ADAPTATION TO VESTIBULAR DISORIENTATION

VIII. "CORIOLIS" VESTIBULAR STIMULATION AND THE INFLUENCE OF DIFFERENT VISUAL SURROUNDS

William E. Collins

Approved by

J. Robert Dille

J. ROBERT DILLE, M.D.
CHIEF, CIVIL AEROMEDICAL INSTITUTE

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August 1967

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VIII. "Coriolis" Vestibular Stimulation and the Influence of Different Visual Surrounds

I. Introduction.

"Coriolis" vestibular stimulation can be produced under controlled laboratory conditions to simulate one kind of "pilot's vertigo." The technique involves the use of a device capable of rotation. If a subject makes head movements during such rotation, he produces an unusual stimulation of the semicircular canals which results in nystagmus, sensations of disorientation and, depending upon the visual surrounds, illusory perceptions of motion in other objects. The present study was designed to evaluate the influence on disorientation of different types of head movements made under different aircraft-simulated conditions regarding the visual environment.

II. Methodology.

Apparatus. A Stille-Werner RS-3 Rotation Device was modified by: (a) attaching a light source which simulated an approaching aircraft in night flight (red and green "wing-tip" lights and a red "rotating beacon"); (b) developing a special head-holder and chin-rest arrangement so that, when properly adjusted, head movements of 30° (from the upright position) could be made by each subject in a uniform manner to the left and to the right; (c) a cabin-frame, filling the visual field, which could be placed around the seated subject. The front of the cabin contained a simulated instrument panel and a rectangular opening (window) through which the light source was viewed. The interior of the cabin was coated with luminous paint (see Figure 1). Subjects were always seated directly over the axis of rotation.

Procedure. Subjects were tested under three sets of conditions: (a) total darkness; (b) simulated aircraft lights viewed in an otherwise totally dark room; (c) simulated aircraft lights viewed through the "window" of the luminous "cabin" in an otherwise totally dark room. There were two experimental groups comprised of 12 subjects each. The age range was 21–27 years.

Group A subjects (9 males and 3 females) performed head tilts to the right with accompanying return-to-upright movements under each of the three visual conditions noted above: for this group rotation was always clockwise. A counterbalanced design was used—half of the subjects began with their heads upright while the other half began with their heads already in the tilted position.

Group B subjects (10 males and 2 females) performed right and left head tilts (with accompanying return movements) during both clockwise (CW) and counter-clockwise (CCW) rotation. This group was divided into three sub-groups of four subjects each, with each sub-group tested under one of the three visual conditions. Half of the subjects began with left tilts and half with right tilts, and within each of the sub-groups, half of the subjects were rotated CW first while the remaining half began with CCW rotations. Thus, in Group B, a replication of the experiment with Group A was effected (right head tilts and return movements during CW rotation) and additional information was obtained.

The number of head movements made by each subject was limited to prevent the effects of habituation from influencing the data. All head movements were 30° of arc and each was accomplished within approximately one second.

For all tests, rotation velocity of the Stille-Werner device was maintained at 12 rpm. This level was attained by means of 3°/sec^2 angular acceleration for 24 seconds. No head movement was made until at least three minutes had elapsed

The assistance of Billy P. Updegraff, David J. D. Schroeder, and Ruth Ann Mertens is gratefully acknowledged.

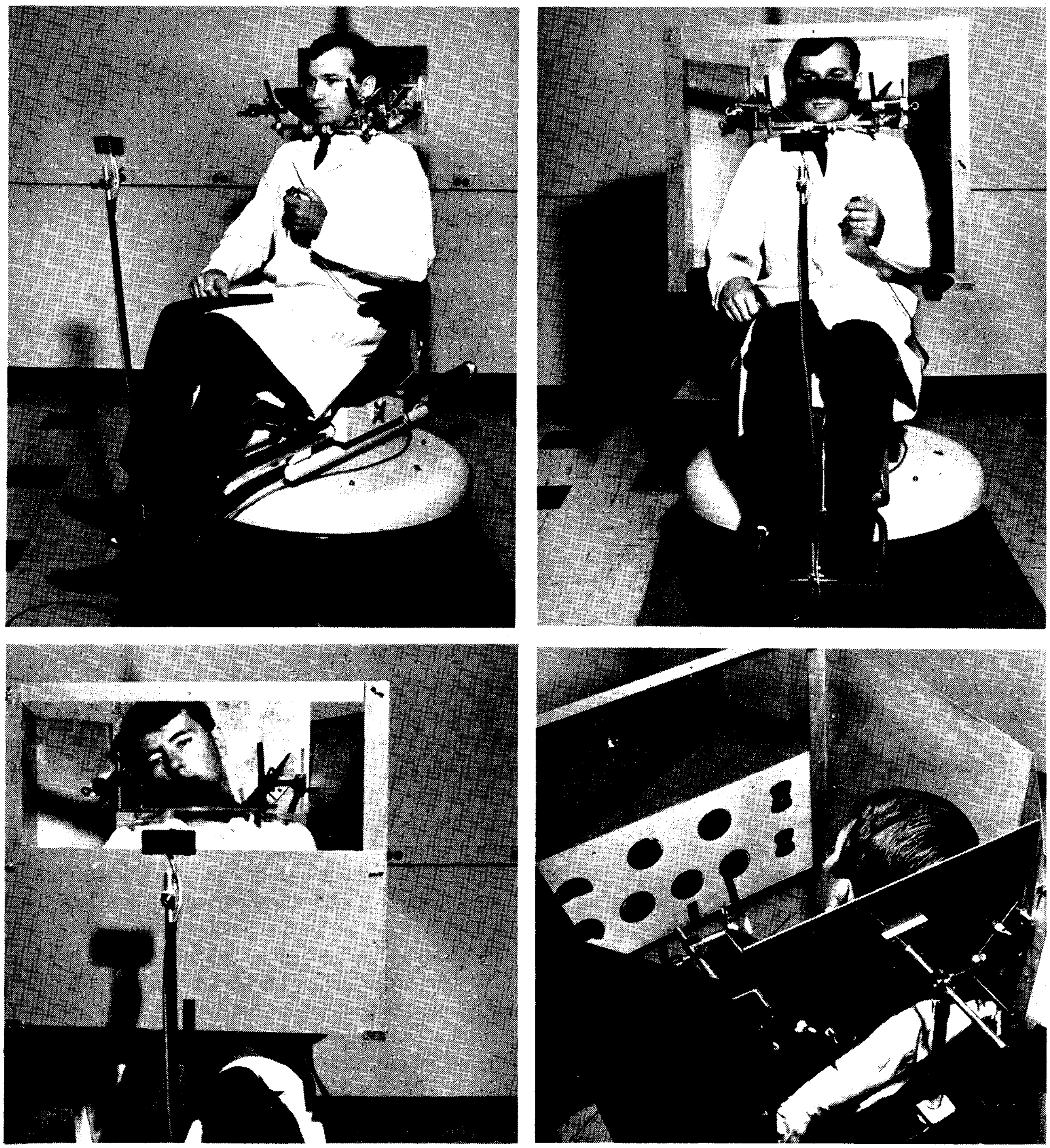

FIGURE 1. Several views of the stimulator. Upper left: experimental arrangement for the total darkness and the wing-tip lights conditions. Upper right: the cabin frame (minus the front panel) has been added. Lower left: front panel added to cabin frame with the subject's head in the right tilt position. Lower right: interior view of the cabin frame condition (wing-tip lights were viewed through the "window" of the cabin).

from the termination of the acceleration. At least three minutes intervened from the end of one head movement to the start of another. Tilt and return movements were considered separately, i.e., they were regarded as independent movements and were separated by the three-minute rest periods.

Subjects gave verbal reports which were tape-recorded during the experiment. They indicated the kind of sensation resulting from each movement, the direction and magnitude (in degrees) of apparent displacement, and gave signals for the onset and termination of their sensations. In addition, ratings of the intensity of each sensation were obtained by having the subjects rate as 100 percent the sensation resulting from one of the first two head movements (a tilt and a return-to-upright); all other sensations were judged against that standard. An omni-directional joy-stick (connected to an X-Y recorder) was used during pilot studies to indicate direction and magnitude information, but it was not employed in the present work since subjects apparently require considerable practice with such a device in order to use it reliably and with confidence.

III. Results and Discussion.

Group A. Subjects consistently rated the sensations produced by 30° head tilts toward the right shoulder as weaker than the sensations produced by return movements of the head to the upright position. These differences were statistically significant by analysis of variance (.01 level) for the three test conditions and agree with other findings.[8] The presence of the "wing-tip lights" produced stronger sensations for both tilt and return movements than did either the "total darkness" or the "cabin" conditions (see Figure 2).

The total duration of the sensations of apparent displacement yielded similar results; return movements produced significantly longer subjective reactions (.05 level) than did tilts (see Figure 2). A breakdown of the sensation into primary and secondary aspects was attempted. With a given head movement, the sensation began almost instantly and maximum apparent displacement was reached very quickly. After some period of time, the subject felt himself returning to a normal ("level flight") position (although he had actually remained motionless). The point at which the subject began to experience a return to the normal position was regarded as the end of the primary sensation of displacement and the start of the secondary reaction. For tilts to the right, mean primary reactions ranged from 23.8 to 31.9 seconds for the three conditions; for head-return movements the range was 29.6 to 35.4 seconds. The mean total time for primary and secondary reactions combined ranged from 48.7 to 78.5 seconds for tilts to the right and from 77.0 to 81.1 seconds for head-return movements.

During CW rotation, right-tilts of the head produced sensations of apparent displacement primarily in a backward direction (similar to a climbing maneuver in an aircraft) accompanied by lateral displacement to the right. Return movements resulted in sensations of apparent forward displacement (similar to a diving maneuver in an aircraft) with some lateral displacement to the right. The average apparent magnitude of displacement was considerable (see Figure 3), ranging from [*head-tilt*] means of 42.9°–60.4° of "climb" with 12.7°–20.6° of lateral movement to [*return-to-upright*] means of 50.0°–75.8° of "dive" with 2.5°–8.8° of lateral displacement. Statistical tests indicated significant differences (.05 level) in the magnitude judgments, with the "wing-tip lights" condition producing the greatest amounts of apparent displacement. Possibly the highly restricted visual field represented by the "wing-tip lights" interacted with the relative motion between the head and the lights to produce the judgments of greatest magnitude. The displacement values obtained are considerably higher than those cited elsewhere.[8]

Group B. Subjects in Group B performed both right and left head tilts with accompanying return movements during both CW and CCW rotation. In agreement with the data obtained from Group A, return head movements from the right tilt to the upright position during CW rotation yielded significantly stronger sensations by analysis of variance (.05 level) than did the tilts to the right (see Figure 4). The same set of head movements yielded "duration of sensation" data which resembled that of Group A. Specifically, during CW rotation, return movements from the right produced longer sensations than did tilts to the right for the "dark" and

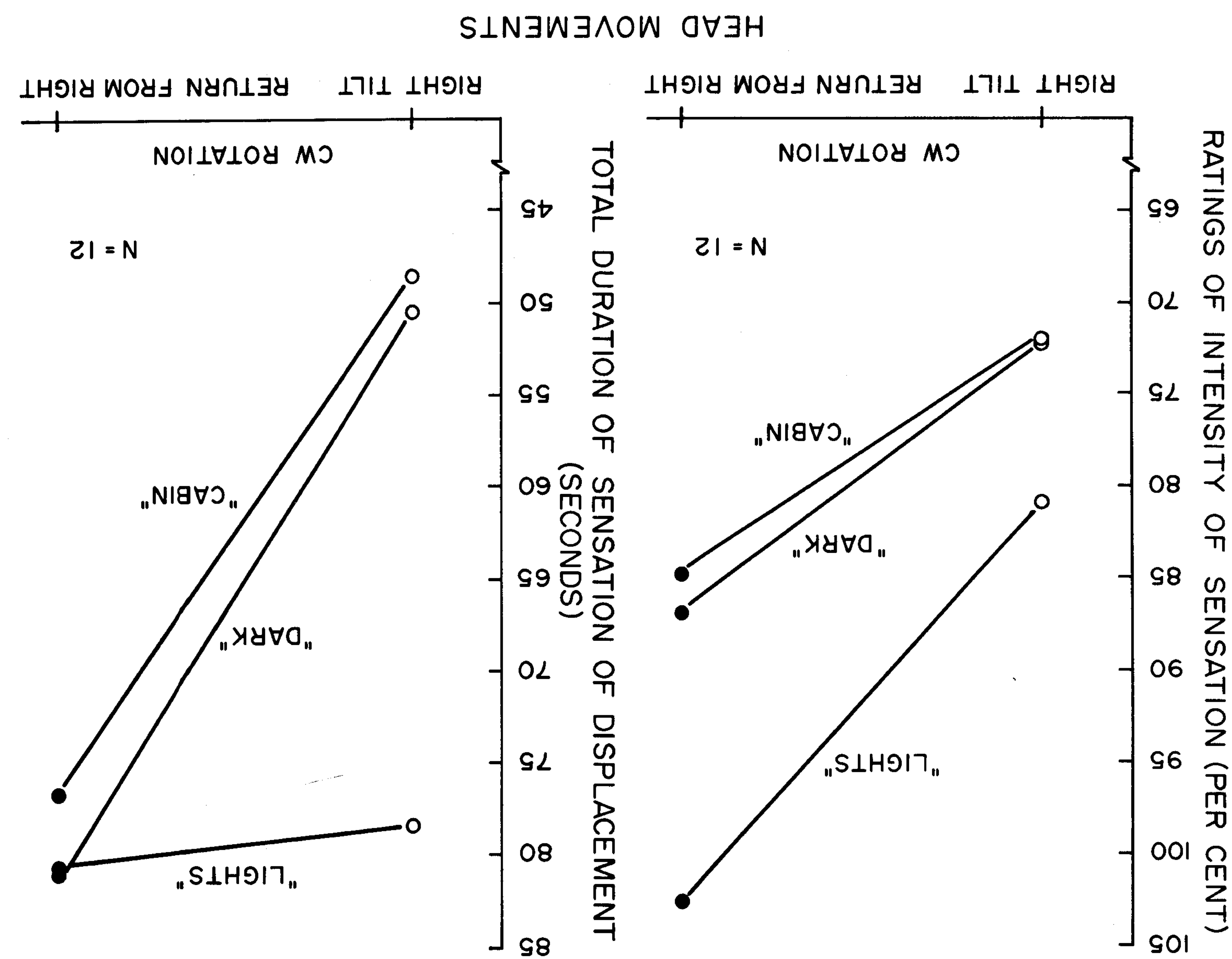

FIGURE 2. Intensity ratings of the sensations occasioned by right-tilt and return-to-upright head movements and the duration of those sensations for the three experimental conditions for Group A. Intensity ratings were obtained by having subjects rate one of the first two sensations as "100%" and judging all others against that standard.

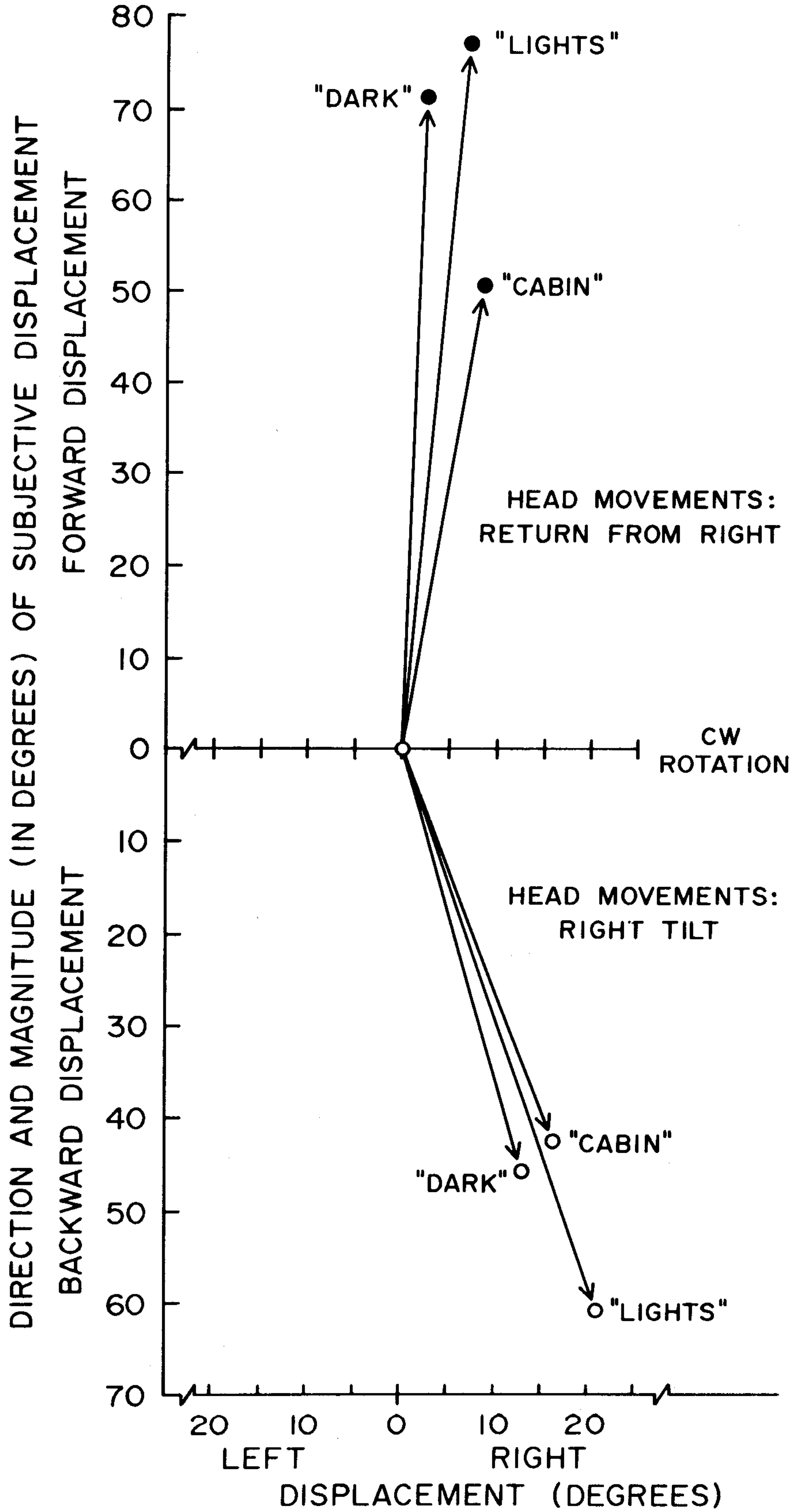

FIGURE 3. Average magnitude and direction of apparent displacement for 12 Group A subjects as a result of right-tilt and return-to-upright head movements for the three experimental conditions. Right tilts result primarily in "climbing" sensations (backward displacement) with additional lateral displacement to the right. Return head movements produce "diving" sensations (forward displacement) with some later displacement to the right.

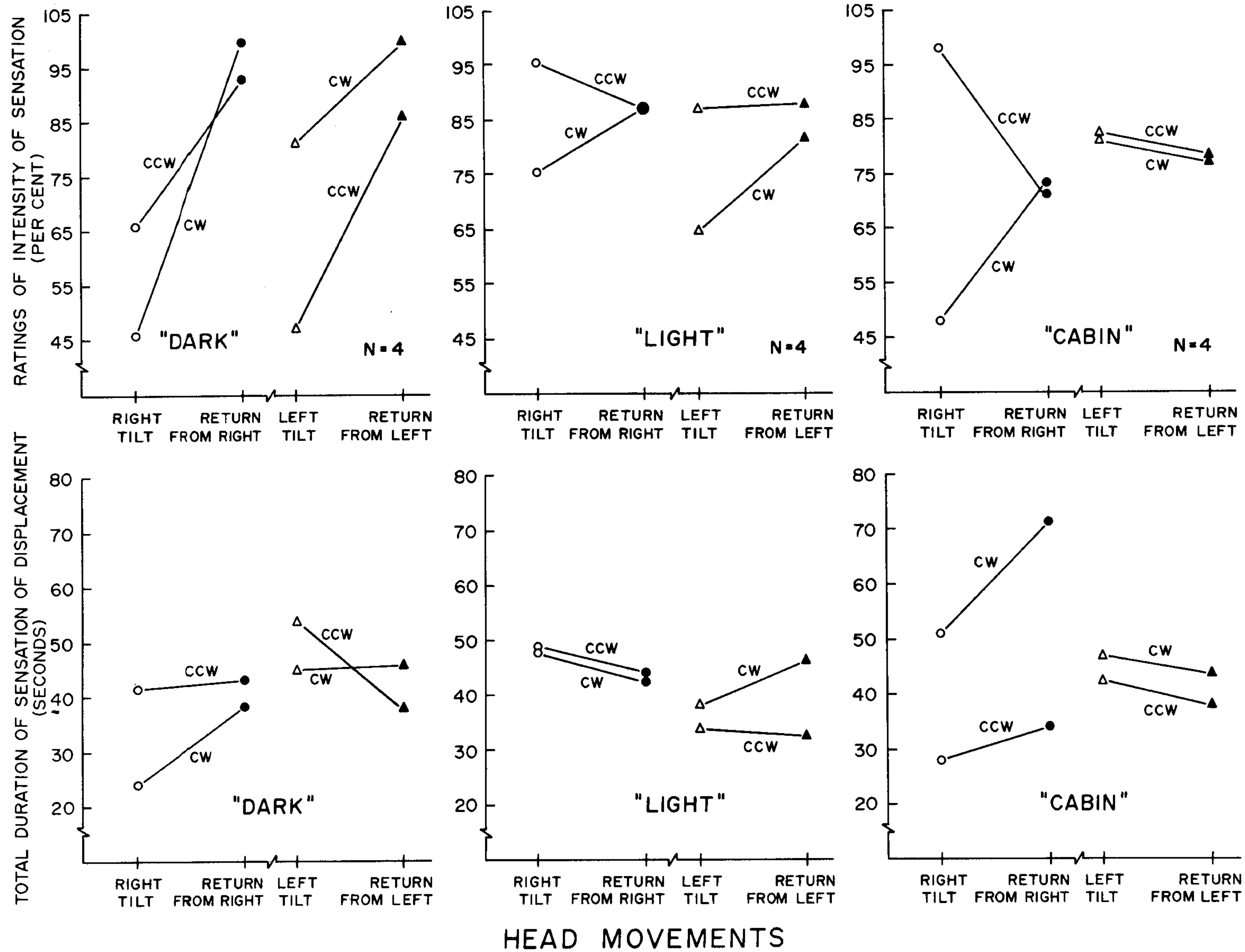

FIGURE 4. Intensity ratings of the sensations occasioned by right-tilt, left-tilt, and return-to-upright head movements and the duration of those sensations for both CW and CCW rotation for Group B subjects. Different subjects were used for the "Dark", "Light", and "Cabin" conditions. Intensity ratings were obtained as in Figure 2. Comparison of the right-tilt and return-from-right head movements during CW rotation can be made with Group A data in Figure 2.

"cabin" conditions, and about equally long sensations for both tilt and return movements in the "wing-tip lights" condition (compare Figures 2 and 4).

Right head tilts and return movements during CCW rotation in total darkness produced the same relationship of "intensity of sensation" ratings as that of CW rotation, i.e., return head movements yielded stronger sensations than did the tilts (see Figure 4). However, this relationship was reversed for both the "wing-tip lights" and "cabin" conditions where the head tilts to the right during CCW rotation produced stronger sensations than the return-to-upright movements. Similarly, in total darkness, left tilts of the head yielded weaker sensations than the return movements for both CW and CCW rotation; this difference was considerably less during the "wing-tip lights" condition and ratings were about equal for the two head movements (for both directions of rotation) in the "cabin" condition. These results found statistical expression in significant "condition by head-movement" (.01 level) and "rotation-direction by head-movement" (.05 level) interactions. Thus the relative intensity of the sensations occasioned by certain tilt and return head movements appeared to be affected by visual information.

In agreement with data from Group A, head tilts to the right during CW rotation produced sensations of apparent displacement backwards (climbing maneuver) with additional lateral displacement to the right. Return-from-right head movements resulted in apparent forward displacement (diving) with less lateral displacement to the right. As in Group A, return movements produced greater apparent displacement than did the tilts. The magnitude of the reported displacement resembled very closely the values obtained from Group A subjects (see Figure 5).

Left tilts during CW rotation produced sensations primarily of forward displacement (diving) as opposed to the apparent backward displacement (climbing) resulting from head tilts to the right. As with head movements in the right quadrant, tilts to the left produced greater lateral displacement than did the return-to-upright movements, whereas the latter produced the greatest amount of displacement "forward" or "backward" (Figure 5). It is of interest that the apparent lateral displacement to right tilts was always to the right (in agreement with data from Group A) while the apparent lateral displacement to left tilts was to the left for the "dark" and "cabin" conditions, but to the right for the "wing-tip lights" condition. A similar result was obtained during CCW rotation.

During CCW rotation, a given head movement yields a sensation opposite that obtained during CW turning (see Figure 6). For head movements in both the right and left quadrants, return-to-upright during CCW turning tended to produce the greatest forward-backward displacement, while tilting movements produced the greatest lateral displacement; however, these differences between tilts and returns were not so great as those obtained during CW stimulation nor were they perfectly consistent. The lateral displacement experienced as a result of head movements in the left quadrant (tilts and returns) was always to the left. For head movements in the right quadrant, however, lateral displacement was to the right for the "dark" and "cabin" conditions, but to the left for the "wing-tip lights" condition. This parallels the finding for CW rotation noted above. Thus certain types of visual information appear to modify the lateral aspect of the direction of apparent displacement.

The degree of apparent pitch forward was considerable, ranging from means of 33.8° to 86.2° depending upon the head movement, yaw direction, and visual condition. For climbing sensations the mean pitch angle ranged from 45.6° to 87.2° (see Figure 5). The primary aspect of the sensations lasted from 13.0 to 24.7 seconds for "climb", and from 12.5 to 34.7 seconds for "dive"; the total time of the sensation (from start of head movement to the point when the subject felt he was in "level flight" again) ranged from means of 24.0 to 53.8 seconds for "climb", and from 28.0 to 71.3 seconds for "dive." Thus, the sensations are long-lasting and the apparent pitch is of considerable magnitude (compare with data from Group A). In addition, the fact that the direction of apparent displacement is in a plane at right angles to both the direction of yaw and the direction of head movement creates a problem of interpretation for the subject; the direction of apparent displacement does not seem to be directly related to the direction of his head movement.

The Sensations. The "intensity of sensation"

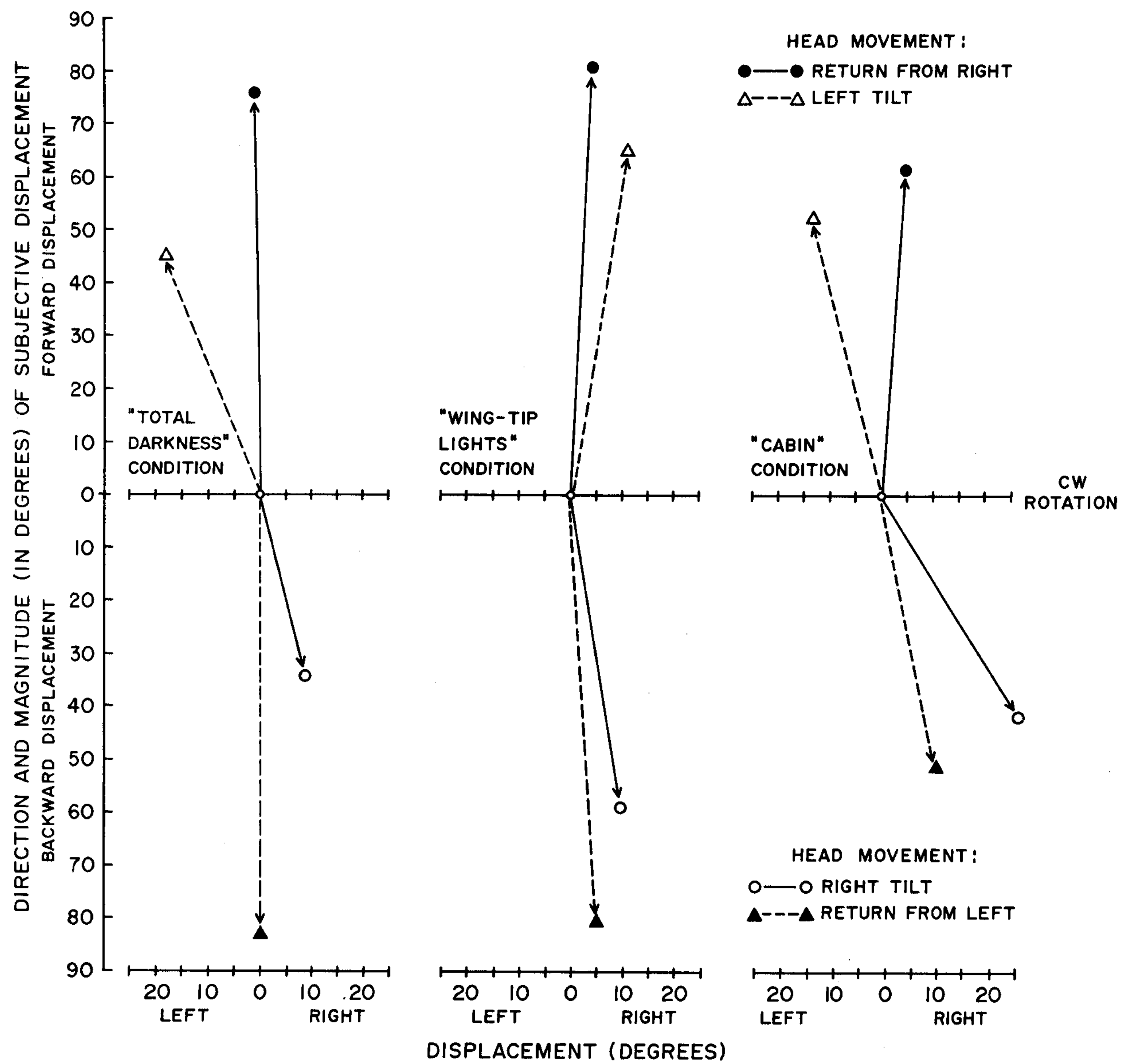

FIGURE 5. Average magnitude and direction of apparent displacement for Group B subjects for right-tilt, left-tilt, and return-to-upright head movements during CW rotation. Four different subjects were used for each of the three experimental conditions. Comparison of right-tilt and return-from-right head movements can be made with Group A data in Figure 3.

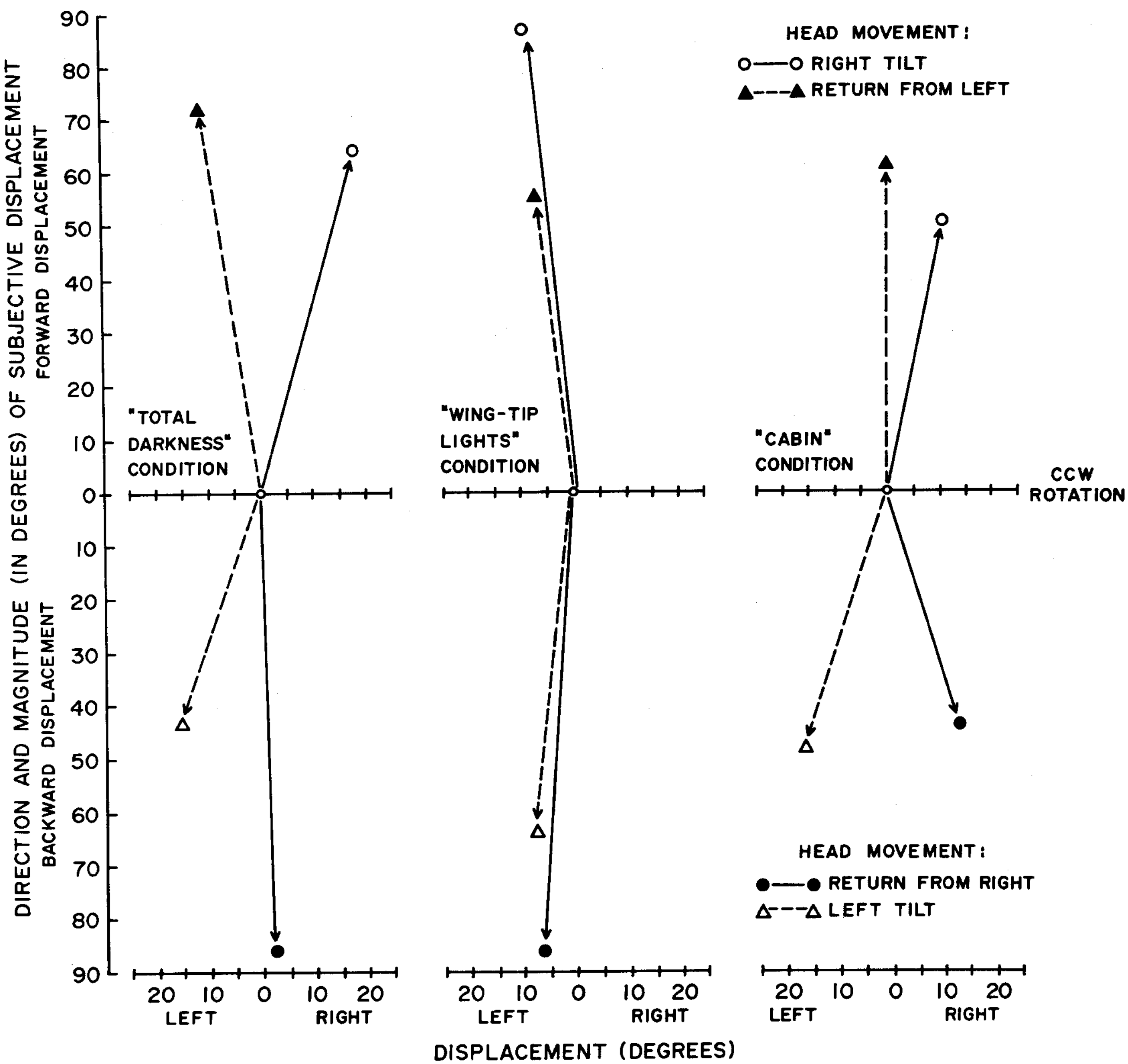

FIGURE 6. Average magnitude and duration of apparent displacement for Group B subjects for right-tilt, left-tilt, and return-to-upright head movements during CCW rotation. Subjects were the same as in Figures 4 and 5.

ratings reported by the subjects were probably not made on an equivalent basis for the three conditions. This is partly due to the fact that some subjects seemed to enjoy the sensations produced by head movements made during rotation while other subjects were quite disturbed (sometimes to the point of nausea) by the same movements. (Several subjects had to be eliminated from the study, prior to completing the small number of head movements required, due to the onset of motion sickness. They were replaced by other subjects.) Also, the conditions produced marked differences in the number and type of events to which the subjects had to attend. In total darkness, attention could be limited solely to the internal sensations produced by the head movements, whereas with the "wing-tip lights" the apparent motion of the lights also had to be considered. In the latter situation, the lights appeared to move in the same direction as the apparent displacement of the subject; however, the apparent velocity of the light and its extent of movement differed with different head tilts. For example, the lights sometimes appeared to have very high velocity but an inappropriately small amount of apparent displacement. At other times the lights had considerably less apparent velocity but greater apparent displacement. These findings have also been noted elsewhere.[7,8] Under the "cabin" condition, the lights appeared simply to move with the "window frame" and the subject experienced a visually reinforced sensation of displacement in that he "saw" the cabin tilt with him. Thus, the ratings assigned to the various sensations were actually based on sets of events which differed among subjects and among the conditions.

General Discussion. These data indicate that a strong sensation of apparent displacement may accompany relatively small head movements during an angular velocity of 72°/sec (12 rpm). In addition, the experienced displacement is of considerable magnitude (ranging from means of 33.8°–87.2°) and is in a direction which the subject does not readily associate with the head movements. Thus, due to the so-called "Coriolis" forces, lateral head movements during rotation about an earth-vertical axis produce illusions of climbing or diving, while nodding motions of the head under the same condition produce sensations of apparent tilt to the right or to the left. Additional illusions are experienced when the "wing-tip lights" are viewed. The lights appear to move at different velocities and to different terminal points depending upon the head movement. Under the "cabin" viewing condition, the lights appear immediately to follow the apparent maneuver of the "cabin" which is clearly seen as tilted in a given direction following a particular head movement. Such illusions may readily occur in aircraft when external visual references are not available or when they provide ambiguous information. The importance of these "Coriolis" effects has been detailed in a number of publications (e.g.[1,9]).

Most studies of "Coriolis" vestibular responses have been concerned primarily with nystagmic eye reactions (the directions of nystagmus resulting from various head movements during CW and CCW rotation have been detailed by Guedry[6]) with relatively limited attention given to the subjective effects.[2,5] Guedry and Montague[8] presented information regarding both reactions but reported relatively low magnitudes of apparent displacement (approximately 15° of displacement for head tilts of 30° during 10 rpm rotation). In this study, apparent displacement averaged three or more times this value. Differences in the magnitude of the "diving" and "climbing" sensations obtained here as compared with those of Guedry and Montague[8] may be due to one or a combination of the following factors. (1) Subjects in this study had no prior practice; those of Guedry and Montague received training trials. Data indicate that repetition produces a reduction in the response.[5] (2) Displacement values in this study represent the verbal estimates of the subjects whereas Guedry and Montague used joy-stick movements as their basic data. (3) The rate of rotation was higher in this study (12 rpm vs. 10 rpm).

It should be noted that a considerable number of licensed pilots (many with prior military fighter aircraft experience) have been exposed to the "cabin" condition during laboratory demonstrations and have given verbal estimates of displacement which are very similar to those reported by the naive subjects in this study. Parenthetically, these individuals have spontaneously commented on the usefulness of the "cabin" device for pilot-training purposes in familiarizing subjects with "Coriolis" vestibular effects.

IV. Summary.

"Coriolis" vestibular stimulation was used to produce disorientation and simulated "pilot's vertigo" under controlled laboratory conditions. During angular velocities of 72°/sec, subjects made 30° lateral head movements under three conditions: (a) in total darkness; (b) while viewing simulated aircraft lights in an otherwise totally dark room; and (c) while viewing the simulated aircraft lights through a "window" in a luminous "cabin" which was secured about the rotating device. Verbal estimates of the illusions of "diving" or "climbing" maneuvers resulting from the head movements ranged from a mean of 33.8° to 87.2° depending upon the head movement and the visual conditions for different groups of subjects. Relative intensity of the sensations occasioned by one head movement as opposed to another depended upon the turning direction (yaw-axis) of the stimulator (CW or CCW) and upon the visual surrounds.

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