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ADAPTATION TO VESTIBULAR DISORIENTATION: II. NYSTAGMUS AND VERTIGO FOLLOWING HIGH-VELOCITY ANGULAR ACCELERATIONS

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In spite of a formidable and still growing literature on the question of habituation of vestibular responses (cf. Collins, 1964; Guedry, 1965), only Mowrer (1934) and McCabe (1960) appear to have examined vestibular reactions in figure skaters. In a footnote (p. 8), Mowrer (1934) indicated that his studies of habituation led him to test nystagmic reactions of a limited number of professional skaters and ballet corps members. He asked these individuals "to spin, in characteristic manner, and permit . . . (Mowrer) , . . to observe their eyes immediately afterwards. In many cases, there was no detectable post-rotational nystagmus whatever. In certain other cases, a noticeable (though distinctly "sub-normal") nystagmus was present . . ." More recently, McCabe (1960) made use of motion picture films as well as visual observations in subjecting two highly proficient figure skaters to ice water caloric irrigations, Barany chair spins, tape walking, and on-ice skating spins. He reported that ". . . Neither vertigo nor nystagmus could be elicited by stimulation of the vertical or horizontal canals."

Electronystagmographic recording techniques were employed in the present study and were supplemented by motion picture films. A total of 8 professional figure skaters were examined. Six of these were given both rotary and caloric laboratory tests and, of these, 4 were tested in an "on-ice" phase of the study. Two additional skaters were given caloric irrigations only.

LABORATORY PHASE

Methodology

Caloric Irrigations. Two water baths were equipped with Bronwill constant temperature circulators. Tubing from the base of each bath terminated in its own plastic nozzle which could be inserted into the external auditory meatus. The temperature of the water at the site of introduction to the ear was maintained at 30° C from one bath and 44° C from the other. Water flow was approximately 15 cc/sec to permit ready monitoring of the stimulus during administration in the dark. Duration of unilateral stimulation (warm or cool water to one of the ears) was 30 sec; that of bilateral stimulation (simultaneous administration of warm water to one ear and cool water to the other) was 15 sec. Trials were conducted with eyes open in total darkness, eyes open in illumination, and eyes lightly closed in illumination.

Angular Accelerations. Rotational stimulation was provided by a Stille-Werner RS-3 rotating chair. Both clockwise (CW) and counterclockwise (CCW) rotations were employed. Stimuli ranged from $5°/sec^2$ to $15°/sec^2$ and were applied for durations of 6 to 24 sec. A typical stimulus sequence consisted of an acceleration (e.g., $5°/sec^2$ for 18 sec), 2 min at constant velocity, and a deceleration of the same magnitude as the acceleration. Subjects were seated upright with heads positioned so that the lateral semicircular canals were in the plane of rotation.

Recording. Electrodes were taped by the outer canthi of the eyes to permit recording of horizontal components of eye movements. An indifferent electrode was located on the forehead. Offner T and TC recording systems were used. For the two subjects (JC and PR) who were exposed only to unilateral 30° C calorics, DC records were obtained. In all other cases, a 3-sec RC time constant was used.

Telemetry. For some tests, subjects performed pirouettes in the laboratory. To record eye movements during and following these body movements, a Telemedics RKG-100 telemetry transmitter and receiver were used to pick up the eye movement signals and feed them into the recorder. Use of the telemetry equipment reduced the time constant in the recorder to approximately 1 sec.

Results

Caloric Irrigations. All of the skaters were given unilateral caloric irrigations. With eyes open in a lighted room and visual fixation on an object (motion picture camera) located approximately 2 feet away, nystagmus was not vigorous; in one subject it was almost undetectable. Eye closure resulted in an accentuated response. When tested with eyes open in total darkness, nystagmic tracings from the skaters to both unilateral (Figure 1) and bilateral (Figure 2) stimuli showed brisk nystagmic eye movements.

Subjective responses to calorizations in total darkness varied considerably. Five skaters indicated no sensation or vague experiences (such as rocking motions or "headiness") to unilateral stimuli. The remaining 3 skaters (JC, PR, RR) reported definite turning sensations, although one of these (PR) reported motion to the left

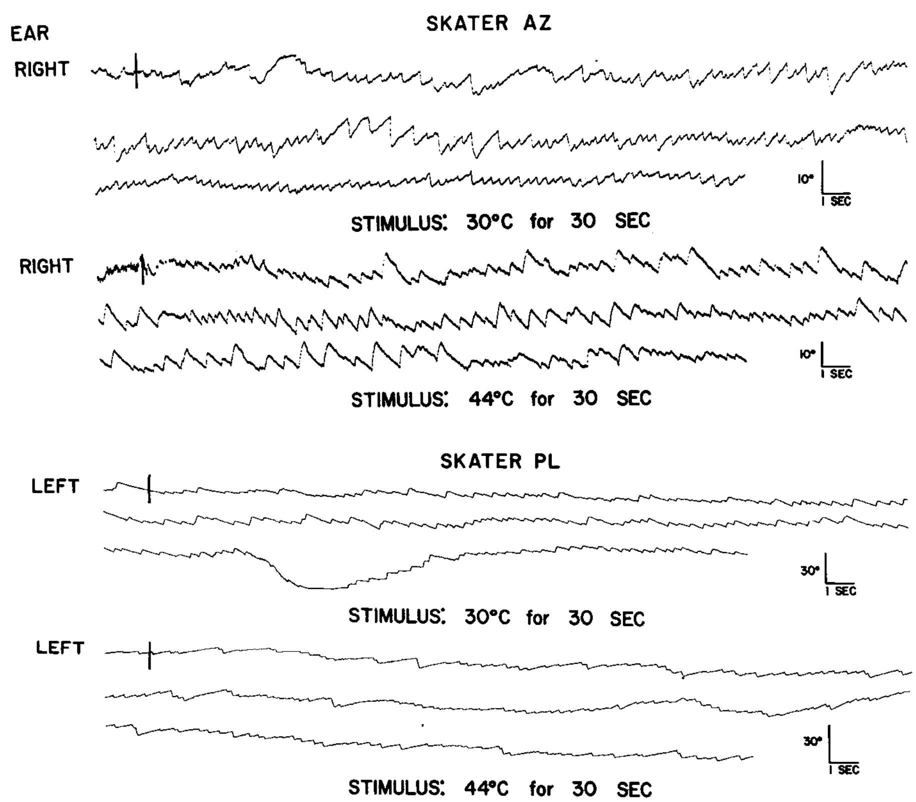

FIGURE 1. Responses of two figure skaters to unilateral caloric irrigations. Vertical bars through the records indicate the point at which the stimulus ended. Eye-movement calibrations appear at the end of each set of tracings. Tests were conducted in total darkness.

ing pirouettes performed in the laboratory. The skaters were simply instructed to whirl themselves about in dancing spins within a circular area about 5 feet in diameter. At a given signal, they stopped abruptly. With eyes open, 2 or 3 beat of nystagmus were occasionally noted immediately after the spin. With eyes closed, vigorous nystagmic eye movements, as in Figure 5, were consistently obtained.

ON-ICE PHASE

In the laboratory situation, the skaters produced strong vestibular responses in total darkness while serving, for the most part, as the passive recipients of vestibular stimulation. On ice, however, the skaters actively induce and control the sensory input by means of a thoroughly practiced discipline which involves psychological as well as physical factors. Four of the skaters examined in the laboratory were therefore tested during and following their on-ice spins.

Methodology

Recording. The telemetry system used to obtain tracings during the laboratory pirouettes permitted the recording of eye-movements during and after the skaters' high velocity, on-ice spins. The Telemedics RKG-100 telemetry system was utilized with a pair of electrodes taped by the outer canthi. The leads were plugged into the transmitter strapped to the skater. The receiving system and the recorder were located at rinkside. Motion picture cameras employing both standard and high speed film were used to obtain additional information concerning the eye and body movements of the skaters.

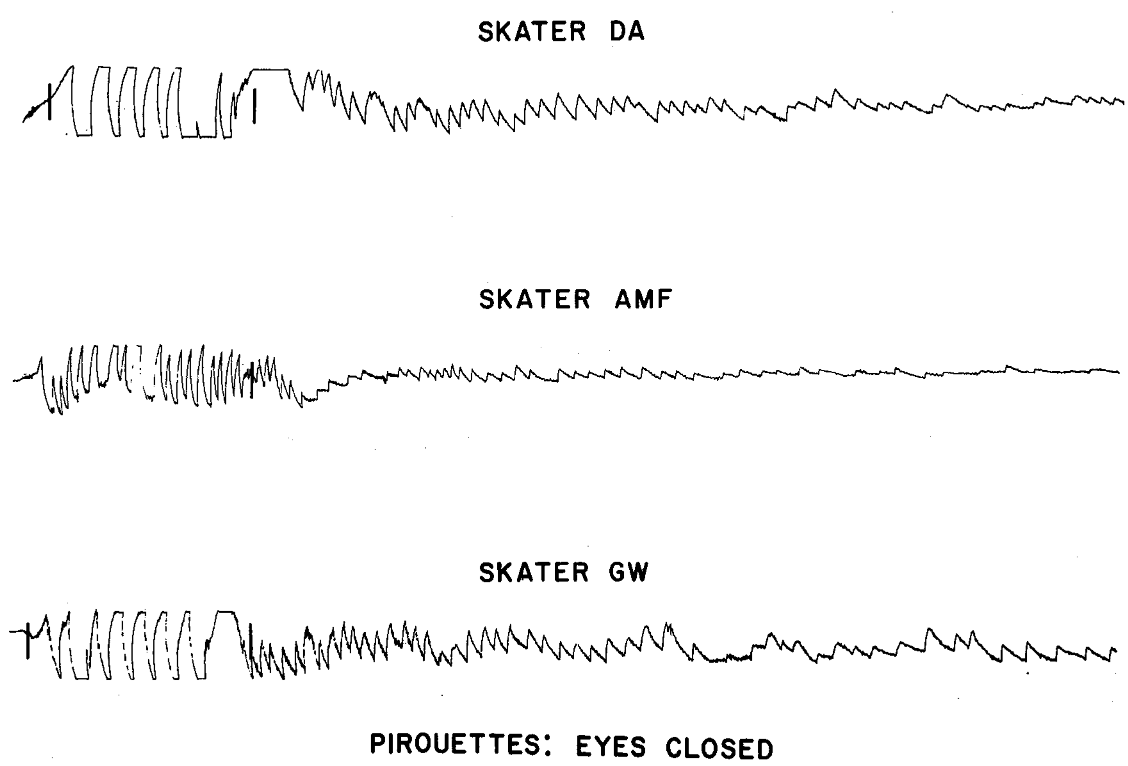

FIGURE 5. Nystagmus resulting from pirouettes performed by three figure skaters in the laboratory. Their eyes were closed throughout the trials. Vertical bars demarcate the turning period. Each tracing represents 30 seconds of recorded activity.

Procedure. The skaters were asked to perform their usual on-ice spins (which place the lateral semicircular canals in the plane of rotation) and, upon stopping, to orient themselves toward the cameras. The skaters then either fixated on the cameras or lightly closed their eyes. Several other types of spins (e.g., camel, layover camel) were also performed. Motion pictures and electronystagmographic recordings were obtained.

During a second on-ice session, the skaters were asked to again perform the spins and, upon facing the cameras at the conclusion of each spin, to walk straight forward. The walking on skates was performed under "eyes open" and "eyes closed" conditions.

Results

Vestibular Nystagmus. At the conclusion of their spins, with eyes open, all of the skaters had a brief nystagmus which was quickly inhibited by visual fixation (see Figure 6). Only one subject (DA) reported blurred vision during this time and his nystagmus was consistently more pronounced and of longer duration than that of the other skaters. (Skater AZ, tested only in the laboratory, reported that her vision blurs upon stopping from an on-ice spin and is frequently still blurred as she begins her next skating movements.) With eyes closed at the end of their spins, vigorous nystagmic eye movements were uniformly obtained from the four skaters. Although these

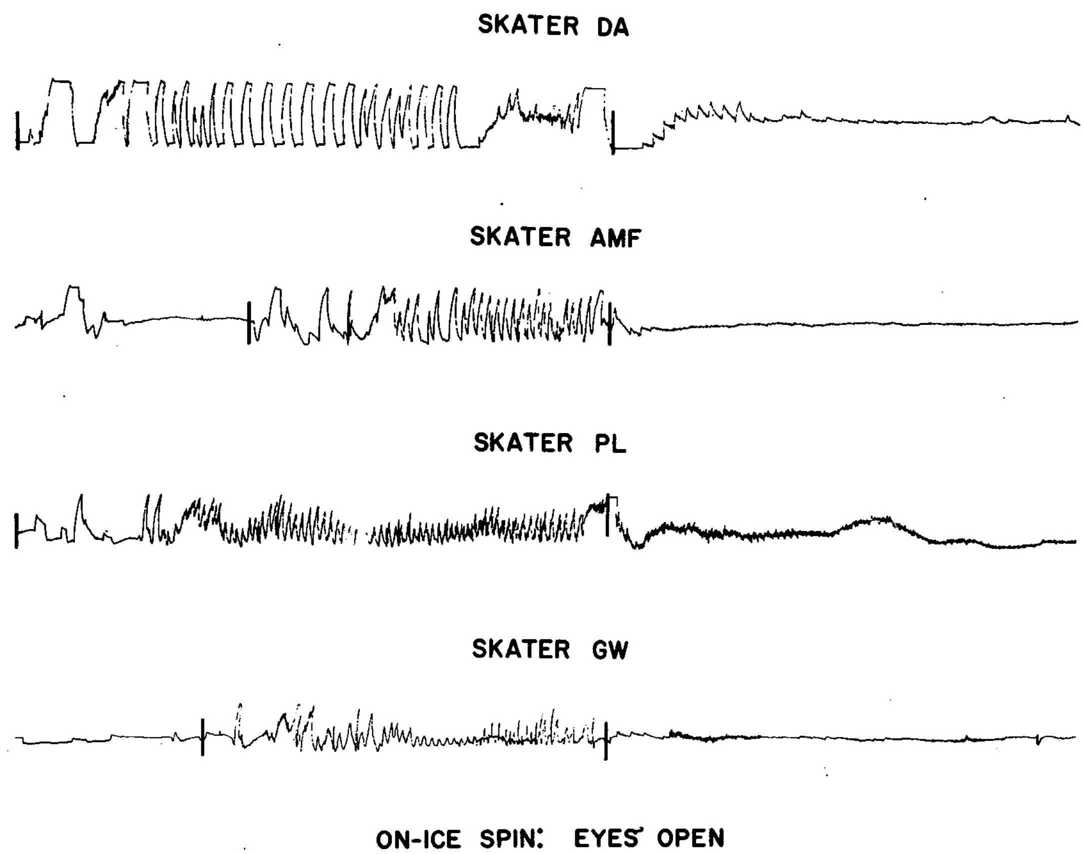

FIGURE 6. Eye-movement recordings obtained by means of telemetry during on-ice spins performed by four skaters with eyes open. Vertical bars demarcate the spinning periods. Several clear beats of nystagmus appear at the end of each spin. The noisy records for PL are due to his tendency to squint his eyes. Each tracing represents 30 seconds of recorded activity.

responses were of considerable duration (see Figure 7), it is possible they may have been attenuated, considering the magnitude of the deceleration stimuli.

Disorientation. At the conclusion of spins in which the lateral semicircular canals were in the plane of rotation, and with eyes open, all of the skaters walked straight forward with no difficulty. Their ability to maneuver gracefully with open eyes is not surprising since their skating routines require well-coordinated movements after completing a spin. However, in performing a "layover camel spin" (stimulating vertical semicircular canals) and completing the skating routine by spinning upright (thereby adding stimulation of the lateral canals),

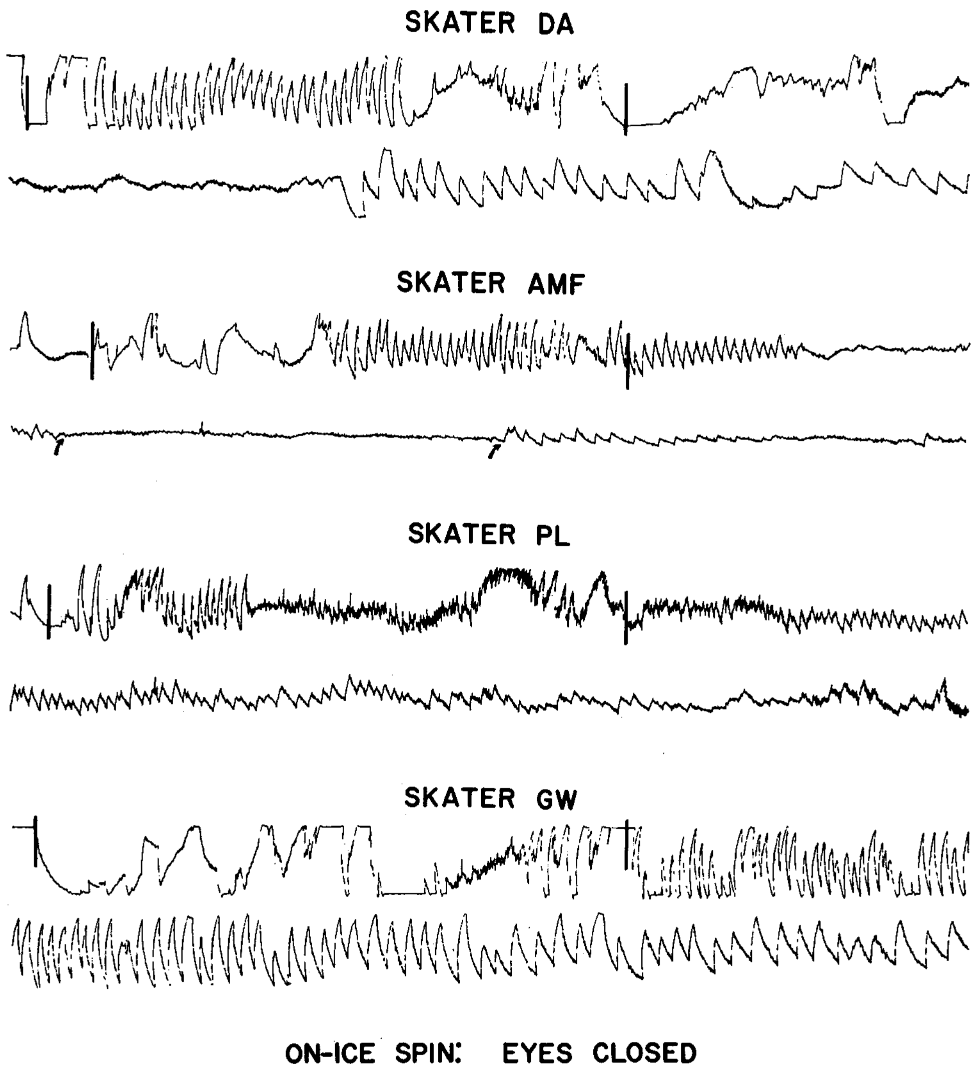

FIGURE 7. Telemetered recordings of eye movement during on-ice spins performed by four skaters with eyes closed immediately following the spin. Vertical bars demarcate the spinning periods. Vigorous nystagmus was obtained in all cases. The two arrows in AMF's tracing indicate the period during which she inadvertently rolled her eyes upward behind her closed lids; nystagmus quickly disappeared. When told to center her eyes (second arrow), still behind closed lids, nystagmus recommenced. The several seconds of unclear eye movements following the spin in DA's tracing may also have been due to upward rolling of the eyes. For each skater, a total of 50 seconds of recorded activity is presented.

subject GW experienced some dizziness and staggered slightly while attempting to walk with eyes open.

With eyes closed after completing a spin, all of the skaters had walking difficulty. In fact PL, the first skater to attempt ambulation with closed eyes, went into a tight turn to his left after just a few steps and fell to the ice. It is of interest that the skaters anticipated no difficulty in maneuvering with eyes closed after spinning and were quite unprepared for the lack of control, disorientation, and dizziness which they experienced. Three of the skaters (DA, AMF, and PL) were clearly staggering or falling to their left during attempted forward movement. GW, however, consistently staggered to her right and reported feeling compelled to move in that direction. It should be noted that this "walking task" consisted of ordinary stepping movements and was not the more difficult heel-to-toe walk frequently employed to test equilibrium.

All of the skaters tested on ice performed their spins in the usual counterclockwise direction. (Apparently relatively few skaters spin habitually in a clockwise direction. Of the 8 skaters examined in this study, only RR is a clockwise spinner.) In attempting clockwise spins the skaters could not perform at anywhere near the level of proficiency which they demonstrated in their usual turning direction. In addition, with eyes closed, they appeared to experience more dizziness from these milder stimuli (slower and fewer turns), and kept a spread stance for a longer period of time after the spin to maintain balance.

It is clear that the skaters do not use the "spotting" technique employed in dancing spins. Not only is their angular velocity too high to permit "spotting," but the skaters demonstrated their ability to spin with eyes closed. Thus, they require no visual reference (such as a blurred line of footlights) to assist them in maintaining balance; apparently proprioceptive and kinesthetic signals are sufficient.

Analysis of High-Speed Film. Twelve spins were recorded on high-speed film. Analysis of the film indicated that peak spinning velocities ranged between 226-289 rpm. Mean peak velocities were 235 rpm for DA, 258 rpm for PL, 268 rpm for GW, and 278 rpm for AMF. It is to be noted that, during these filmed sequences, the skaters were not necessarily attempting to achieve a maximum velocity, that they were wearing the telemetering transmitter, and that since the testing schedule called for a total of 10-20 spins per subject, fatigue may have been an additional factor affecting the peak values on those spins which were photographed. It is clear, however, as McCabe (1960) has noted, that the skaters regularly achieve spinning velocities between 250-300 rpm.

The high-speed film also showed some effects of such rapid angular motion on the skaters. Some of these changes are evident in Figure 8. During spins, the skaters' eyes tend to roll upward and the lids are sometimes partly closed (see also McCabe, 1960). For 3 of the skaters, the eyes seemed to be displaced, for the most part, in the direction of the spin. The single exception (GW) appeared to have her eyes displaced in the direction opposite the spin. In addition to considerable bodily tension, the high spinning velocities produced facial distortion in all of the skaters; their cheeks tended to pull away from the skull and blood was drawn to the extremities, causing a clearly observable reddening of the nose.

General Discussion

The present data indicate that there is no total suppression of vestibular responses from figure skaters as a consequence of repeated, high-velocity, angular motion. Without opportunities for visual fixation, both in the laboratory and on ice, all of the skaters gave brisk nystagmic reactions to angular accelerations. In addition, clear sensations of angular motion were experienced in the laboratory to mild rotatory stimulation. However, the skaters appear to have learned to reduce vestibularly-induced ocular movements to some extent by means of visual fixation. This ability to exert some visual control over the effects of vestibular stimulation may account for Mowrer's (1934) observation and McCabe's (1960) report that skaters showed either "distinctly subnormal" responses or no nystagmus at all. It is even possible that nystagmic responses of the skaters in total darkness may differ in some ways, on the average, from responses of ordinary subjects and, in addition, our laboratory data

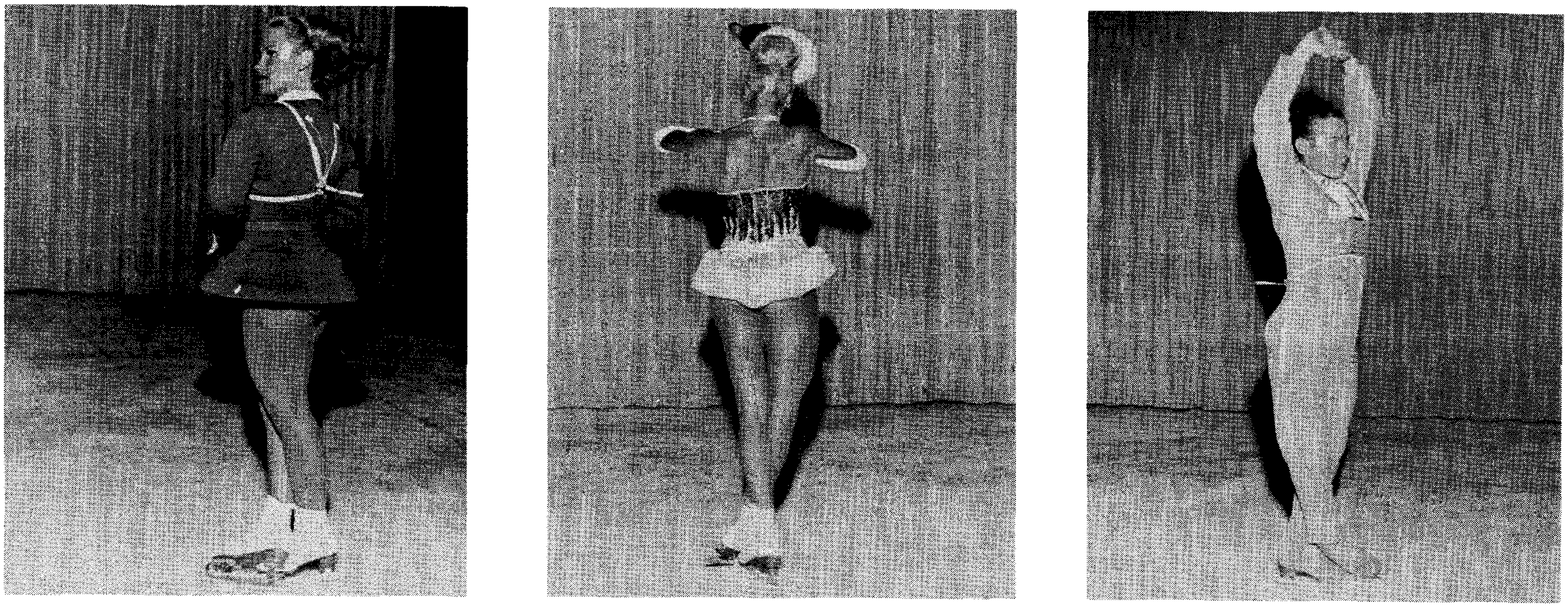

FIGURE 8. Photographs of AMF, GW, and DA taken as they reached the peak velocity of their spins. Distortion and tension are evident in the faces of AMF and DA. Their eyes also appear to be displaced upward and in the direction of the spin. The physical strain of high-velocity spinning is further emphasized in the tensed back muscles of GW.

indicated some possibility of directional differences in the skaters' nystagmus favoring right-beating responses. A larger sample of skaters, quantification of nystagmus, and statistical comparison with a non-skater group would be required to establish these relations.

The fact that clear turning sensations as well as brisk nystagmic responses were obtained from the skaters in darkness somewhat complicates current views on the question of vestibular habituation. The data, however, support our previous laboratory work in which repeated caloric irrigations (Collins, 1965) and repeated angular accelerations (Collins, 1964) did not result in a severe reduction or abolition of nystagmus in ordinary subjects; some response decline occurred (approximately 30% reduction in slow-phase displacement) but, in alert subjects, increased vestibular activity (greater number of nystagmus beats) was concomitantly present under some conditions (Collins, 1964; 1965). Two hundred unidirectional angular accelerations in darkness also did not abolish sensations of angular displacement in ordinary subjects, although a 35-40% decline in this response was obtained (Collins, 1964). It would seem that, when the lateral semicircular canals are held rigidly in the plane of rotation, some initial decline in the magnitude of the slow-phase sweep of the eyes may occur, but repeated stimulation will not result in complete suppression of nystagmus or of the sensation of angular motion in the absence of visual stimuli. The form of the nystagmic response may change, however, and such a change (lower amplitude, higher frequency nystagmus) may still be evident after one month without stimulation (Collins, 1964).

Summary

Several professional figure skaters who, as part of their daily routine, subject themselves to strong semicircular canal stimuli, were given a series of laboratory tests consisting primarily of caloric irrigations and mild angular accelerations. Brisk nystagmus and clear turning sensations were consistent findings in total darkness. Motion pictures and telemetered eye-movement recordings were then obtained during and following the skaters' normal spins on ice. Mean peak velocities of 235-278 rpm were achieved by four of the skaters. Vigorous nystagmus and dizziness or turning sensations occurred following spins when visual fixation was not permitted. Loss of equilibrium and disorientation also occurred when the skaters attempted to maneuver after their spins without visual cues. The notion that complete suppression of vestibular responses occurs in figure skaters as a result of their repeated exposure to high velocity angular accelerations is not upheld by the present data.

Acknowledgment

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