistically significant ($p<.001$) increases in mean slow-phase eye velocity one hour after drinking for both Y- and Z-axis oscillation. During subsequent post-drinking sessions, mean slow-phase eye velocity returned toward the pre-drinking level such that, four hours after drinking, the velocity measure for motion about the Y axis was 21% below the pre-drinking level whereas, for Z-axis motion, the values were still slightly above (11%) the pre-drinking level. However, it should be noted that the mean eye velocity for Y-axis stimulation was still significantly higher than that for Z-axis stimulation (compare Figures 6 and 7).

Tracking Error. The absolute tracking error was integrated and then recorded in digital and graphic form. Means for both static and dynamic tracking error are plotted in Figure 8.

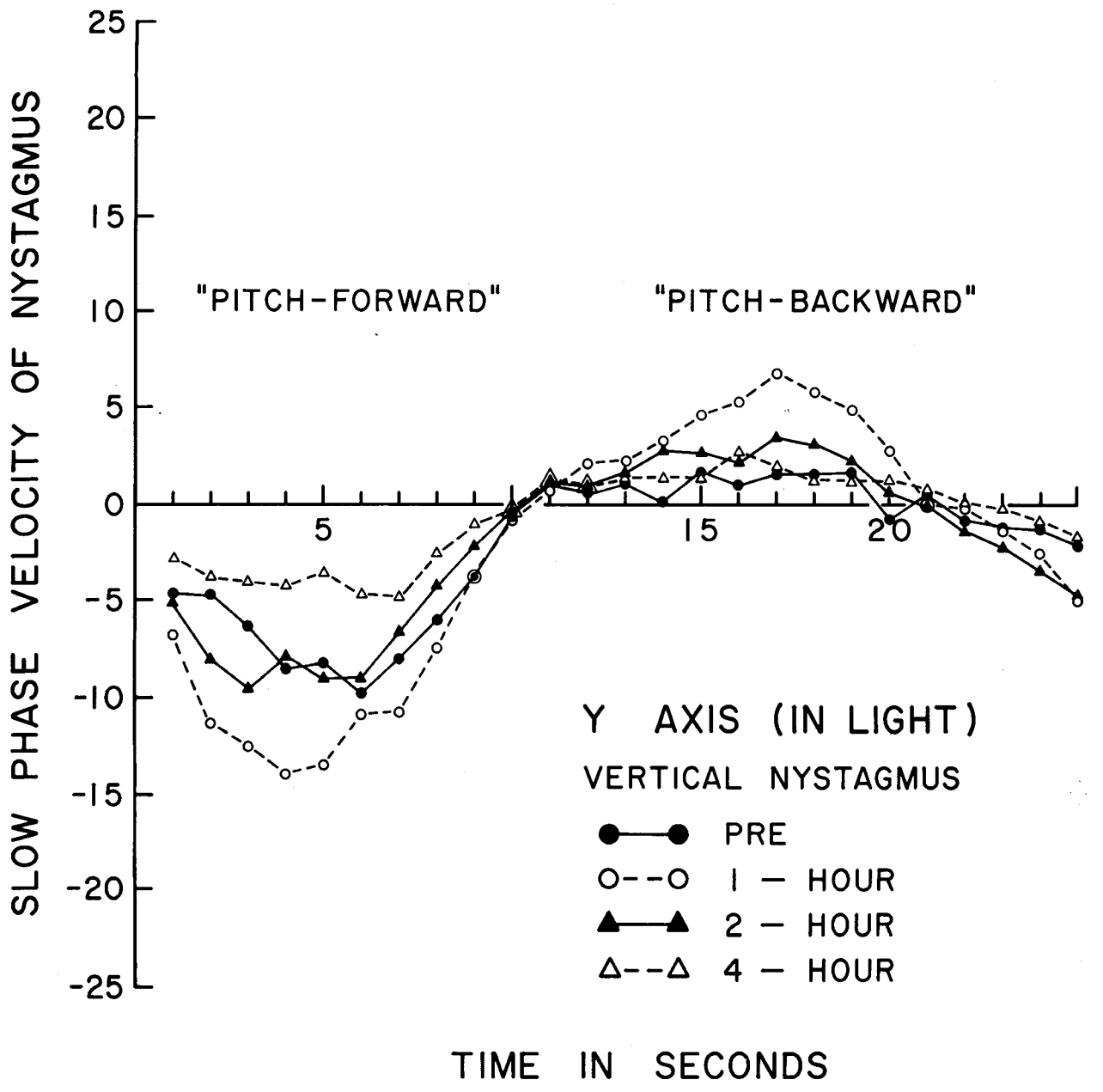

FIGURE 6. Second-by-second plots of slow-phase eye velocity in the light for Y-axis stimulation of the alcohol subjects.

Post-drinking means for static tracking were 5–15% above their pre-drinking levels for both the upright and the right-side-down position. However, only one static tracking score, that for the right-side-down position two hours after drinking, was significantly above the pre-drinking level ($p<.05$).

Dynamic tracking errors for Y-axis oscillation were significantly greater than for Z-axis oscillation during all sessions ($p<.001$). Mean dynamic tracking errors one hour after drinking were 32% (Y axis) and 20% (Z axis) above pre-drinking levels (significant at $p<.01$ and $p<.05$, respectively). Although the increase in error during Y-axis oscillation was 12% greater than that for the Z axis one hour after drinking, and errors during Y-axis stimulation remained proportionately greater during the two remaining post-drinking sessions, these differences were not statistically significant. However, mean

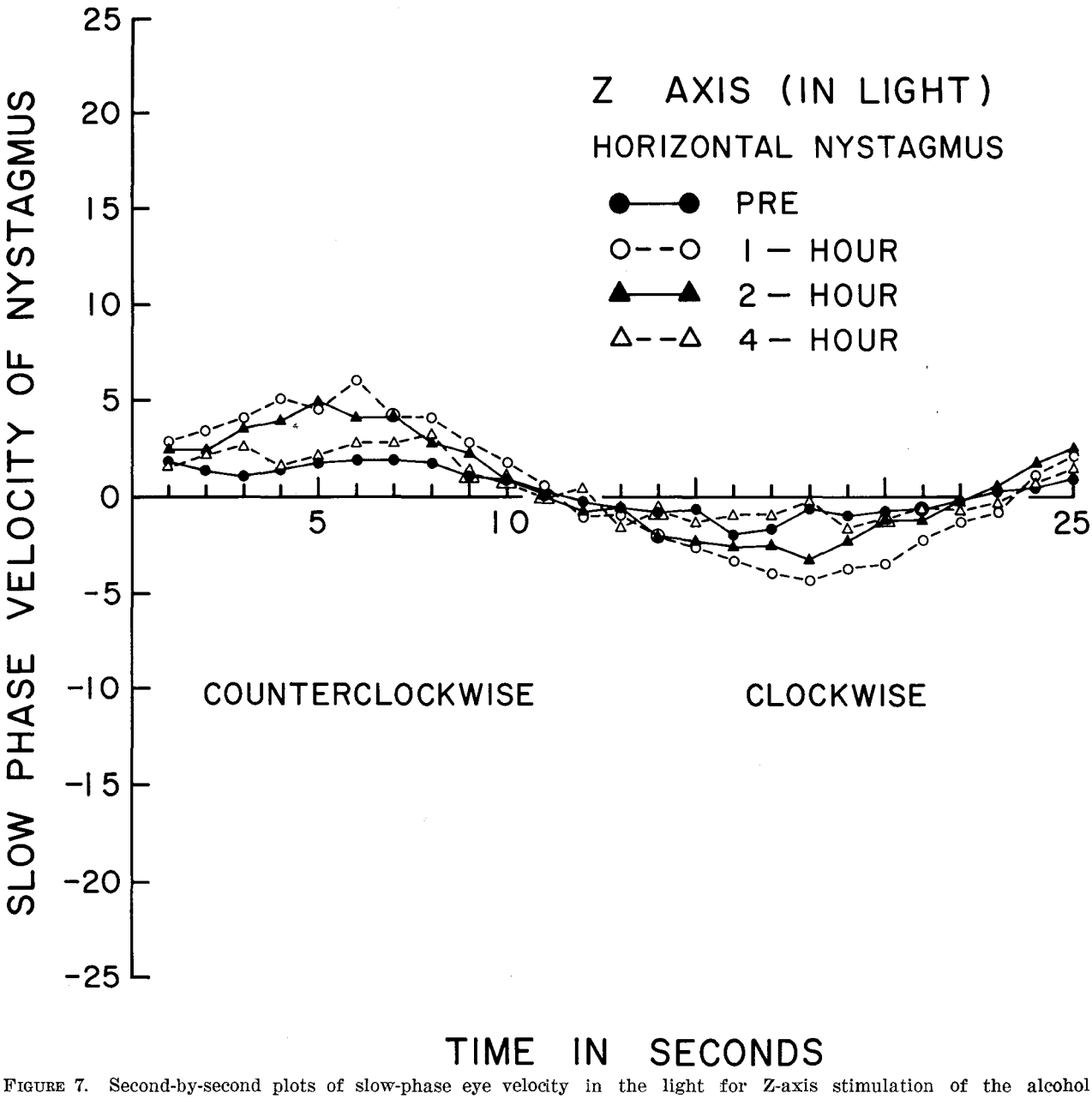

FIGURE 7. Second-by-second plots of slow-phase eye velocity in the light for Z-axis stimulation of the alcohol subjects.

tracking errors for the 2-hour and 4-hour post-drinking sessions gradually returned to the pre-drinking level for both axes of stimulation, with the 4-hour post-drinking error for the Z axis dropping slightly below the pre-drinking level. These apparent differences between axes of stimulation were due primarily to the tracking error incurred during the equivalent of "pitch-forward" motion. Mean tracking error, across time, for the Y and Z axes are plotted in Figures 9 and 10. In agreement with previous findings,[1 5 6 8] while tracking error for the two half-cycles was approximately symmetrical for Z-axis stimulation, the error during Y-axis stimulation was significantly greater during "pitch-forward" motion as opposed to "pitch-backward" motion.

Comparison of the Alcohol and Control Groups

For ease of comparing the differences between the alcohol and control groups in nystagmic activity and tracking performance, "change" scores were computed across sessions. The derived values represent the percentages of increase or

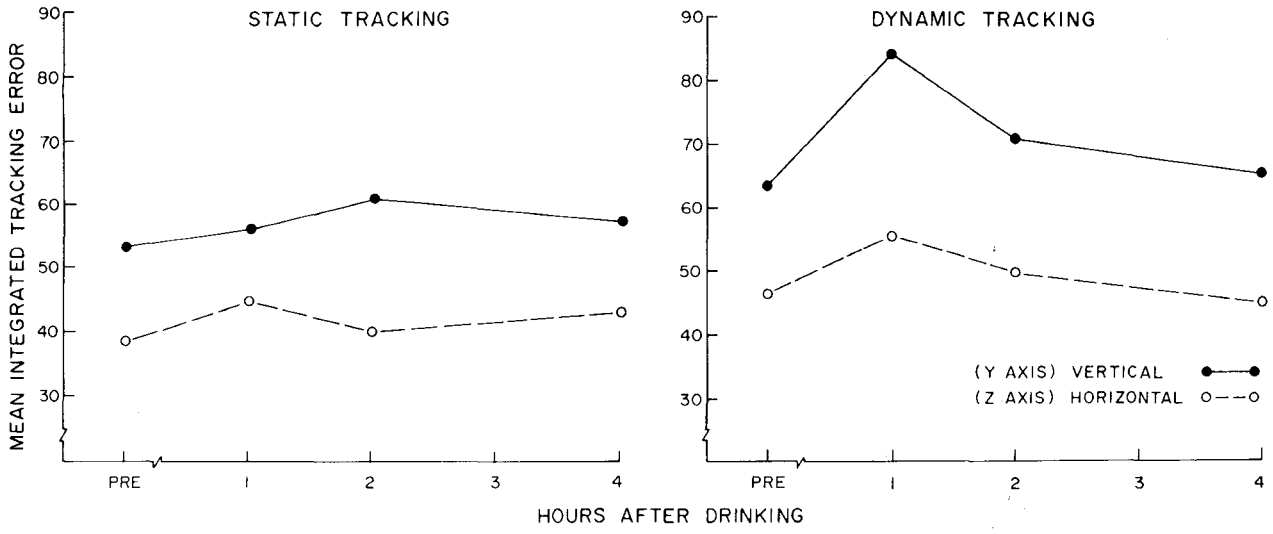

FIGURE 8. Static and dynamic tracking error by alcohol subjects during each session of Y- and Z-axis stimulation.

decrease in nystagmic activity and in tracking error for each post-drinking session based on the pre-drinking level for each group and each condition.

Nystagmus. There was little evidence of any alcohol effect under "dark" conditions. Nystagmus changed very little under either Y- or Z-axis stimulation and no difference between the two groups in ocular output was statistically significant at any session for corresponding axes of oscillation (see Figure 11). However, under the "light" (tracking) condition there was a general pre- to post-drinking decline in nystagmic activity for the control group while the alcohol subjects evidenced sharp increases in eye velocity (Figure 11). The changes in eye velocity (from the pre-drinking level) which were obtained during the "light" sessions conducted one and two hours after drinking were significantly higher for the alcohol group ($p<.001$ and $p<.05$, respectively) than those noted for the control group, for both axes of stimulation.

Tracking Error. Pre- to post-drinking changes in static and dynamic tracking error, expressed in percentages for both the alcohol and control groups, are presented in Figure 12. While the alcohol group evidenced slight post-drinking increases in static tracking error for both the Y and Z axes, the control group generally evidenced slight declines. None of these pre- to post-drinking changes in static performance between the two groups was significant for the right-side-down position; however, similar comparisons for the upright position were significant one and four hours after drinking ($p<.05$).

Changes in dynamic tracking error (Figure 12) generally reflect changes observed in the slow-phase velocity of the eye movements (Figure 11). While the alcohol group evidenced pre- to post-drinking increases in dynamic tracking error for both axes of oscillation, the control group evidenced declines. Statistical comparisons of the differences in dynamic tracking performance between the alcohol and control groups were significant, for both the Y and Z axes, at the testing sessions conducted one ($p<.001$ and $p<.01$, respectively) and two ($p<.01$ and $p<.05$, respectively) hours after alcohol ingestion.

General Comment

Evidence from this study concerning alcohol effects on eye-hand coordination in the absence of whole-body motion was inconclusive. Only in the upright position, one and four hours after drinking (but not two hours after drinking), was the increase in tracking error for the alcohol group significantly greater than that of the control group. These findings of minimal, inconsistent or nonsignificant effects of alcohol on static tracking error agree with earlier findings.[2,4]

The consistent differences obtained in this and our previous studies[2,4] regarding dynamic tracking performance following drinking can be attributed to an impairment in vision. Since alcohol ingestion apparently interferes with the

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