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INFLUENCE OF VESTIBULAR STIMULATION AND DISPLAY LUMINANCE ON THE PERFORMANCE OF A COMPENSATORY TRACKING TASK

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Loss of acuity for visual details in aircraft during unusual maneuvers has been documented by Melvill Jones. Recent investigations of this problem have served to define the magnitude of semicircular canal stimulation necessary to produce nystagmus of sufficient strength to degrade visual acuity. Present work extends former observations by investigating the effects of levels of illumination during semicircular canal stimulation on the performance of a task requiring vision. The illumination levels were selected to encompass the range used in aircraft cockpits.

A compensatory tracking task with an aircraft instrument as the display provided an indirect measure of this loss of visual acuity and a direct practical measure of performance. It was found that decreasing the luminance of the display over a range from the highest to the lowest levels normally used in cockpits significantly magnified the degradation of tracking performance resulting from vestibular stimulation, while producing only small changes in nystagmus. Without vestibular stimulation, the same changes in luminance resulted in no significant alterations in tracking performance. It appears that for a given level of nystagmus, performance of visual tasks may or may not be impaired depending on the level of illumination. It is suggested that the adverse effects of retinal smear resulting from nystagmus-produced image movement across the retina are augmented by decreases in luminance. Application of these results to aircraft operation is discussed.

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SUMMARY PAGE

THE PROBLEM

Loss of acuity for visual details in aircraft during unusual maneuvers has been documented by previous investigators. Recent investigations of this problem have served to define the magnitude of semicircular canal stimulation necessary to produce nystagmus of sufficient strength to degrade visual acuity. Present work extends former observations by investigating the effects of levels of illumination during semicircular canal stimulation on the performance of a task requiring vision. The illumination levels were selected to encompass the range used in aircraft cockpits.

FINDINGS

A compensatory tracking task with an aircraft instrument as the display provided an indirect measure of this loss of visual acuity and a direct practical measure of performance. It was found that changes in display luminance over a range from the lowest to the highest levels normally used in aircraft cockpits significantly improved tracking performance during vestibular stimulation, while producing no significant change in nystagmus. Without vestibular stimulation, the same changes in luminance resulted in no significant alterations in tracking performance. For a given level of nystagmus, performance of visual tasks may or may not be impaired, depending on the level of illumination. Thus the adverse effects of nystagmus-produced image movement across the retina may be offset fairly effectively by increases in luminance. The results appear to have practical implications for control of instrument lighting in aircraft during flight conditions that introduce strong vestibular stimulation.

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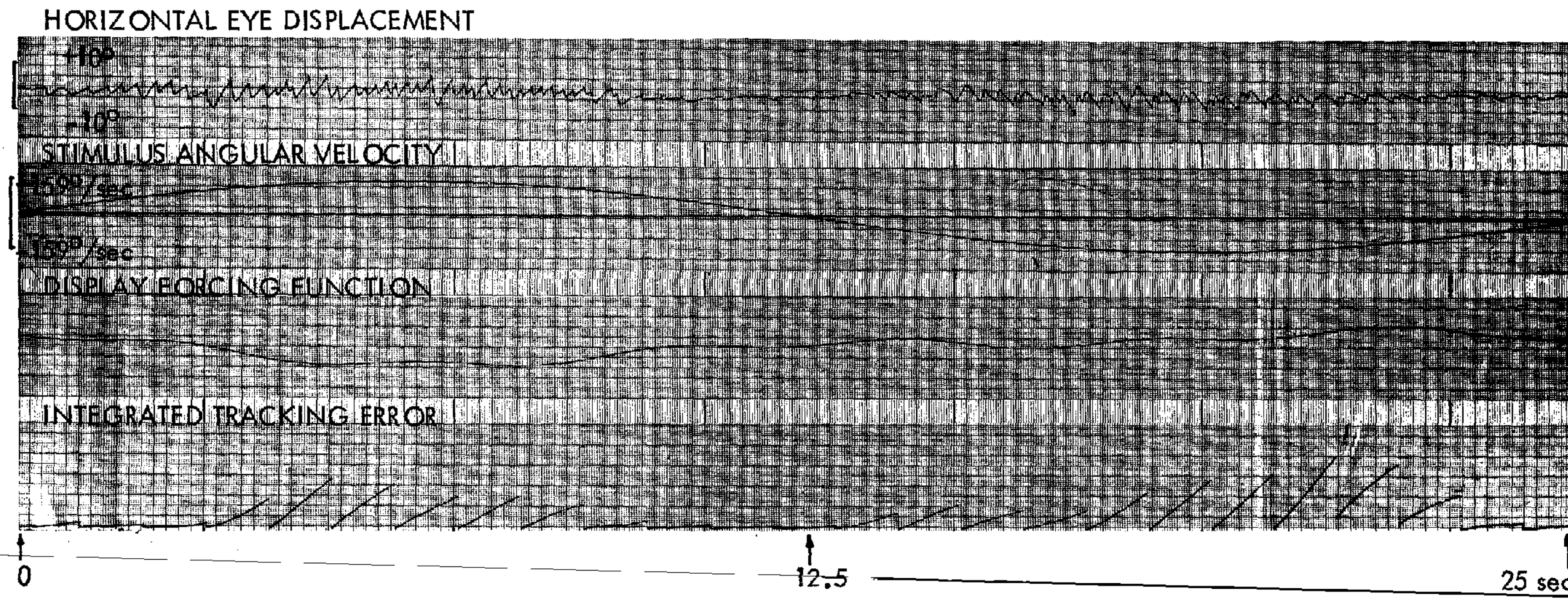
The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

control. The voltage difference between the tracking signal, θ_i, and the voltage related to joystick position, θ_o, was proportional to instantaneous tracking error, and the modulus, or absolute value, of this error signal integrated over 1-sec intervals provided the measure of tracking performance. To facilitate the measurement and analysis of tracking performance, the magnitude of the integrated modulus error signal was read by a digital voltmeter and printed out at the end of each 1-sec interval. The forcing function, integrated error, stimulus angular velocity, and nystagmus were also displayed on a chart recorder; a sample record over one stimulus cycle is shown in Figure 2.

The tracking display was a dc-powered cross-pointer indicator (Daystrom, Inc., Western Instrument Division). This instrument has two needles, one centered vertically and the other horizontally, and is of the type commonly used in aircraft as a localizer and glide slope indicator for instrument landing system (ILS) approaches. Only the vertical needle movement was energized in the present experiment. The instrument was mounted in the center of a large black panel in a position comparable to that found in several different types of military aircraft. The 4-cm face of the meter subtended a visual angle of 2.9 deg and was situated approximately 40 cm below eye level, 80 cm from the subject. The instrument face was lighted in the darkened HDD capsule by a small projector, appropriately masked and shielded to provide localized and reflection-free illumination of the display. The voltage across the projector lamp was adjusted until the luminance of a card, painted with instrument white lacquer and placed over the instrument face, was 20 ft-L. Luminance measurements were made with a MacBeth illuminometer on the card which, after painting, had the same reflectance as the pointers of the instrument display. Neutral density filters inserted in the slide carrier of the projector allowed the luminance of the display to be adjusted to levels of 0.01, 0.1, 1.0, and 10.0 ft-L. These values are in accord with the recommended luminance of aircraft instruments over a wide range of ambient light conditions (15).

The manual control was a short joystick coupled to a potentiometer from which was obtained a voltage proportional to stick position. From the center, null position, forward or backward movement of the control deflected the pointer of the display to the right or left, respectively. The control was centered, without detente, by linear springs requiring a maximum force of ±500 grams to move the control through the limits of its travel (± 13 cm). The handle of the control was situated approximately 38 cm horizontally from the abdomen, between the subject's legs and at a height permitting a comfortable grasp and arm rest.

The forcing function which controlled the tracking signal voltage, θ_i, was produced by combining, without regard to phase relationships, five sine waves with periods of 4.00, 11.56, 20.52, 40.22, and 79.82 sec, the amplitude of each sine wave being approximately proportional to its period. The resulting complex waveform was recorded on magnetic tape and provided the subject with essentially unpredictable needle deflections for the duration of the test session.



Luminance = 1.0 ft-L

Figure 2

A sample record showing for one stimulus cycle: horizontal nystagmus, HDD angular velocity, tracking task forcing function, and 1-sec integrals of absolute tracking error.

Lateral eye movements were recorded by a conventional electro-oculographic technique. The angular velocity of nystagmic eye movements was measured from the graphical record (Figure 2) with the aid of a special trace reader (6).

Nystagmus was recorded in five of the twenty subjects during performance of the tracking task and in darkness.

METHOD

Each subject initially underwent a 7-min period of dark adaptation, during which time the experimental procedure was explained, the instructions were read, and trial oscillations were given. The subject was told that his task was to keep the needle of the display centered for as much of the time as possible, even though the needle might become blurred on occasions. He was advised that smooth movements of the stick rather than jerky ones would probably be more successful and that full stick travel would be necessary at times. During the next 4 min the subject was presented with the tracking task at one of the four luminance levels without any imposed vestibular stimulation. Tracking error was recorded over the last minute of this period to obtain a measure of static performance for comparison with subsequent measures taken during vestibular stimulation. Then after a brief rest period the oscillatory motion was commenced and the subject resumed tracking. The first 30 sec of oscillation were used to provide additional tracking practice under these conditions and to allow the cupular response to approach a steady state condition. Following this, at least ten stimulus cycles (250 sec) were completed with the subject tracking continuously before the HDD was stopped.

Each subsequent trial followed the same procedure except that the initial 7-min dark adaptation period was eliminated and the period for practice tracking without vestibular stimulation was reduced from 3 min to 30 sec. A complete experimental session, which took approximately 40 min, consisted of four trials, one at each luminance level. Those subjects whose eye movements were recorded received an additional trial in darkness. The order of presentation of luminance levels was determined by a randomized design.

RESULTS

TRACKING TASK PERFORMANCE

Comparison of error scores obtained when the subjects were stationary with those recorded when they were exposed to angular oscillation (Table I) indicated that vestibular stimulation brought about a substantial decrement in performance of the tracking task. The magnitude of the performance decrement was found to be dependent upon the luminance of the display. For example, at 10.0 ft-L the error score was increased by 17 per cent, whereas at 0.01 ft-L there was a 90 per cent increase in the mean error score. Analysis of variance and post-hoc comparisons (8) revealed a significant ($P < .01$) difference in performance during oscillation at 1.0, 0.1, and 0.01 ft-L display luminances; at 10.0 ft-L the error score was not significantly different from that obtained at 1.0 ft-L.

Performance during the static condition did not differ significantly ($P > 0.1$) at the four luminance levels.

Records of the modulus tracking error, integrated over successive 1-sec periods (Figure 2), indicated that performance of the tracking task changed in a regular manner during each 25-sec stimulus cycle. This was confirmed by the plots of mean error scores averaged over ten cycles for the twenty subjects (Figure 3A). These show that the error waxed and waned twice during each cycle. The biphasic periodicity was present at all luminance levels, though it was more pronounced at 0.1 and 0.01 ft-L.

Table I

Mean Error Scores

N = 20

Display Luminance (ft-L)	Error Score (Arbitrary Units) Static	During Oscillation
0.01	128.7	244.4
0.1	107.0	164.6
1.0	106.5	134.8
10.0	107.4	125.7

EYE MOVEMENTS

Lateral eye movements were recorded and analyzed in five of the twenty subjects who participated in the experiment. During sinusoidal oscillation, nystagmus characteristic with this type stimulus was present as shown in Figure 2. Nystagmus slow phase velocity was measured at 1-sec intervals for five cycles at each luminance level and in total darkness. From these data, mean graphs of eye velocity over the 25-sec stimulus cycle were prepared (Figure 3B).

In the dark, nystagmus velocity was of the expected (9) sinusoidal form with a zero crossing at 1.15 sec before that of the stimulus (i.e., a phase advance of the compensatory eye movement of 16 deg). When the display was illuminated, the peak eye velocity was reduced to about one-third that recorded in the dark. As shown, both in Figure 3B and by the mean modulus values of slow phase velocity (Table II), the brightness of the display had little effect on the intensity of the nystagmic response. Although the mean modulus velocity was higher with the lower luminance, this relationship was not consistently exhibited by all the subjects, and hence in the small sample was not statistically significant.

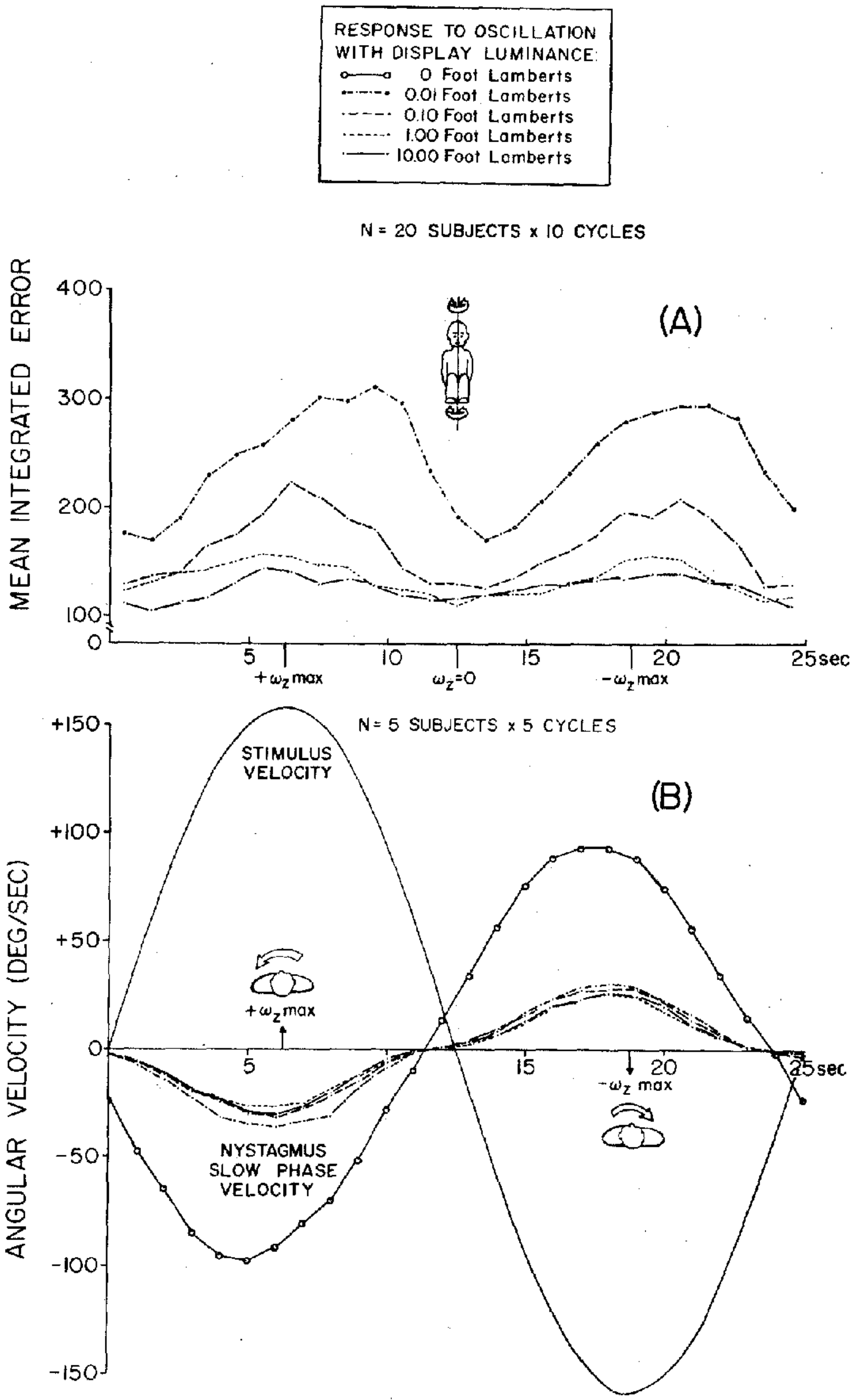


Figure 3

(A) Effect of display luminance on tracking performance during sinusoidal oscillation in yaw at 0.04 Hz. Each point is the mean 1-sec integrated error score over 10 cycles for 20 subjects at each luminance level. Maximum angular velocity in a counterclockwise direction is indicated by $+\omega_{z\ max}$.

(B) Effect of display luminance on nystagmus during sinusoidal oscillation in yaw at 0.04 Hz. Nystagmus slow phase velocity in the dark is shown by the solid line with filled points; the broken lines with small points indicate eye velocity when the display was illuminated. Each point is the mean eye velocity over 5 cycles for 5 subjects. The stimulus waveform is superimposed.

Apart from the reduction in nystagmus velocity that occurred when the tracking task was performed, eye velocity departed from the simple sinusoidal form obtained in darkness and also reached a maximum slightly later in the cycle. These alterations in the time course of the nystagmus are better shown in Figure 4 where eye velocity with the display illuminated is plotted against eye velocity in the dark at successive seconds during the stimulus cycle. The sigmoid shape of the loop that relates these two variables demonstrates greater suppression of the low than of the high velocity nystagmus by the visual stimulus. The opening and closing of the loop is a manifestation of phase lag at high eye velocities with the display illuminated and of its disappearance at zero eye velocity.

Table II

Mean Nystagmus Velocity

N = 5

Display Luminance (ft-L)	Mean Modulus Slow Phase Velocity (dec/sec)
0	58.8
0.01	17.3
0.1	15.2
1.0	13.2
10.0	13.9

Over all of the conditions in which the target was illuminated, the mean peak slow phase velocity was 30 deg/sec for left-beating nystagmus and 26.4 deg/sec for right-beating nystagmus. Although this difference was small, it was statistically significant ($F = 10.5$, $df = 1$ & 4, $P < .05$). The difference was also present in the same direction in darkness for four of five subjects. An explanation of this effect is not immediately apparent. The direction of the initial stimulus within a trial was determined by chance and, as measured from the angular velocity record, the angular acceleration profiles of opposite signs were congruent.

RELATIONSHIP BETWEEN ERROR AND EYE VELOCITY

Comparison of Figure 3A and 3B clearly shows a relationship across time, albeit with varying phase lags, between tracking performance and nystagmus at each luminance level. Irrespective of the direction of rotation at or just after peak slow phase velocity, tracking error was at a maximum. Likewise, at or just past the point where the slow phase velocity passed through zero, errors were at a minimum. This was to be expected in view of the known relationship between nystagmus and the decrements in visual acuity that it engenders (5). The mean difference in tracking performance during clockwise and counterclockwise rotation was in the direction expected on the basis of the directional difference in nystagmus indicated above, but it was not statistically significant ($P > .10$).

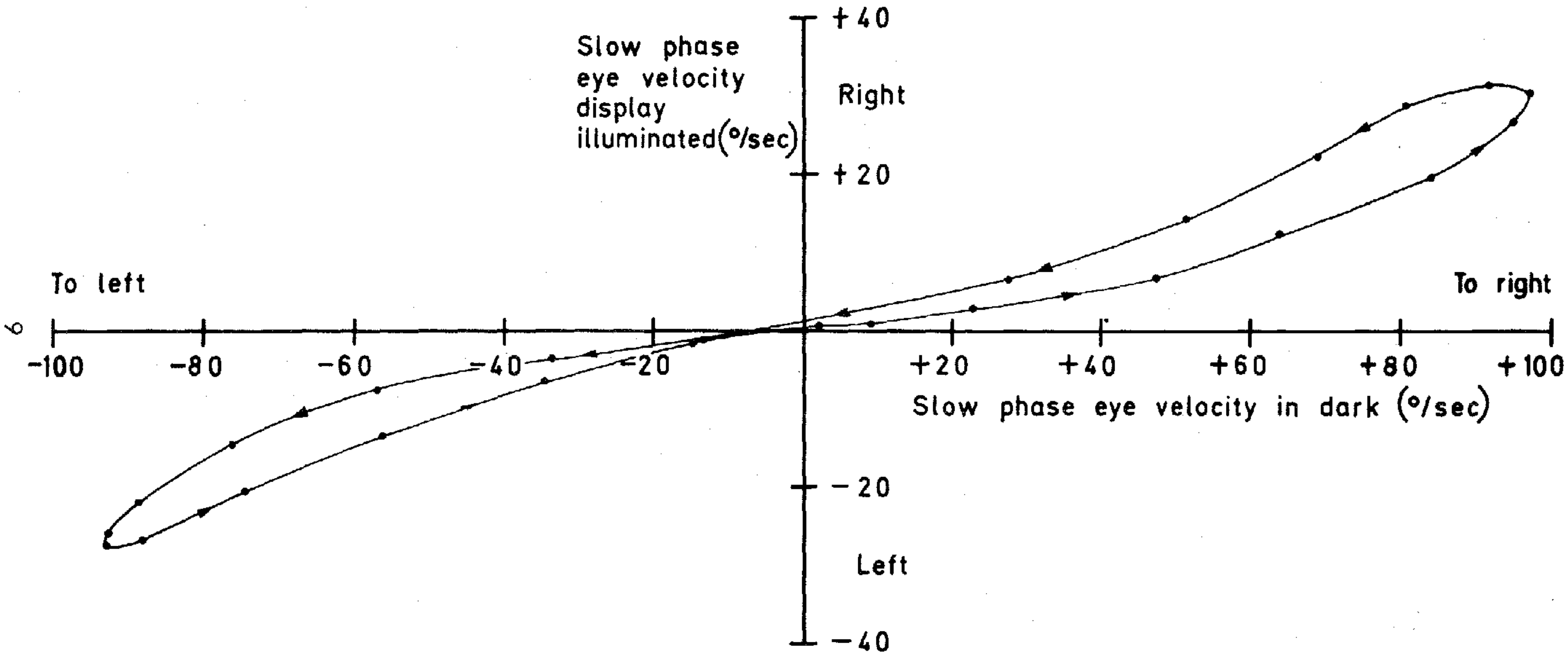


Figure 4

Relationship of nystagmus slow phase velocity (with display illuminated) to slow phase velocity in darkness, over one stimulus cycle. The x coordinate of a point is the mean eye velocity in darkness for 5 subjects over 5 cycles. The y coordinate is the eye velocity, at the same time in the stimulus cycle, when the display was illuminated and is the mean velocity of the 4 luminance levels for the 5 subjects over 5 cycles.

More detailed information about the relationship between performance and nystagmus was afforded by plots of mean error scores against the contemporaneous mean eye velocities at 1-sec intervals during the stimulus cycle (Figure 5). At the luminance levels represented in Figure 5, divergent upward-sloping loops were obtained that were disposed in an approximately symmetrical manner about the ordinate at zero eye velocity. Thus there was a definite dependence of tracking error on eye velocity; the higher the slow phase velocity, the greater the error. This dependency was in part obscured by the increase in phase lag of error on eye velocity that occurred at low luminances and that was manifested as an opening of the loops.

Although the averaged data show a general relationship between tracking error and eye velocity, individual differences in tracking performance during angular oscillation at a particular display luminance were not primarily dependent on the intensity of the evoked nystagmus. This is shown by Figure 6 where the mean error scores of each subject are plotted against the corresponding mean modulus eye velocity for each test condition. Figure 6 also emphasizes the importance of display luminance as an important determinant of performance. Individual subjects showed a progressive decrement in performance with a decrease in luminance without systematic alteration of eye velocity (e.g., S.4 in Figure 6), while the mean values for the group fell close to a line that rises steeply with a gradient of 65 error units per 1 deg/sec change in eye velocity.

DISCUSSION

There would appear to be three possible ways by which performance could be degraded by the angular oscillation stimulus employed in the present experiment: by interference with 1) visual perception, 2) motor function, and 3) central integration and control. Of these three, impairment of visibility of the instrument display, engendered by inappropriate nystagmic eye movements, is undoubtedly the most important.

It has been demonstrated clearly that angular motion sufficient to cause nystagmic eye movements can seriously degrade the performance of a tracking task that depends upon a visual input for the closure of the control loop. Peak eye velocity occurred shortly before peak stimulus velocity, and error scores reached a maximum shortly after peak stimulus velocity. These objective measures are in accord with reports by subjects that, at some time in each half-cycle, the display became blurred and they were unable to see the vertical pointer. Accordingly, they were not able to generate appropriate movements of the control stick, and errors accumulated. The reason for the apparent phase lag of tracking errors behind nystagmus is probably twofold. When the display image was lost, some time was required before the forcing function sufficiently deflected the needle to create a significant error. Moreover, time was required for the subject to recover tracking proficiency after regaining the image. These effects would be more pronounced for longer periods of visual interference.

Disruption of motor function may also have had its effects. During each stimulus half-cycle the tangential acceleration at the control handle in its maximum forward position did not exceed 0.03 g, but the radial acceleration which acted in the direction

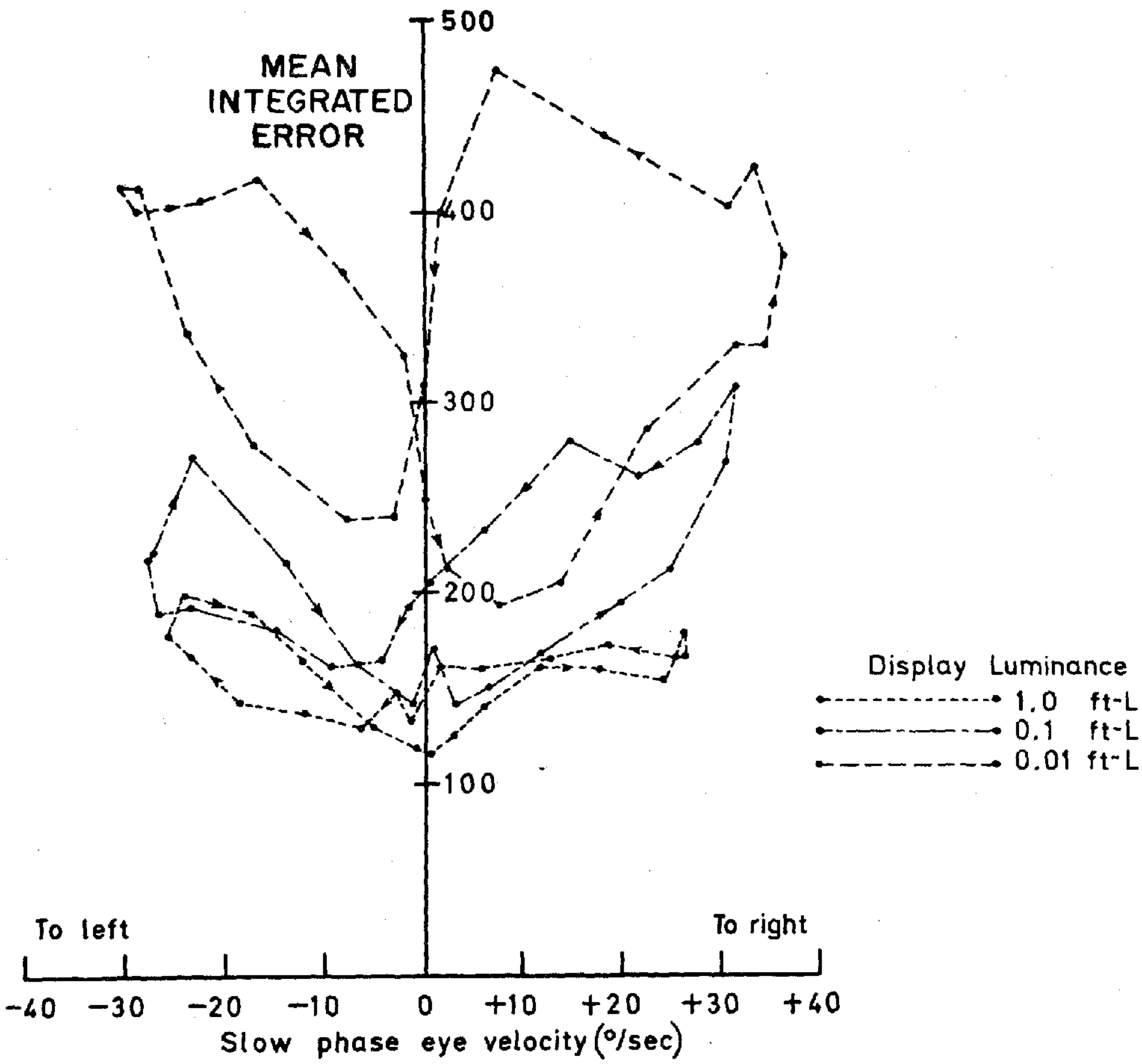


Figure 5

Relationship between tracking performance and nystagmus during sinusoidal oscillation in yaw. Each point relates the mean integrated error to the concomitant mean nystagmus slow phase velocity at 1-sec intervals during the stimulus cycle. Error scores were averaged in 5 subjects over 10 cycles and eye velocity over 5 cycles at 3 luminance levels.

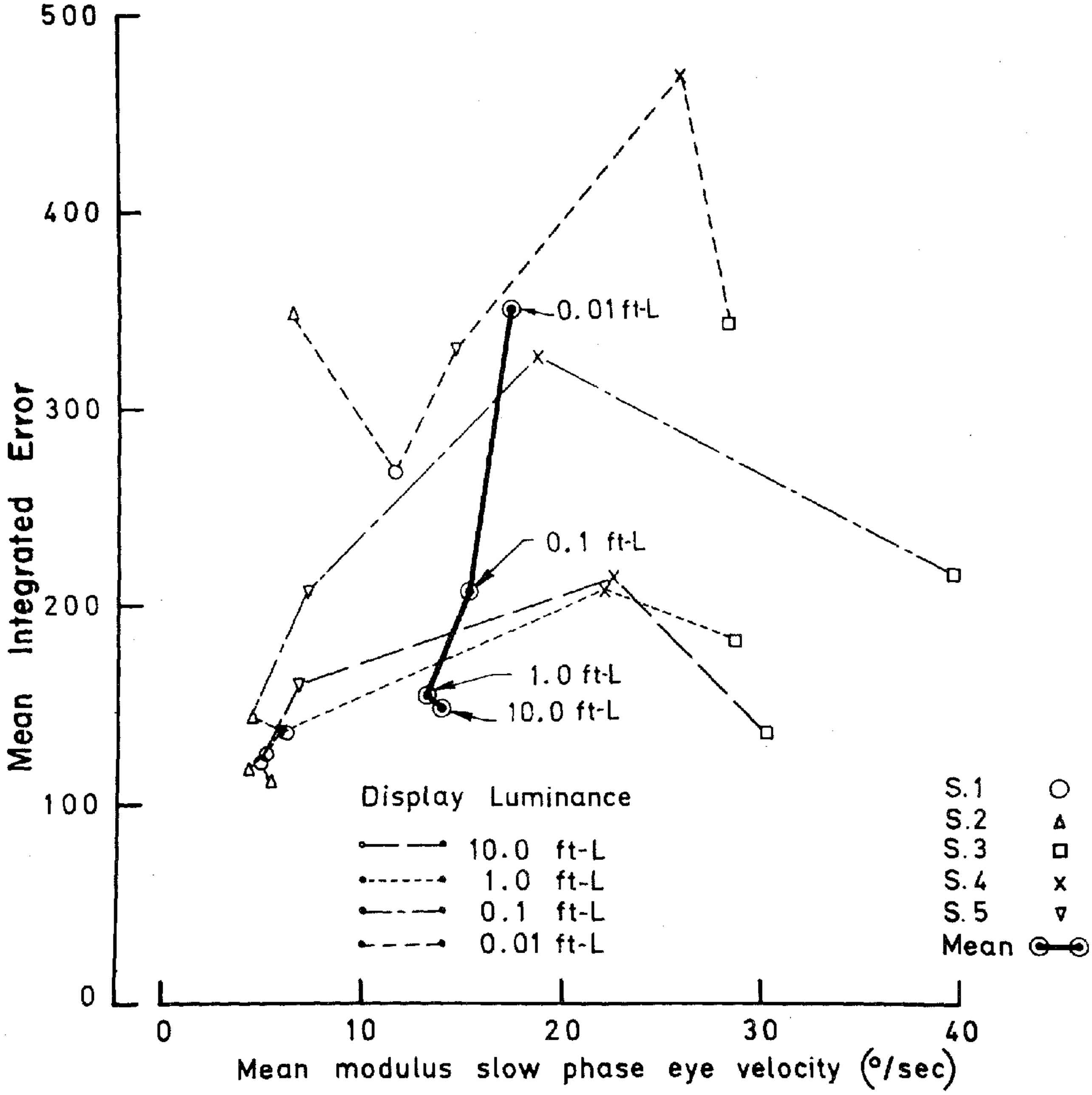


Figure 6

Relationships among error score, display luminance, and nystagmus slow phase velocity to show intersubject differences. Each point compares a subject's error score (averaged over 10 cycles) with the modulus eye velocity (averaged over 5 cycles) at a particular display luminance. Subjects are identified by symbols, and the measures obtained at each display luminance are joined by broken lines. The heavy solid line shows the mean performance and eye velocity of the 5 subjects at each level of illumination.

of control movements varied from 0 to 0.55 g. Such a change in the force environment could interfere with fine corrective motor responses at peak stimulus velocity.

Performance of a psychomotor task can also be degraded by distracting sensory cues. The sensation of turning, and perhaps nausea, evoked by the relatively intense angular oscillation in an unfamiliar environment might well have directed the subjects' attention away from the task, or lowered their performance criteria so that tracking errors would increase. As with the postulated disturbances in motor function, such an effect might have contributed to the observed cyclical alteration in tracking accuracy.

The considerable variation of performance with the brightness of the display implies that the postulated nonvisual mechanisms made only a small contribution to the error score. Even with the brightest display, it was not possible to exclude deterioration of visual performance as either a contributory or even a prime cause of the small decrement in tracking accuracy that occurred in this experimental condition.

Impaired visibility of the display and the consequent impairment of tracking performance during vestibular stimulation were expected from earlier studies (5). However, it was not anticipated that the brightness of the display would have such a profound effect on task performance without comparable changes in nystagmus velocity. It is known (1,7) that the presence of any structure in the visual field brings about a reduction in the amplitude and velocity of labyrinthine nystagmus in relation to that which the same vestibular stimulus would evoke in the dark. The present experiment has shown that the suppression produced by a poorly illuminated instrument dial in an otherwise black visual field is little less than that achieved by a display with a thousand times greater luminance.

The alteration of the nystagmus velocity profile from the pure sinusoidal form recorded in darkness to the distorted form obtained with an illuminated display is a manifestation of nonlinearity in the inhibitory mechanism. This is in accord with Guedry's observations (5) on the visibility of Snellen test-type charts during sustained angular acceleration. He found that nystagmus velocity did not increase in a progressive manner, which reflected the logarithmic time course of the canal signal, but rather that there were step increments in velocity, which corresponded to the subjects' failure to resolve letter groups of increasing size. Thus it would appear that the intensity of the visual suppression of nystagmus is a function of a subject's ability to discriminate detail in the visual material presented. The sigmoid shape of the curve in Figure 4, which relates nystagmus velocity (with display illuminated) to nystagmus velocity in the dark, implies a progressive reduction in the potency of the suppressive mechanisms as the intensity of the semicircular canal signal (equated to dark nystagmus velocity) is increased. At low eye velocities the ability to resolve visual detail is greater than at higher angular velocities; accordingly, visual suppression of nystagmus is proportionately greater in the former situation than in the latter.

The phase lag of eye velocity with display illuminated on eye velocity in the dark is the manifestation of hysteresis in the suppressive mechanism. When eye velocity is decreasing, comparable visual suppression is achieved at a lower velocity than when eye velocity is increasing.

Though the level of display illumination, with the exception of total darkness, had little effect on nystagmus, it was evident that the brightness of the display determined substantially the quality of performance of the tracking task; furthermore, there was a differential effect which depended upon the time course of the stimulus and the evoked nystagmus. For example, when nystagmus was at peak velocity, the differential effect of luminance on tracking performance was most pronounced, even when no allowance was made for phase differences. As nystagmus slow phase velocity decreased, the differential effect of luminance also decreased steadily until a minimum was reached when the eye velocity passed through zero. It should be recalled that different luminance levels had no significant effect on tracking without the concurrent vestibular stimulation; that is, without nystagmus. In all conditions, the more intense the nystagmus, the more display luminance reduced errors and improved tracking performance.

This reduction in tracking error with a bright display must be attributed to an improvement in visual performance. There is an important similarity between the present experiment, where vision was degraded by inappropriate movement of the eye in relationship to a stationary target, and studies of dynamic visual acuity, where movement of the retinal image occurs because the tracking eye movement does not match with precision the velocity of the target. It has been shown (14, 16) that increasing the illumination of the visual target (even up to 500 ft-L) improved dynamic visual acuity, but had little effect on static acuity. Likewise, in psychomotor tasks, such as pursuit tracking where the eye has to follow the target over an appreciable visual angle as a necessary part of the task, it has been found (13, 17) that performance decreased as target brightness was decreased. It would thus appear that in situations where there is movement of the visual image on the retina, whether this be caused by movement of the eye with respect to a stationary target, as in the present experimental studies, or by the eye attempting to track a moving target, an increase in the brightness of the observed object improves visual acuity. The mechanism underlying this phenomenon probably depends upon spatio-temporal interactions between consecutively excited retinal elements or between neurons at a higher level in the visual pathways. Graham (4) has theorized on the manner in which such interactions might alter border contrast.

It is germane to consider the application of the experimental results, here reported, to instrument illumination in aircraft or spacecraft, even though the particular type of motion employed (continuous sinusoidal acceleration about the z-axis) is unlikely to be encountered during normal flight operations. Situations do arise where the pilot is exposed to an angular motion that is a powerful stimulus to semicircular canal receptors. On entry or recovery from a high-rate spin or rolling maneuver during flight in severe turbulence or as a consequence of aerodynamic instability (11), nystagmic eye movements may be evoked. When canal information is correct, that is, it is in accord with the angular motion of the aircraft (e.g., on entering a spin), the eye movements are compensatory and tend to stabilize the position of the eye in relation to fixed objects outside the aircraft but are inappropriate for objects within the aircraft. When canal information does not accord with the physical stimulus (e.g., on recovery from a prolonged spin or as a result of Coriolis stimulation), the eye movements are inappropriate for objects both inside and outside the aircraft. Thus nystagmus engendered by canal stimulation will always tend to degrade the visibility of cockpit instruments. The intensity and time course of the visual impairment will depend upon the magnitude and direction of the motion stimulus; but, for a given stimulus, vision will be degraded least when flight instruments are well illuminated. During daytime flight this condition is commonly fulfilled; however, at night or in poor light conditions aviators should be advised to turn on instrument flood (thunderstorm) lights if they experience, or are likely to experience, severe angular-motion stimuli. A bright instrument display will minimize any decrement in visual performance associated with vestibular nystagmus and perhaps prevent the impairment of vehicular control that might ensue.

REFERENCES

1. Aschan, G., Bergstedt, M., and Stahle, J., Nystagmography: Recording of nystagmus in clinical neuro-otological examinations. Acta otolaryng., Stockh., Suppl. 129, 1965.

2. Benson, A. J., Spatial disorientation in flight. In: Gillies, J. A. (Ed.), Textbook of Aviation Physiology. Oxford: Pergamon Press, 1965. Pp 1086-1129.

3. Gain, P., and Fitts, P. M., A simplified electronic tracking apparatus (SETA). WADC Tech. Rept. 59-44. Wright-Patterson Air Force Base, Ohio: Wright Air Development Center, 1959.

4. Graham, C. H., Perception of movement. In: Graham, C. H. (Ed.), Vision and Visual Perception. New York: John Wiley & Sons, 1965. Pp 575-588.

5. Guedry, F. E., Relations between vestibular nystagmus and visual performance. Aerospace Med., 39:570-579, 1968.

6. Guedry, F. E., and Turnipseed, G. T., Two devices for analysis of nystagmus. Ann. Otol., 77:1071-1085, 1967.

7. Guedry, F. E., Collins, W. E., and Sheffey, P. L., Perceptual and oculomotor reactions to interacting visual and vestibular stimulation. Percept. Mot. Skills, 12:307-324, 1961.

8. Hays, W. L., Statistics for Psychologists. New York: Holt, Rinehart, and Winston, 1963.

9. Hixson, W. C., and Niven, J. I., Application of the system transfer function concept to a mathematical description of the labyrinth: I. Steady-state nystagmus response to semicircular canal stimulation by angular acceleration. NSAM-458. NASA No. R-1. Pensacola, Fla.: Naval School of Aviation Medicine, 1961.

10. Hixson, W. C., and Niven, J. I., A bioinstrumentation control center for the Human Disorientation Device. NSAM-848. NASA No. R-1. Pensacola, Fla.: Naval School of Aviation Medicine, 1963.

11. Jones, G. Melvill, Disorientation due to rapid rotation in flight. In: Evrard, E., Bergeret, P., and van Wulften Palthe, P. M. (Eds.), Medical Aspects of Flight Safety. AGARDograph 30. London: Pergamon Press, 1959. Pp 92-101.

12. König, A., Die Abhängigkeit der Sehschärfe van der Beleuchtungsintensität. Sitzber. Akad. Wiss. (Berlin), 35:559-575, 1897. Cited by Riggs, L. A. In: Graham, C. H. (Ed.), Vision and Visual Perception. New York: Wiley, 1965.

13. Lincoln, R. S., and Smith, K. V., Visual tracking: II. Effects of brightness and width of target. J. appl. Psychol., 36:417-421, 1952.

14. Ludvigh, E. J., Visual acuity while one is viewing a moving object. Arch. Ophthal., 42:14-22, 1949.

15. Morgan, C. T., Cook, J. S., Chapanis, A., and Lund, M. W., Human Engineering Guide to Equipment Design. New York: McGraw-Hill, 1963.

16. Van Nes, F. L., Enhanced visibility by regular motion of retinal image. Amer. J. Psychol., 81:367-374, 1968.

17. Voss, J. F., Effect of target brightness and target speed upon tracking proficiency. J. exp. Psychol., 49:237-243, 1955.