CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

THE EFFECTS OF POST-ROTATIONAL NYSTAGMUS ON VISION

A thesis submitted in partial satisfaction of the
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Psychology

by

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ABSTRACT

THE EFFECTS OF POST-ROTATIONAL NYSTAGMUS ON VISION

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Eight pilots and eight non-pilots were rotated in a Bárány chair at 30 revolutions per minute and 45 revolutions per minute for 60 and 120 seconds. The subjects were required to track a target on a computer screen after the rotation to determine the amount of time for their vision to clear. The dependent variable was the amount of time to attempt to hit the target the first time or the mean time for each of the first five attempts. There were no significant differences between conditions, however, there were some weak interactions between groups and conditions ($p<.10$). The literature suggests there would be no difference due to the rotational speed. The lack of significant differences can also be attributed to experimental error, and lack of sensitivity of the tracking task. Pilots tended to have faster speeds, indicating they may

have habituated to the stimulus because of their flying. Further research with differing age groups and differing experience levels is indicated.

INTRODUCTION

BACKGROUND

The primary function of the vestibular and kinesthetic systems is to allow the organism to remain balanced during movement while a secondary function of the vestibular system is to keep vision clear during movement. When the semicircular canals are stimulated, there is a corresponding compensatory eye movement in the opposite direction from the head movement called the vestibular-ocular response (VOR). Normally, eye movement is equal but opposite to the head movement in which the gain (the ratio of head to eye movement) is one.

The vestibular organs are made up of the saccule, utricle, and semicircular canals (Figure 1). They are stimulated by both linear and angular accelerations. The otolithic organs (the utricles and saccules) respond to the direction, and change of direction, of linear acceleration. The utricle is filled with a fluid called endolymph.

> The utricular receptor is called the macula, and it is composed of cilia imbedded in the inner surface of the utricle....The statoliths in the utricle sac are calcium carbonate crystals....When the body is speeding up or slowing down in a straight-line motion or when the head is tilted, that is, with linear acceleration (changes in the rate of motion), the inertia of the statolith particles brings about a bending of the hair cells with a consequent discharge by attached nerve

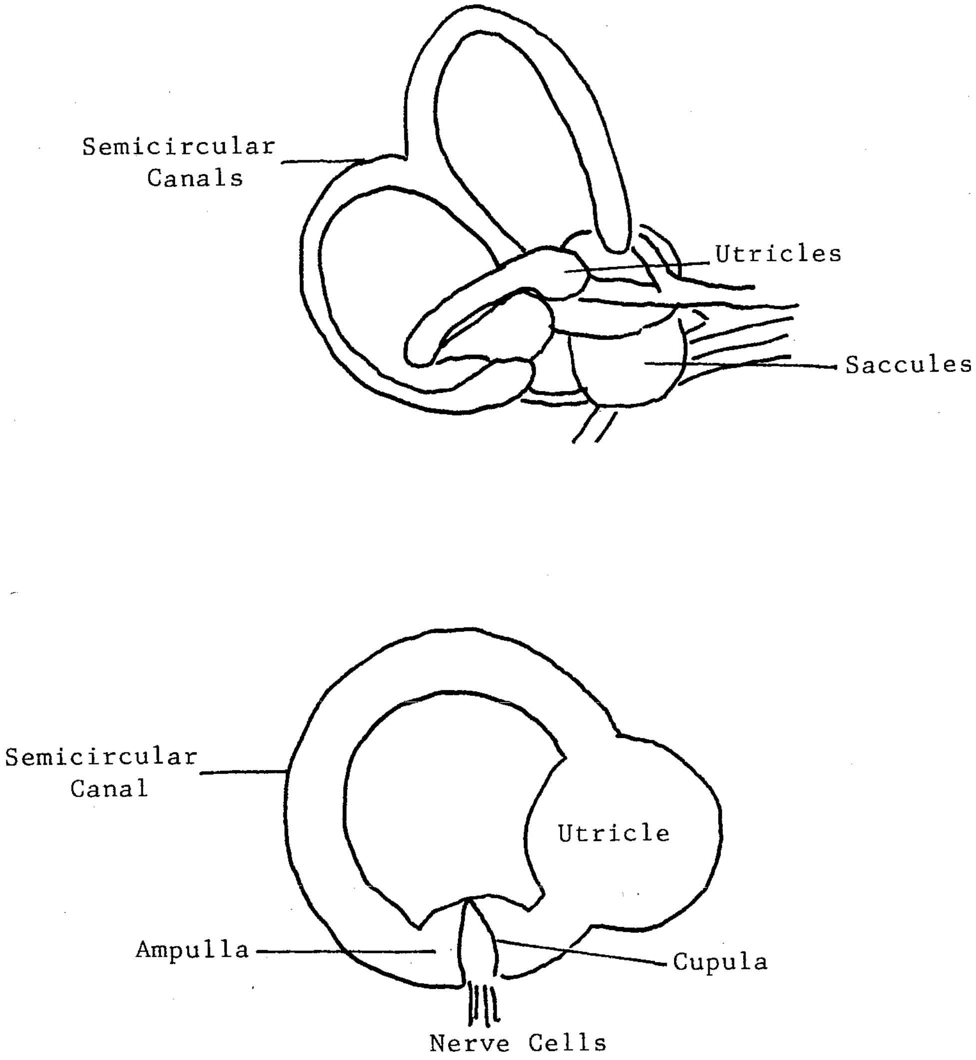


Figure 1

The Vestibular System

> fibers (Schiffman, 1976).

The ampullary receptors of the six semicircular canals are stimulated physiologically by angular acceleration. The semicircular canals are endolymph filled enclosures that lie at approximately right angles to each other. Each of the three canals relates to a plane of the body (Figure 1).

> Within each canal is a set of sensory hair cells. These receptors are stimulated when pressure is exerted on the fluid of the canal, such as during rotary acceleration resulting from movement of the head. Each canal widens at its base into a somewhat spherical, fluid-filled chamber called an ampulla, which contains the vestibular receptors. Each of the ampullae contains a tongue-shaped protuberance...called the cupula. It is composed of crests of hair cells and tufts from the vestibular nerve and is encased in a gelatinous mass. The cupula is fixed at its base, the crista, but swings freely into the ampullar cavity and is capable of being bent by the pressure of the endolymph. This movement at the crista stimulates the hair cells, which transmit a series of impulses to the brain ....The endolymph fluid of the canals circulates and becomes displaced appropriate to the head rotation, creating hydraulic pressure. This resultant pressure causes a bending of the cupula, its deflection being proportional to the force of the head

> turn....When the rotation ceases or its rate stabilizes, the deflection is canceled and the cupula returns to its normal position (Schiffman, 1976).

When people are subjected to sufficient angular acceleration, they may become dizzy and fall. They develop somesthetic and visual sensations of rotation which are usually ascribed to the semicircular canals. The "falling down" aspect of the experience can be ascribed to slight tilts of the head after stopping rotation which lead to changes in the plane of apparent rotation. The somesthetic effects of this change tend to bring about a falling response. An alternative point of view is that rotation somehow affects the static sense. This implies that angular acceleration may affect the otolith organs or the central nervous system (CNS) associated with the utricles (Gray, 1960). The idea that the CNS associated with the utricles is affected by semicircular canal stimulation further implies that the otolith organs and the semicircular canals have a combined function.

Another involuntary eye movement is nystagmus, which can occur when the head is rotated about one or more of it`s axes or can also be produced by the visual presentation of a moving field. The eyes move slowly in the opposite direction of the head motion (slow phase) and quickly in the same direction (fast phase). The movement of the eyes continues after the rotation has ended. This decays over time, but the subject's perception is of continued rotation in the opposite direction. The eye-movements themselves are not perceived. Visual perception of the fast phase is disregarded, while that during the slow phase is relatively clear. Therefore, the eye-movements produce a tracking of the image across the retina which is perceived as a movement of the object rather than of the eyes. For nystagmus to occur the subject is rotated at a constant velocity long enough so the cupula is returned to the neutral position because of it's elasticity. No signal is given to the semicircular canals at this point. If the rotation is stopped, the deceleration causes the fluid to be displaced and the resulting false signal is issued when the cupula is again deflected. The displacement is proportional to the original velocity. In response to this signal the eyeballs are deflected. The duration of this reaction depends on the magnitude of the original angular velocity of the head (Mayne, 1950).

Guedry (1968) measured visual acuity during nystagmus conditions. He accelerated subjects in the dark with the targets illuminated after the predetermined angular velocity was attained or in the light with the targets illuminated from the beginning. When the targets were illuminated after rotating in the dark (the first condition) nystagmus decreased rapidly (in two seconds). During the second condition, the time for nystagmus to decay depended on the magnitude of the stimulus. The nystagmus growth and decay curves departed markedly from the curves found in both pitch and yaw oscillations. They used angular velocities of 60 to 159 deg/sec. for about 5 minutes. Performance was more degraded in pitched forward motion.

Clark, Randle and Stewart (1975) studied the effects of angular acceleration on visual accommodation. They found that high level rotary deceleration produced positive accommodation or a pseudo-myopia. This accommodation was substantially greater and lasted longer during fixation on a target through a pinhole. They hypothesized that this increase was a result of a vestibular-ocular accommodation reflex.

One real-world implication of the VOR and nystagmus is in the flying of aircraft, especially when outside cues are not visible. If the aircraft enters a spin, or some other uncontrolled maneuver, the pilot's vision of his cockpit instruments may be affected. He may also sense that he is still in a spin, when in fact he is not. This is the classic "graveyard spin" which occurs when the pilot has recovered from the spin, but his vestibular senses tell him he is in a spin in the opposite direction. He then tries to recover from the phantom spin and only succeeds in putting himself into a true spin, often ending in a crash. Military pilots are taught to recognize the symptoms of post-rotational nystagmus and ignore them, but many general aviation pilots are never taught this. Melvill Jones (1965) recorded the accelerations of a spinning airplane simultaneously with the eye movements of the pilot. There was limited capacity for optokinetic following in the roll plane of the skull. This may drive an inappropriate oculomotor response which is virtually unchallenged by visual fixation.

Inappropriate vestibular signals are an important cause of spatial disorientation. Martin and Melvill Jones (1965) theorized that the pilot of a high performance aircraft could worsen the situation during a "push over" maneuver by relying on the apparent gravity vector for orientation. The pilot can resolve the conflict between erroneous vestibular cues and the visual cues of aircraft orientation provided by the flight instruments. However, after prolonged high rate spins or rolling maneuvers, the stimulus to the semicircular canals can be of such a magnitude that the evoked nystagmus degrades the pilot's vision of the cockpit instruments. When it is necessary to view objects such as aircraft instruments which are moving along with the head, the VOR is inappropriate. The VOR can be suppressed in such situations requiring visual fixation of a target moving with the subject's head. The principal suppression mechanism involves the control of eye movement by the visual system, and is influenced by a number of factors including vestibular signal strength, reflexive eye movement direction, the frequency and peak velocity of head oscillation, and the state of the central nervous system (Guedry, Lentz, and Jell, 1979). Gauthier, Piron, Roll, Marchette and Martin (1984) studied VOR at rotations in the

0.5-30 Hz range. Rotations above 8 Hz had not been studied previously. Their results indicated that from 6 to 30 Hz, "...the VOR cannot be significantly mediated by visual inputs".

Barnes, Benson, and Prior (1978) did three experiments to study the ability to suppress the VOR. In the first, they studied the decrement in visual acuity during angular oscillation. In the second experiment, they compared eye movements during a reading task and in the absence of any visual stimulus. The degree of VOR suppression was assessed at different frequencies of oscillation. The third experiment investigated the amount of VOR during a pursuit tracking task. In the first experiment they found a marked decrement in the ability to read 3 digits at frequencies above 1 to 3 hertz (Hz) when oscillated about the pitch and yaw axes. With both pitch and yaw stimulation, the decrement in performance was greater and started at a lower frequency at the higher angular velocities, suggesting that the ability to suppress inappropriate eye movements is a function of both frequency and velocity of the stimulus. During oscillation about the yaw axis, the performance decrement was modified by digit size.

They also found in the second experiment that the breakdown in visual performance was associated with an increase in the amplitude of inappropriate eye movments. At frequencies of 0.1 to 0.2 Hz, there was very little eye movement when the subject fixated on the display, compared with that obtained from stimulation of the VOR with the eyes closed. The subjects had little difficulty reading the display at these frequencies. However, as the frequency increased, there was a progressive decrease in visual performance. This performance decrease was nearly linear after 0.2 Hz. The degree of VOR supression was calculated as the ratio of eye velocity with the eyes open and eyes close. Suppression was fairly adequate at frequencies up to 1.0 Hz, but at higher frequencies, there was a breakdown in the ability to suppress unwanted reflex eye movements, leading to much greater reading errors. Suppression was expected to break down at frequencies at which the pursuit reflex not longer functioned effectively. The experimental results confirmed this.

In the third experiment the ability to follow a sinusoidally oscillating image of a digital display broke down repidly at frequencies above 1.0 Hz. The response curves of the visual suppression and the pursuit eye movements are very similar with the greatest performance decrement at 0.8 to 1.6 Hz.

The experimenters` conclusion was that visual feedback was unable to suppress the inappropriate vestibularly generated eye movements at frequencies greater than 1 to 2 Hz. During turbulent, low-level flight, considerable levels of vibration are likely to be transmitted to the pilot's head, mostly in the 1 to 10 Hz range, in which the suppression of VOR is ineffective.

Collins (1968) compared nystagmus in skaters and non-skaters in dark and light who were instructed to fixate on a marker on the wall. Skaters produced significantly less primary slow-phase eye displacement than did non-skaters, but the groups did not differ in number of eye movements nor in duration of nystagmus. Fixation significantly shortened primary nystagmus and produced an accentuated secondary nystagmus for both groups. Durations of turning sensations were shorter for skaters than for non-skaters. For both groups the period of room illumination, allowing subjects to fixate on stationary visual objects, significantly shortened or abruptly terminated the subjective reaction.

The VOR can also be controlled without visual cues (Barr, Shultheis, and Robinson, 1976). Subjects were rotated sinusoidally from 0.1 to 1.0 Hz in the dark. When subjects fixed a visible target light on the wall, eye movements were always equal and opposite to head movements at all frequencies (gain of one). When subjects were asked to look at a target light that rotated with them, their eyes moved very little in their heads (gain of zero). The target lamps were turned off and subjects were instructed to both imagine and continue tracking them in complete darkness or they were asked, at unexpected times, to switch from one imaginary target to the other and to continue to track it. There was no difference in the results and the subjects were able to augment or depress their gain for long periods of time. The experimenters concluded that the gain of the VOR is under the control of a central mechanism concerned with spatial localization.

Lentz and Guedry (1982) investigated the apparent bending of the instrument horizons during rolling maneuvers in Navy fighter aircraft. Their experiment used two ambient light conditions as an independent variable. In the low light level condition the subjects were exposed to a head fixed background. In the no ambient lighting condition only the illuminated target line was visible. These groups of subjects were tested on a rotating chair. Another group of subjects was tested on a short-arm centrifuge in a dark condition. Both sets of subjects were positioned with heads in the the X axis. A lighted horizon line was positioned about 470 mm from the subject's head. Each group received the same rotationary stimulus. They reported any apparent horizon movement. Apparent horizon deflection was seen in 81 out of 84 trials. Several types of horizon deflection were seen, however, one was more popular. It appeared that the right end rotated up and the left rotated downwards through the center of the horizon. The results suggested that the VOR can produce an apparent deflection of the instrument horizon during, and after, roll maneuvers involving high peak angular velocities. This perceptual aberration could disturb a pilot attempting to use this instrument horizon and could lead him to suspect instrument malfunction if he were unaware of this phenomenon.

Benson and Bodin (1966a) found that linear acceleration can modify the pattern of vestibulo-ocular activity produced by an angular acceleration. After subjects were rotated about the horizontal axis, lying supine so that the axis of rotation coincided with the longitudinal axis of the body, there was an absence of after-sensations of turning when rotation ceased. At the commencement of rotation there was a sharp anti-compensatory eye movement in the same direction as the angular motion. Nystagmus developed with a slow phase component which beat in the opposite direction to that of the angular motion and persisted throughout the rotation. The time constant of decay of the nystagmus was consistently shorter than when the axis or rotation was in the vertical. The experimenters' hypothesis was that there was direct action on the canal system by linear acceleration.

Benson and Bodin (1966b) also found that nystagmus decayed more slowly when subjects remained vertical than when they were moved to various horizontal positions. The mechanisms by which the direction of the linear acceleration vector modifies nystagmus were postulated. Two theories were proposed; (1) linear acceleration alters the dynamics of canal-cupula-endolymph system in such a way that the viscous damping of the cupula is less when the vector is co-planar with the canal; or (2) signals from the otolithic and other somaestetic receptors, which are in conflict with the inappropriate signals from the semicircular canal receptors, are able to modify the neural pathways of the VOR in such a way as to accelerate the decay of the afferent signal from the ampullary receptors.

Barnes (1979) found that when a subject moved his head and eyes to acquire visual targets in the horizontal plane, the eye movement consisted of an initial saccade in the direction of head movement followed by a slower return towards orbital center which compensated for the remaining head movement. When the head was moved either voluntarily or passively in the dark, the pattern of eye movment was very similar to that seen during target acquisition. In all experimental conditions gaze displacement at the end of the initial saccade was normally related in a predictive manner to final head position. His hypothesis was that the role of the vestibular saccade was to induce a rapid offset of the eyes in the direction of head movement, thus facilitating rapid search and target location. The experimental results provided support for this hypothesis.

Graybiel, Clark, and MacCorquodale (1947) studied the effects of angular acceleration on the oculogyral and oculogravic illusions during flight. The oculogyral illusion refers to a form of apparent movement often referred to as "visual vertigo", which arises after the receptors in the semicircular canals are stimulated by angular acceleration. The oculogravic illusion refers to the apparent displacement of an object which occurs when "the otolith organs are stimulated by an accelerative force which forms a resultant vector with the force of gravity". A stationary, collimated star was mounted in front of the observer in the back seat of an SNJ-6 aircraft. The observer reported on any apparent movement of this star during turns, rolls, and other aircraft maneuvers. The greatest results were found during the climbing and diving turns. The star was usually displaced between 20° and 30° but a displacement up to 60° was reported.

Clark, Graybiel, and MacCorquodale (1948) studied the same illusions in a similar experiment, also looking at centrifugal force during flight. They found three specific illusions: (1) At the onset and during turns they noticed vertical displacements of the target, which the experimenters considered to be examples of the oculogravic illusion, (2) Lateral motions superimposed on the upward displacement, which was considered to be an example of the oculogyral illusion resulting from the angular acceleration during the turn, and (3) Rotation of the target dependent on the stimulation of the semicircular canals.

Graybiel, Clark, MacCorquodale, and Hupp (1947) studied these illusions in the laboratory and found similar results. They concluded that the results have important implications for flying, especially at night or instrument flying.

Clark (1967) reviewed 25 studies that report the stimulus thresholds for the perception of angular acceleration. The thresholds ranged from $.035^{\circ}/sec^{2}$ to $8.2^{\circ}/sec^{2}$.

There were variations among the studies in terms of definitions of threshold, rotation devices, and psychophysical methods. The general findings of these 25 studies were: (1) The perception of the oculogyral illusion are lower that the perception of rotation, (2) Thresholds are lower about the yaw axis than the pitch or roll axes, (3) Thresholds during flight under optimum reporting condiions are about the same as found in rotating chairs, and, (4) Thresholds for pilots are the same as for non-pilots.

Clark and Stewart (1969) studied and measured the perception of rotation and the oculogyral illusion to determine the sensitivity to angular acceleration about their yaw axis. The thresholds for the perception of rotation varied from 0.05 to 2.20^{o}/sec^{2}. The thresholds for the perception of the oculogyral illusion were much smaller, from 0.04 to 0.28^{o}/sec^{2}.

An application of vestibular stimuli could be the prediction of airsickness during pilot training. Ambler and Guedry (1966) administered a Brief Vestibular Disorientation Test (BVDT) to naval aviation trainees during the latter part of their pre-flight training. After the trainees either completed training or not, the test results were compared to three criteria: (1) Students separated from flight training for all causes versus completions; (2) Tension and/or airsick separations versus all others; and (3) Airsick separations versus all others. The airsick/separation group had the highest mean BVDT sensitivity score suggesting that this test could be used as a predictor of those who would be unable to complete flight training due to airsickness.

PROBLEM

The fact that nystagmus affects vision is well established. Most of the research has been done to discover the dynamics of nystagmus, but less has been done to establish an operational impact. An attempt was made to devise a measure that was related to the flying task, to help define this operational impact, and if possible, to establish a predictive measure of performance.

HYPOTHESES

The hypotheses tested were that intensity and duration of rotation about the Z axis affected nystagmus and affected the performance on a tracking task. The greater the rotational speed, and the longer the duration, the greater the number of tracking errors, the larger the error, and the longer the degradation lasted.

METHODS

VARIABLES

The independent variables were the speed and duration of rotation about the X axis. The speeds used were 30 revolutions per minute (rpm) and 45 rpm. The durations of the rotations were one and two minutes. An additional independent variable was whether the subjects were pilots or not. The dependent variables were time and error.

EXPERIMENTAL DESIGN

The experimental design was a 2x2x2 factorial with repeated measures on the second and third variables (the speed and duration of rotation). A counterbalanced presentation was used to help eliminate any order effects

SUBJECTS

Subjects were 16 male Air Force employees, 8 pilots and 8 non-pilots. Of the pilots, 6 were former instructor pilots in the T-37, the primary Air Force trainer. They had extensive experience in spinning aircraft, as that is one of the purposes of the initial phase of pilot training. Of the non-pilots, 6 were on flying status, meaning they periodically flew in support aircraft, but were not pilots. The pilots ranged in age from 32 to 44 and the non-pilots ranged in age from 23 to 42. All were in excellent health. The pilots must pass a rigorous flight physical each year, and are probably without any vestibular abnormalities. The non-pilots who flew must pass a less rigorous physical each year. The non-pilots had varying degrees of flying experience, but most had very little experience.

APPARATUS

The apparatus consisted of a rotating Barany chair with a brake that was rotated by a variable speed drill press (Figure 2). The chair was rotated at two speeds, 30 rpm and 45 rpm. The chair accelerated to this speed in approximately 5 seconds. The chair was stopped immediately by the application of its brake. The stimulus was a "video game" using a Radio Shack Color Computer with a television screen and joystick. The game consisted of graphics blocks that randomly appeared in one of the four corners of the TV screen. The TV screen was mounted on a movable hospital tray table at a distance of approximately 30 inches from the subject. The joystick was placed on the forward edge of the table. The target block measured 0.25 inches and the visual angle was $0^{\circ}\ 28'\ 39''$ of arc. The subject moved the joystick causing the cursor to move. When the cursor was on the graphics block the subject would press the button on the joystick. The computer registered this as a hit or miss, computed the distance from the center of the graphics block, and recorded the time for the cursor to move from the center of the screen (where it automatically returned to after every attempted hit) to the pushing of the button.

PROCEDURES

Prior to his initial trial, each subject was given the opportunity to "play" the video game to become familiar

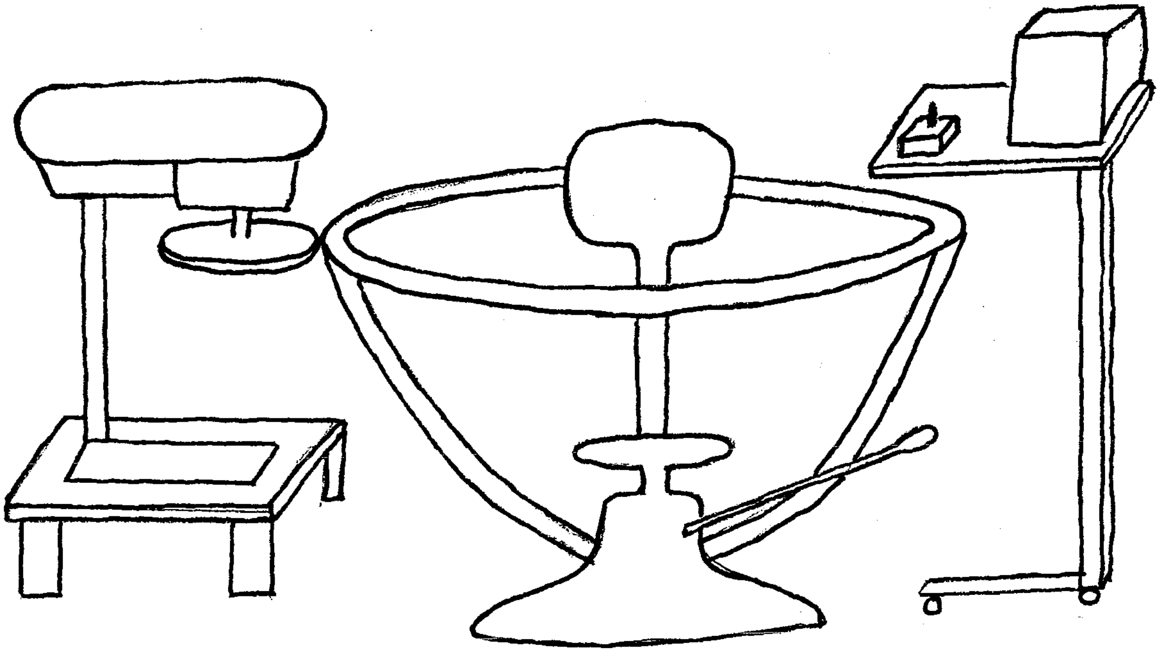


Figure 2

The Experimental Apparatus

with it. A substantial learning curve was observed (Figure 3). The cursor control was very sensitive and it took a few minutes of practice to become proficient at manipulating it. When the subject consistently hit the target and felt comfortable with the joystick, the initial trial commenced.

The subjects were strapped in the chair and instructed to close their eyes while the chair was spun and to open them when the rotation stopped. This kept them from focussing and suppressing their nystagmus. An assistant held the drill press to the Barany chair and the chair was spun at one of two speeds. The experimenter timed the rotation for one or two minutes. At the end of the appropriate duration the assistant removed the drill press and the experimenter applied the brake. The subject was stopped directly in front of the TV monitor and joystick. He then reached for the joystick and proceeded to move the joystick so the cursor was on the target block on the screen. When he thought the cursor was on the block he pressed the button on the joystick and let go of the joystick. The cursor returned to the center of the screen and another target block was displayed. This was repeated until the subject felt his vision had returned to normal. The computer recorded the times and distances and displayed them to the experimenter who then hand recorded the data.

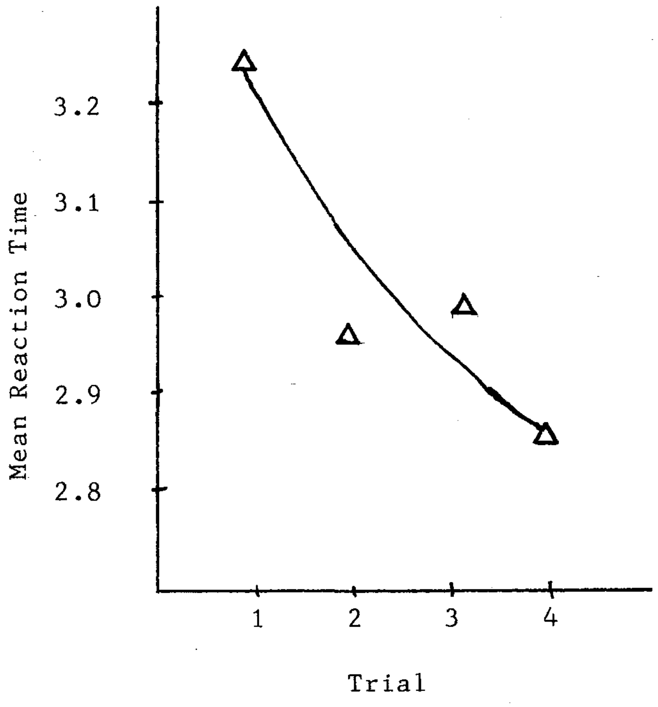


Figure 3

The Learning Curve

RESULTS

The measurement of error proved to be unusable as a dependent variable. The error was measured in pixels away from the center of the graphics block on the computer screen. Most of the subjects made errors throughout the trial, even when they stated their vision had cleared, because of the sensitivity of the joystick. Errors tended to level off after the fifth attempt at hitting the target, and the means of the times to attempt to hit the target five times and the first time became the measure of the dependent variable of time for vision to clear.

The means of the times are in Tables 1 & 2. An analysis of variance was done on the means of the time for the first attempt and the first five attempts to hit the target. Results are contained in Tables 3 and 4. A graph of the interactions is in Figure 4.

The only significant results were a speed/groups interaction, $F(1,14) = 4.37$, $p < 0.10$, a time/groups interaction, $F(1,14) = 4.00$, $p < 0.10$ and a speed/time/groups interaction, $F(1,14) = 3.17$, $p < 0.10$. This was only significant for the means of the first attempt at hitting the target, not the first five attempts.

There were no simple main effects due to speed or duration of rotation. Figure 5 graphically shows the means for the first five reaction times. Pilots consistently had faster times, but the difference was not significant.

TABLE 1

Mean Times to Hit the Target First Five Attempts (in seconds)

	Condition*			
Subject	A	B	C	D
(pilots)				
1	1.7	1.7	1.3	2.0
2	1.4	1.5	1.6	1.7
3	2.8	3.1	2.8	3.3
4	1.7	1.8	1.9	2.1
5	2.4	2.6	3.3	2.4
6	2.6	1.9	2.0	2.0
7	2.4	2.3	1.8	2.4
8	1.6	1.5	1.9	2.2
Mean	2.075	2.05	2.075	2.2625
(non-pilots)				
9	2.1	2.0	2.4	1.9
10	2.5	2.4	4.9	3.7
11	2.2	1.9	2.1	2.2
12	2.6	3.0	2.9	2.3
13	2.1	2.0	2.4	2.2
14	2.4	2.2	1.9	2.1
15	1.4	1.4	1.6	1.9
16	2.4	2.2	1.9	2.3
Mean	2.2125	2.1375	2.5125	2.325

* Condition A=30 rpm., 60 sec. duration
Condition B=30 rpm., 120 sec. duration
Condition C=45 rpm., 60 sec. duration
Condition D=45 rpm., 120 sec. duration

TABLE 2

Mean Times to Hit the Target First Attempt (in seconds)

Subject	Condition*			
	A	B	C	D
(pilots)				
1	2.0	2.4	1.7	2.6
2	1.5	2.3	2.4	2.4
3	4.0	5.5	3.4	5.2
4	1.9	2.4	2.5	2.4
5	3.1	2.9	1.5	2.4
6	3.2	2.4	2.6	2.1
7	5.7	3.3	0.7	4.0
8	2.9	1.9	3.7	3.4
Mean	3.0375	2.8875	2.3125	3.0625
(non-pilots)				
9	1.9	1.7	4.0	2.0
10	2.9	3.7	12.8	4.5
11	3.7	2.3	3.3	3.3
12	3.8	4.5	5.8	3.7
13	2.4	1.8	3.8	2.8
14	2.9	3.1	3.1	3.4
15	1.3	1.7	2.2	2.7
16	3.4	3.5	3.2	3.4
Mean	2.7875	2.7875	4.775	3.225

* Condition A=30 rpm., 60 sec. duration
Condition B=30 rpm., 120 sec. duration
Condition C=45 rpm., 60 sec. duration
Condition D=45 rpm., 120 sec. duration

Table 3

ANOVA of Reaction Time of First Attempt

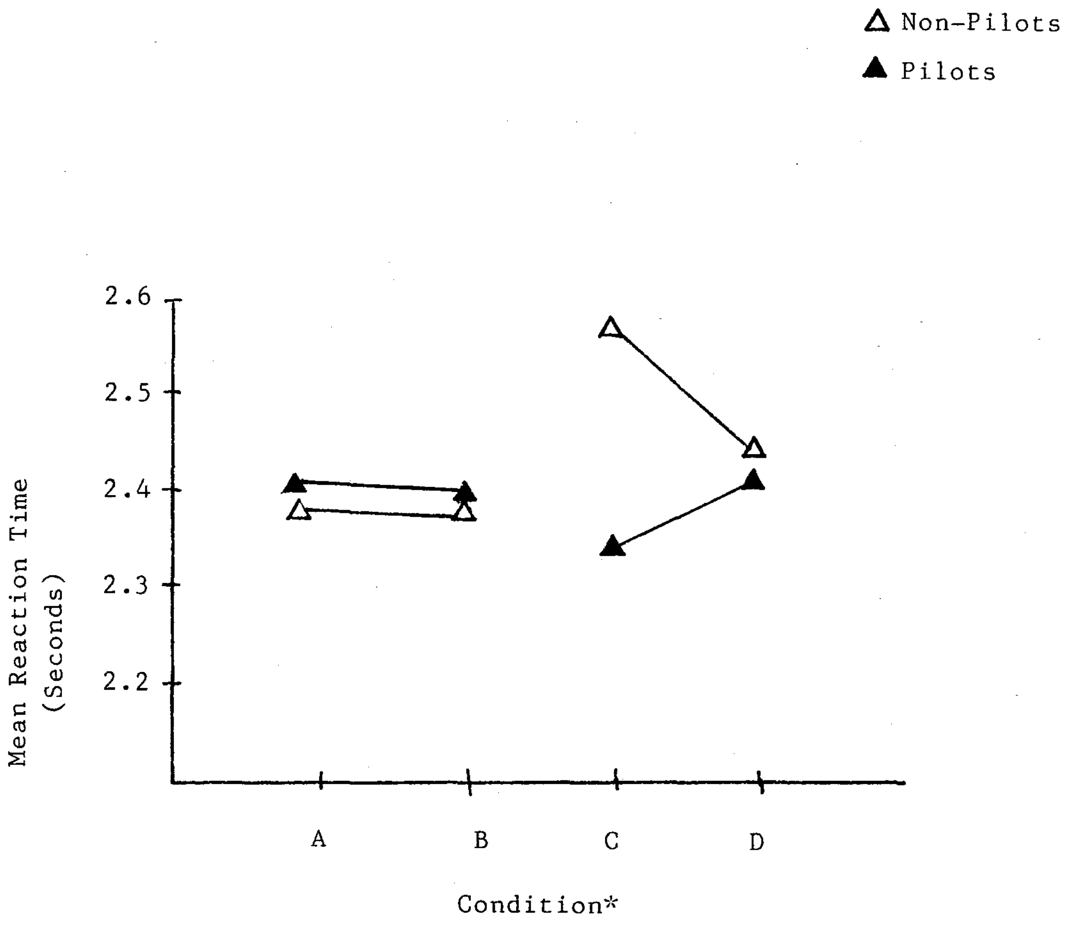
Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Groups	5.176	1	5.176	1.13
Error	64.014	14	4.572	
Speed	3.516	1	3.516	1.73
Speed X Gr	8.850	1	8.850	4.37*
Error	28.369		2.026	
Time	0.902	1	0.902	0.78
Time X Gr	4.622	1	4.622	4.00*
Error	16.170	14	1.155	
Speed X Time	0.422	1	0.422	0.22
Sp X T X Gr	6.002	1	6.002	3.17*
Error	26.490	14	1.892	

*p<.10

Table 4

ANOVA of Reaction Time of First Five Attempts

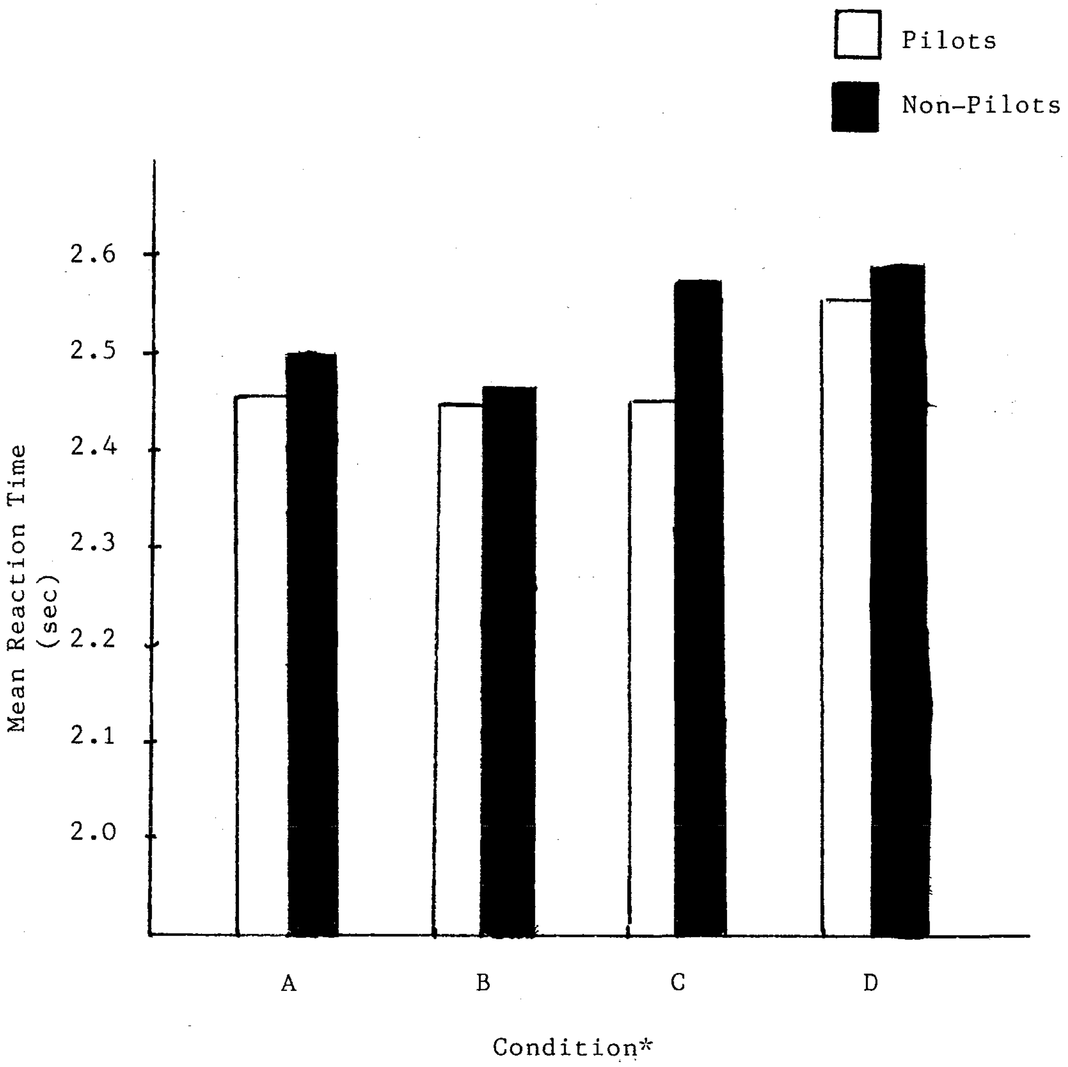
Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Groups	0.526	1	0.526	0.49
Error	14.992	14	1.071	
Speed	0.490	1	0.490	1.78
Speed X Gr	0.076	1	0.076	0.28
Error	3.844	14	0.275	
Time	0.010	1	0.010	0.14
Time X Gr	0.181	1	0.181	2.46
Error	1.029	14	0.074	
Speed X T	0.010	1	0.010	0.10
Sp X T X Gr	0.101	1	0.106	1.06
Error	1.34	14	0.099	



* A= 30 rpm., 60 sec. duration
B= 30 rpm., 120 sec. duration
C= 45 rpm., 60 sec. duration
D= 45 rpm., 120 sec. duration

Figure 4

Interaction Effects



*A=30 rpm., 60 sec. duration
B=30 rpm., 120 sec. duration
C=45 rpm., 60 sec. duration
D=45 rpm., 120 sec. duration

Figure 5

Mean Reaction Times
First Five Attempts

DISCUSSION

There were no significant effects due to rotational speed and duration. Although there were no simple main effects shown, some trends were noted. The non-pilots' times were usually greater than the pilots' times for the first five attempts at hitting the target. This supports the hypothesis that pilots would have a greater tolerance to vestibular disturbances. The reason for this may be selection; those who cannot withstand the vestibular disturbances "wash out" of pilot training (Ambler and Guedry, 1966). Or the pilots may have acclimated themselves to unnatural conditions during their many hours of flying. One explanation for the pilots' lack of difference between conditions may be habituation. Marshall and Brown (1967) found that during periods of uniform visual arousal, nystagmus was decreased. Subjects habituated in darkness showed an increase in slow-phase nystagmus when tested with vision, however, those habituated with vision, continued to show a decrease in nystagmus when tested with vision. Graybiel, Guedry, Johnson, and Kennedy (1961) demonstrated the habituation of the oculogyral illusion during a bizarre stimulation (subjects were in a rotating room, in a tilted chair for up to 64 hours). The subjects used varied greatly in their susceptibility to motion sickness, with the least susceptible showing the effect of the stimulation. This implies that pilots may be habituated to the angular accelerations of a spinning aircraft. As mentioned before, these pilots were mostly training pilots who had considerable experience in spinning aircraft. Anecdotally, the one fighter pilot, who was used to tracking targets, had the fastest times of all the pilots. However, the fastest time was by a young non-pilot who had considerable experience with video games. However the non-pilots had faster reaction times for the first attempt for the first two conditions (low speed, low time and low speed, high time), but not for the second two conditions. This interaction is reflected in the data.

Hauty (1953) found that no relationship appears to exist between primary nystagmus duration and the intensity of acceleration. However, duration of acceleration was directly related to the duration of primary nystagmus. He used rotational speeds from 12°/sec. to 180°/sec, and durations up to 90 seconds. Hauty and Wendt (1953) also found that the duration of primary nystagmus is not affected by the strength of the stimulus. They suggested that the restoration of the cupula does not affect the duration of nystagmus. So the lack of significance due to rotational speed is not totally unexpected, although it was not hypothesized at the beginning of this experiment.

A possible explanation for the lack of difference between rotational durations may have been due to the lengths of duration chosen as the independent variable. Any effect due to duration probably would be seen at lower durations. Parsons (1970) used rotational durations of 1 to 9 seconds and measured the first effect and after effect of the oculogyral illusion. He found that the main effect of duration was a significant effect for time to maximum estimate of the first effect of the oculogyral illusion. The main effect for intensity of acceleration and the duration X intensity interaction were significant. His conclusion was that there was a reciprocal relationship between acceleration time (duration) and intensity. Clark, et al. (1975) used rotation times of 30 seconds and measured visual accomodation. They found a positive ocular accomodation due to high level rotary acceleration. Collins (1968), using rotation durations of more than 2 minutes, however, did find differences in the sensation of turning between skaters and non-skaters during light and dark trials. A greater effect due to rotational duration may have been seen if durations such as 30 seconds and 1 minute had been chosen. The lack of difference between 1 minute and 2 minutes may have been due to habituation. The cupula returns to an upright position after the acceleration ends, and the speed remains constant. This undoubtedly occurred prior to 30 seconds.

In condition C (high speed, low time) the high mean of the non-pilots was due to an unusually long time taken by one subject to reach for the joystick and hit the first target. Condition D (high speed, high time) had larger means than the other three conditions, suggesting that there was an effect of speed and duration, or an interaction effect, which was borne out by the data on the first reaction time.

The lack of simple main effects was probably partially due to experimental error. Clark (1967) in his literature review of thresholds for the perception of angular acceleration states that rotating chairs have limited control of the stimulus (angular acceleration) and very limited capability for measuring it. It is not entirely clear that angular acceleration per se is the stimulus, and often velocity measures are used to define the stimulus, as they were in this experiment. A major problem with rotating chairs, in threshold measurements, is that the transitions from zero velocity to a constant angular acceleration and from a constant acceleration to a constant velocity have unacceptable abruptions which produce a highly variable stimulus. The device used to rotate the chair in this experiment was not easily controlled in that the drill press had to be physically moved against the Barany chair, and there was no way of verifying the rotational speed was constant, so these variabilities undoubtedly exist. The rotational speed was measured with several of the subjects to verify that the number of rotations per minute was the same, but the rotational speed could have been variable over the course of the trials.

The computer video game was also a source of error. Because the subject had to reach for the joystick upon the cessation of the rotation, he often misjudged his reach, accounting for some of the time for the first "hit". A large learning curve was observed in using the game. With increased practice the performance improved. Even though subjects were given as much practice time as needed, performance seemed to improve throughout the test. The joystick was very sensitive and the least amount of movement of the hand moved the cursor off the target, accounting for some of the errors.

The interaction effects were very weak ($p < 0.10$). The possibility of committing a Type I error exists. The highest order interaction is the most important and suggests that the effects of both speed and duration of rotation was different for pilots and non-pilots. Again, this difference may have been due to the abnormally high score for one non-pilot on the high speed/low time condition (Figure 5).

The original intent of this experiment was to quantify how long it took for the vision to clear after rotation. This goal was not achieved. Most of the subjects reported their vision had cleared somewhere between the fifth and tenth attempt at hitting the target. However, most of them were able to hit the target after the first attempt. This indicates that while the subjects were still experiencing a turning sensation, they were able to focus on a small target, and using eye-hand coordination, hit that target. The action of focussing on the target inhibited the nystagmus, just as the VOR can be suppressed by visual stimulation.

The pilots' average age was 37; the non-pilots' was 26. Had a significant difference been found between the two groups, a prediction of performance based on age may have been made. Most psychological research is done using college students. Most of the research done in the area of this project has been conducted by the military, which is also very limited in the age groups tested. Using subjects from older age groups is an area for further study. This may lead to a predictor not only of the effects of vestibular stimulation, but also, perhaps, to other brain functions that are decreased with age.

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