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THE EFFECTS OF OPTICAL DISORIENTATION ON TASK PERFORMANCE AND MOTION SICKNESS (U)

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TECHNICAL REVIEW AND APPROVAL

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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Our work confirms that unfamiliar and unexpected optical information can by itself lead to disorientation, performance decrements, bodily discomfort, and motion sickness symptoms, specifically dizziness, queasiness, and unsteadiness. We manipulated the visual environment of 15 subjects by prismatically up-down reversing the field of view, preceded by a no-prism baseline condition. Methodologically we held vestibular stimulation constant. Through the reversing prism Ss saw what Stratton in 1896 called "the swinging of the scene" as they moved around. Subjects' responses while performing a battery of behavioral tests that included perceptual tasks, equilibrium tests, fine and gross motor coordination tests, and motion sickness ratings, were then compared to the no-prism baseline. We observed (1) dizziness and queasiness, especially during head movements; (2) poor balance while standing; (3) unsteady equilibrium while walking; (4) disorientation while moving about and during attempted precise eye-hand coordination; and (5) associated autonomic activity, including changes in sweating,

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(GSR), muscle tension (EMG), skin surface temperature (EDG), and pulse throughout the protocol. We tested for adaptation by having Ss repeat all six visually guided fine motor coordination tasks; rapid improvement occurred even in Ss who reported extreme dizziness and queasiness throughout the protocol. The results demonstrated the prominent role played by unfamiliar and unexpected optical movement information in the etiology of disorientation, disequilibrium, performance decrements, and motion sickness symptoms.

SUMMARY

Whereas most research into Space Motion Sickness has emphasized the etiological role of altered vestibular functioning, several lines of evidence indicate that even in the relative absence of vestibular stimulation, unfamiliar and unexpected optical information can by itself lead to disorientation, performance decrements, bodily discomfort, and motion sickness. We manipulated the visual environment of 15 subjects by prismatically up-down reversing the field of view, preceded by a no-prism baseline condition. Methodologically we held vestibular stimulation constant. Subjects were exposed to seeing the unfamiliar optical motions and movements they produced by their own eye-, head-, hand-, leg-, and body movements. Through the reversing prism Ss saw what Stratton in 1896 called "the swinging of the scene." Subjects' responses, while performing a battery of behavioral tests that included perceptual tasks, equilibrium tests, fine and gross motor coordination tests, and motion sickness ratings, were then compared to the no-prism baseline.

We observed (1) dizziness and queasiness, especially during head movements; (2) poor balance while standing; (3) unsteady equilibrium while walking; (4) disorientation while moving about and during attempted precise eye-hand coordination; and (5) associated autonomic activity, including changes in sweating (GSR), muscle tension (EMG), skin surface temperature (EDG), and pulse throughout the protocol. We tested for adaptation by having Ss repeat all six visually guided fine motor coordination tasks; rapid improvement occurred even in Ss who reported extreme dizziness and queasiness throughout the protocol. The results demonstrated the prominent role played by unfamiliar and unexpected optical movement-information in the etiology of disorientation, disequilibrium, performance decrements, and motion sickness symptoms.

This experimental paradigm is the first step in our research program designed to demonstrate the effectiveness of our prism training/adaptation technique as a safe, noninvasive, and economic countermeasure to the perceptual and performatcry decrements associated with disorienting situations and the often attendent motion sickness experienced by ground and flight personnel as well as by astronauts. Such disorienting situations include passive transport in moving vehicles over rough or unfamiliar terrain, turbulent water, air, or in microgravity. Our experimental paradigm is believed to perceptually innoculate--to pre-adapt--personnel to the ill effects visually inherent in disorienting situations, thus preparing them perceptually, psychologically, and operationally to overcome the effects of disorientation and various forms of motion sickness.

PREFACE

This study was initiated by the Crew Systems Effectiveness Branch, Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, under Work Unit 6893-01-30. The research was conducted by Hubert Dolezal, 1960 Lincoln Park West, Chicago, Illinois 60614. The work was funded by the Laboratory Directors Fund of AAMRL. The project monitor was Captain Thomas Connon, who has since left the Air Force and is in practice in the Dayton area. The final document was prepared by Hubert Dolezal. Helpful suggestions for changes were made by Major Melvin R. O'Neal of AAMRL.

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HISTORICAL BACKGROUND

The frequency, duration, and intensity of motion- weightlessness- or space-motion sickness (SMS), the space adaptation syndrome (SAS), weightlessness-sickness, and airsickness experienced by astronauts and flight personnel have generated considerable concern because of their potential survival hazard during space walks without lifeline and because of the debilitating effects on in-flight tasks. Blurred vision, bodily instability, and apprehension have been reported (e.g., Johnson & Jongkees, 1974). Other performance-degrading symptoms experienced by astronauts in microgravity include the perception of cold or flushing, pallor, sweating, increased salivation, yawning, drowsiness, sleepiness, depressed appetite, dizziness, disorientation, headache, stomach awareness, epigastric discomfort, nausea, and vomiting (Ambler & Guedry, 1966; Dowd, 1973; Graybiel & Knepton, 1976; Graybiel & Lackner, 1977; Grose, 1967; Guedry, 1968; Homick, 1983; Lackner, 1976; Melvill Jones, 1970; Pitblado & Mirabile, 1977; Potvin, Sadoff & Billingham, 1977; Ryback, Rudd, Matz, & Jennings, 1970; Spector, 1974). We will refer to these symptoms collectively as bodily discomfort.

Control of balance, locomotion, orientation, and performance, whether achieved on earth or in microgravity, rests on two important and closely related perceptual achievements that govern visual stability (Gibson, 1958, 1966, 1970, 1972, 1979; Howard, 1974, 1978; Howard & Templeton, 1966; Lee, 1978; Richards, 1975; Ryan & Ryan, 1940; Sandstroem, 1951; Schilder, 1935). First, astronauts or flight personnel must accurately distinguish movements and events that are self-generated from motions and events originating in the environment. Second, they must achieve a relatively stable visual world during eye, head, and body movements, an accomplishment known as visual position constancy (Rock, 1966, 1975; Shebliske, 1977; Welch, 1978). Astronauts' self-generated movements and events, as well as environmental events, generate <u>relative optical motions</u> whose complex rate of change characteristics are available at the retina and represent the visual stimulation and information that guides the astronaut's orientation and action.

Space motion sickness has been assumed to be largely due to the abnormal stimulation of the vestibular receptors under microgravity conditions. In order to develop a model system for studying vestibularly induced motion sickness, to explore methods of overcoming it, to identify candidates with greater or lesser susceptibility, and to habituate personnel prior to flight, a number of experimental paradigms have been explored. In one of these, subjects (<u>S</u>s) were required to execute head movements while sitting in a (e.g., Stille-Werner) chair that rotates at varying angular velocities (Ambler & Guedry, 1965; Cowings & Toscano, 1982; Graybiel, 1979; Graybiel & Lackner, 1977; Guedry & Benson, 1978; Levy, Jones, & Carlson, 1981; Miller & Graybiel, 1969, 1970a; Toscano & Cowings, 1982). In variants of this method, <u>S</u>s were rotated in either the earth horizontal or vertical plane with the head assuming one of several positions. Different configurations of these produced greater or lesser degrees of motion sickness, dependent on the axis of rotation and the S's head position relative to this axis (Graybiel & Lackner, 1977; Guedry & Benson, 1978; Leger, Money, Landolt, Cheung, & Rodden, 1981).

The motion sickness produced by such movements has been shown to be exacerbated when Ss are placed in a freefall environment, using parabolic flight maneuvers in both hyper- and hypo-gravity conditions (i.e., flying an aircraft in Keplerian parabolic trajectory in which the gravitational force of the earth is counterbalanced by the centrifugal force of the aircraft) (Graybiel & Miller, 1976; Howard & Templeton, 1966, Ch. 16). In sudden stop vestibulo-visual tests, also studied during parabolic flight, Ss in a rotating chair, enclosed in a striped cylinder, were rapidly decelerated multiple times after being rotated at an angular velocity of 300°/sec (Lackner & Graybiel, 1981, 1983). In another experimental paradigm Ss executed head movements out of the plane of rotation within a slowly rotating room (e.g., the Pensacola Slow Rotation Room) (Graybiel, 1964; Graybiel & Lackner, 1983; Guedry, 1965; Guedry, Kennedy, Harris & Graybiel, 1964).

While all of these manipulations have been shown to produce motion sickness and have differentiated Ss with greater or lesser degrees of susceptibility, in most cases it has been noted that the effects produced are partially dependent upon whether Ss eyes were open or closed, suggesting that interactions between the visual and vestibular systems are crucial for understanding motion sickness and SMS (Bock & Oman, 1982; Dichgans & Brandt, 1973; Graybiel, 1980; Graybiel & Lackner, 1980; Lackner & Graybiel, 1983; Lackner & Teixeira, 1977; Leger, et al., 1981; Wong & Frost, 1981). The need to go beyond vestibular considerations in order to understand SMS has been recognized in a number of recent theoretical formulations (Collins, Schroeder, & Elam, 1982; Graybiel & Lackner, 1983; Homick, 1979; Money & Oman, 1983; Pitman & Yolton, 1983; Reason, 1974; Smith, 1982). Several hypotheses attribute motion sickness to a mismatch between the visual, motor, proprioceptive, and vestibular activities in the experimental conditions relative to the coordinated activational patterns of these systems that the S is accustomed to in everyday experience (Dolezal, 1982; Dolezal & Held, 1975; Guedry, 1970; Reason, 1978 a,b; Steele, 1968). In microgravity, the development of SMS can also be presumed to result from the unfamiliar and unexpected visual, motor, proprioceptive, and vestibular interrelationships that occur due to vestibular and visual stimulation (Dolezal, 1982; Homick, 1979).

Several lines of evidence indicate that even without any alteration of direct vestibular activation it is possible to bring about some of the symptoms of motion sickness by modifying visual experience alone. One familiar example of this is the effect created by wide-screen movies shot from the point of observation of the viewer or conveyance (e.g., a car at ground level, the wing of a banking aircraft, the tip of a downhill racing ski, or the bow of a ship in heavy sea). The common denominator in these instances is unfamiliar and/or unexpected optical motion information that is discordant with the vestibular, motor, and proprioceptive input of the stationary observer, and induces the perception of one's self being moved, frequently accompanied by queasiness and postural adjustments (Benfari, 1964; Dolezal, 1983; Dolezal & Held, 1975; Parker, 1971).

More detailed experimental evidence was reported by Stratton in his two classic experiments on "vision without inversion of the retinal image," created by a set of monocular inverting lenses (1896, 1897a,b). He was the first to describe prismatically induced visual instability and mild nausea which he attributed to the seen displacement of his field of view; he called the phenomenon the "swinging of the scene". Several subsequent investigators confirmed Stratton's observations, including Brown (1928, p. 134), Ewert (1930, p. 351), Kohler (1951, p. 17; 1964, p. 31), Kottenhoff (1957, p. 153), and Peterson & Peterson (1938, p. 25). Only one subject denied experiencing a "swing effect" or nausea but reported dizziness and nausea as an aftereffect (Snyder & Pronko, 1952, pp. 125, 142-143). Each investigator observed that the perceived "swinging" stops after 3-6 days of wearing the lens, mirror, or prism device, and that an aftereffect occurs upon removing the spectacles. Individuals who don a new pair of eyeglasses commonly report mild effects of motion sickness, especially during locomotion, presumably due to altered rates of optical motions in the peripheral field of view (Lackner & Graybiel, 1983).

The visually perceived correspondence between the actual and the observed rate and direction of head movements was recently studied in the laboratory by Wallach and his co-workers who followed Duncker's (1929) lead; they concluded that only when the seen relative displacement of the environment closely approximates that which is normally produced by head movements is the environment perceived as stationary (Wallach & Kravitz, 1968, p. 299; see also Wallach & Floor, 1970; Wallach & Frey, 1969, 1972; Wallach & Kravitz, 1965a,b; Wallach, Frey, & Romney, 1969).

A notable example of learning a technique of visually "anchoring" or stabilizing oneself (principally the eyes and/or head) to a fixed place in the environment is represented by dancers and figure skaters; their visual "spotting" during multiple pirouettes and fouettes entails fixating a stationary object by keeping the head immobile for as long as possible during these rapid turns of the body. The head is then whipped around, covering an arc of approximately 360°, regaining visual fixation with an again stationary head. For the experienced dancer the angular velocity of the head may be in excess of 500°/sec, decelerating at a rate of $2000°/sec^2$ within a one-quarter turn (Osterhammel, Terkildsen, & Zilstorff, 1970). The fact that ballet dancers do not experience vertigo or nausea during or after such turns (Collins, 1966; Tschiassny, 1957), even though they elicit powerful vestibular stimulation, demonstrates that visual stabilization can thoroughly overcome even the most severe perturbations of the vestibular system, fully preventing any loss of balance or motion sickness. This successful maintenance of equilibrium is clearly due to a visual override of the vestibular system and cannot be attributed to a general habituation which can be shown by measures of the Ss subsequent nystagmic threshold responses to angular acceleration (Dix & Hood, 1969).

The Prism Approach to Optical Disorientation

One five week prism adaptation study focused explicitly on the applicability of a disorientation paradigm to the study of motion sickness during space flight (Dolezal, 1982, Ch. 12). The subject wore spectacles that up-down reversed his field of view. Normal up-down and tilt head movements, especially rapid and repeated head movements during locomotion, yielded immediate, unpredictable seen destabilization of the visual environment which was accompanied by perceived unsteadiness, disorientation, "light-headedness", sweating, tachycardia, trembling of the limbs, and a strong inclination to vomit. Behavioral disorientation and confusion were characterized by a general slowing of all body movements and by incompetent actions such as misreaching, incompetent pointing, pouring, pushing, pulling, and erroneous pursuit and compensatory eye-head movement sequences (Dolezal, 1982, Chs. 7-9, 12).

Adaptation to this optical up-down reversal was characterized by some attenuation of nausea during the first 6 hours of prism exposure. Sweating, tachycardia, and nausea disappeared following a subsequent 4-hour nap. Gross motor movements, especially walking, improved markedly following this period of sleep (Dolezal, 1982, Ch. 12). Overall, improvements of performatory competence varied widely: S improved most quickly his gross motor coordinations such as visually guided pointing and reaching for stationary objects during fixations and after saccades; executing correct eye-head sequences was his next accomplishment; fine eye-hand coordinations adapted last; correct eye-head-arm pursuit of rapid events (e.g., intercepting a tennis ball) was not achieved, even after over 200 waking hours of exposure and hundreds of practice trials, spread over a period of 2 weeks (Dolezal, 1982, Chs. 7, 8, Appendix A). Repeated exposure to the initially nausea-creating optical motions during active head movements ceased to adversely affect a wide variety of everyday tasks, including walking, hiking, bike riding, swimming, water skiing, or driving a car. However, after adapting to up-down reversal for 10 days and more than 125 hours, S, while still wearing prisms, experienced severe nausea, vertigo, and generally motion (being moved) sickness while a passenger in the front seat of a car going up and down a curvy mountain road and moving at only 15-35 kms/hr. The S was driven for 45 minutes, followed by a 20 minute rest stop, 20 more minutes in the car, a 90 minute stop, and then a final 35 minutes in the car. There was no remission in severity of nausea, and as S got out of the car he was quite close to vomiting. The experience of severe nausea was especially pronounced when the driver shifted gears, applied the brakes, or accelerated (i.e., whenever an unexpected rate of change was introduced over which S had no control). These force changes resulted in S experiencing unfamiliar and unexpected optical information, vestibular stimulation, and proprioceptive input--being jerked, joggled, and bounced in ways he could not anticipate, counteract, or control. Ten minutes later while still wearing the same reversing prisms, S competently drove the same car without experiencing any noticeable discomfort or nausea (Dolezal, 1982, pp. 317-318).

The above study showed that optical information processed by the oculomotor system represents a critical aspect of motion sickness induction. When optical information conflicts with vestibular information in its specification of the rate and direction of head and body movements, the observer uses the optical information to adapt, suggesting visual system dominance over vestibular input. A specific example of this dominance is that vestibularly "driven" compensatory eye movements--the so-called vestibulo-ocular reflex--were "overridden" by prismatically up-down reversed afferent optical information in which compensatory eye movements physically reversed their usual direction and rate of movement during up-down head movements (Dolezal, 1982, Ch. 7).

The feasibility of teaching visual control over SMS is suggested by dual findings: the evident plasticity of the vestibular system as exemplified by the reversed compensatory eye movements and the remarkable control function the visual system exerts. (The aftereffects of 180° phase-reversed compensatory eye movements in the dark confirm this unexpected vestibular plasticity and altered visual-vestibular and haptic-kinesthetic coordination (Davies & Melvill Jones, 1976; Gonshor & Melvill Jones, 1973, 1976; Melvill Jones, 1976; Melvill Jones & Davies, 1976; and Melvill Jones & Gonshor, 1972, 1975)). In addition to the attenuation of motion sickness, visually guided control is reestablished for orientation, locomotion, and most eye-hand-limb coordinations. This is presumably because the ecological constants that continue to be available optically, even in the reversed field of view, begin to be attended to and their spatial relationships become meaningful once again and can thus be responded to competently. An example of one such constant occurs as S moves his head toward his feet; the feet eventually become visible even though the optical motion information during the head movement erroneously specifies, "You are raising your head".

Donning a reversing prism necessarily creates a complex family of mismatches or contradictory specifications as to S's motorically, proprioceptively, auditorily, vestibularly, and nosmically specified actions, and the seen result of S's actions which contradicts this account. Thus, adaptation depends on re-establishing consistencies that validate one another within and across all perceptual and action systems. For example, even if moving the head towards the feet initially looks like an upward head movement during the movement, its visual meaning becomes consonant with the end result (i.e., having moved the head toward the feet). In addition, even though moving the head toward the feet looks and feels like moving away from the feet, the "felt position" comes to agree with the visual meaning change (i.e., "I'm moving my head toward my feet"). Hence, visual-visual-motor consonance or adaptation is achieved. This account is elaborated to show how hypothesized visuomotor program mechanisms change their control parameters to allow for such adaptations to these novel (mismatched) input-output and output-output requirements that govern the eye movements, eye-head movements, head-eye movements, of various types (i.e., saccadic, compensatory, optokinetic or vestibular nystagmus, and pursuit), and combinations of eye-limb and eye-head-limb movements (Dolezal, 1982, Ch.11).

What is novel in the above optical disorientation approach is the prominence given the analysis of the unfamiliar and unexpected optical information in microgravity environments and its role in potentially affording S visual stability and physical comfort with competent equilibrium, locomotion, orientation and action. Second, broadly construed, this approach emphasizes the dominance of the visual system in governing bodily stability. Third, this approach points out the adaptability to unfamiliar and unexpected information of the visual system in learning a new set of visual-visual, visual-vestibular, visual-motor, visual-auditory and visual-proprioceptive correspondences. Having learned such correspondences allows the adapted S to cope confidently and masterfully in virtually any unfamiliar environment that initially creates mismatches, including the microgravity of space travel.

It might be noted that whereas none of the 26 astronauts in the 16 Mercury and Gemini missions experienced SMS when confined to their seats in these earlier small capsules, astronauts in the Apollo, Skylab, and Space Shuttle programs began experiencing SMS (33%, 54% and 50%, respectively) while freely moving around in these larger space vehicles (Homick, 1979, 1983). During Skylab flights, for example, SMS lasted for 3-5 days for the 5 affected crewmen (Graybiel, Miller & Homick, 1974). Although astronauts in all of the flight programs were exposed to similar microgravity conditions, it might be argued that the salient difference giving rise to the SMS in the later missions was as follows: A fully mobile astronaut, while initiating purposeful, complex, and full-body movements in pursuit of an in-flight task, sees and feels that the amount of force he actually exerted yields an unexpected and hence grossly surprising rate, extent, and direction of movement, accompanied by discordant optical motions of the visual environment. Also, any additional relative optical motions that are not under his direct control are seen to be asynchronous with commonly experienced sights. This point extends to the astronaut suddenly floating in an inverted orientation, the craft's movements relative to seen external surfaces, and any craft movement, seen relative to himself. Moreover, what is optically, motorically, vestibularly, and proprioceptively expected and achieved are mismatched, creating very evident visual feedback that is discordant with the astronaut's terrestrial experience. In terms of the immediate effects of exposure and the time course of adaptation (i.e., initial disorientation, nausea, unsteadiness, general debilitation, and performance decrements, followed by gradual amelioration and recovery within 1-5 days) there are striking parallels between the experience of the astronaut and the prism-wearer exposed to unfamiliar optical information.

OBJECTIVES

The objectives of this study were: (1) to demonstrate the prominent role played by unfamiliar and unexpected optical motions in producing disorientation, bodily instability, performance decrements in visually guided tasks, and bodily discomfort akin to motion sickness; (2) to measure these potential effects objectively by behavioral and physiological tests as well as by self-reports; and (3) to assess, by means of this experimental paradigm of wearing a prism that up-down reverses the field of view, the course of rapid adaptation, especially in overcoming performance decrements.

RATIONALE

Whereas research into space motion sickness has focused principally on the etiological significance of altered vestibular input, considerable research (reviewed in the background section) points to a significant, perhaps even dominant, role of visual information in controlling orientation, performatory competence, and the perception of bodily well-being. Experience from previous spaceflights indicates that changes in vestibular activation associated with microgravity environments per se did not produce SMS when astronauts were constrained from moving (i.e., in the Mercury and Gemini programs); however, 33-54% of astronauts developed SMS when moving about freely in the much more spacious Apollo, Skylab, and Space Shuttle crafts.

The SMS experienced in these more recent flights is presumably related to the novel perceptual correlations of unfamiliar and unexpected optical motions seen by the astronaut when he initiates a movement, when relative motion of the craft is seen, and when his own movements produce unexpected results. Such experiences have been conceptualized as a mismatch between optical, motor, vestibular, and proprioceptive input and output. A mismatch of comparable intensity that produces motion sickness is readily produced experimentally by wearing a prism that optically reverses the field of view. The demonstration of adaptation in this paradigm (Dolezal, 1982) shows that a person can regain visual stability, performatory competence, and overcome motion sickness, presumably by learning a new set of visual-visual, visual-vestibular, visual-motor, visual-proprioceptive, and visual-cognitive relationships.

This paradigm may be useful in identifying individuals with a greater or lesser ability to overcome optically induced motion sickness, afford a reliable means of assessing medications in alleviating optically induced motion sickness, and may by itself have a facilitating effect in alleviating disorientation, performance decrements, and bodily discomfort associated with the unfamiliar and unexpected optical-vestibular-motor-proprioceptive relation-ships experienced in microgravity.

The ultimate objective of this work is to provide a framework for preparing crew members psychologically, perceptually, and physiologically for the microgravity conditions in flight and also provide the basis for design-modifications of spacecraft that would stabilize the visual environment of astronauts and obviate the development of SMS.

METHODS AND MATERIALS

Subjects. Fifteen college-educated subjects (9 men, 6 women) participated as paid volunteers. All were between the ages of 20 and 45; for men, the mean age was 28.3 years; for women, 27.7 years. All Ss had binocular, uncorrected or contact lens corrected acuity of 20/40, as determined by prebaseline Snellen chart measurement, with 11 Ss at 20/20 or better. Ss had to demonstrate an understanding of the instructions by accurately recounting the test protocol and by meeting the criteria for head movement accuracy and sitting still during physiological recordings. All Ss were healthy. Persons were excluded from participation in the study if they (1) were physically unsuitable as determined by Miller & Graybiel's (1970 b) health questionnaire; (2) were pregnant or menstruating; (3) had a history of anemia, asthma, back problems, bronchitis, glaucoma, clotting, heart condition, abnormally high or low blood pressure, thyroid, or seizure disorders; (4) had inner ear difficulties or a history of severe problems with dizziness, vertigo, fainting, nausea, car or plane sickness; (5) had a history of neurological or psychiatric illness; (6) used or abused drugs, including medication at the time of the experiment, especially antihistamine preparations; marijuana could not have been used for one month, LSD for two years and no alcoholic beverages for at least 24 hours prior to testing; (7) had a history of gastrointestinal disease such as ulcers, migraine headaches, present ear infections, common cold, active sinus condition or any active disease state.

Informed Consent. The health and welfare of Ss was safeguarded in 5 ways. First, Ss were informed as to the true and exact nature of the experiment verbally and preprinted on a Statement of Informed Consent that included a copy of Principle 9, Research with Human Participants, from the APA Ethical Principles of Psychologists, 1981, pp. 637-638, and the freedom to discontinue participation at any time and yet be paid for their participation for that session. All Ss read and signed this form. Second, a health questionnaire allowed only healthy persons to serve. Third, S's behavior and discomfort ratings were closely observed to detect any incipient unease so that testing could be terminated before any S reached a level of frank sickness with vomiting. Fourth, provisions for post-experimental rest prior to operating a bike, motorcycle or car were made available, encouraged, and complied with by all Ss; transportation, though unnecessary, was also available. Fifth, the experiment was approved by the Committee for the Protection of Human Subjects of Northeastern Illinois University, Chicago, Illinois.

Protocol

Table 1 gives a quick overview of the conduct of the experiment. An explanation of each test procedure follows.

Table 1

Protocol for Baseline (No Prism) and Experimental Condition (With Up-Down Reversing Prism) for the Short Session (27 steps) and the Long Session (41 steps) [1]

Step #	Step Description	S location
1	MSRS/pre-experimental [2]	sitting
2	Pre-Experimentation Questionnaire	sitting
3	Helmet donned by S [3]	sitting
4	Physiological hookup [4]	sitting
5	MSRS 1	sitting
6	Physiological 1	sitting
7	One Leg Balance Test 1	standing
8	Eye-Hand Coordination Tasks 1 [5]	sitting
9	Head Movement 1: 40 bpm [6]	standing
10	MSRS 2	sitting
11	Physiological 2	sitting
12	Walking Task 1 [7]	walking
13	MSRS 3	sitting
14	Physiological 3	sitting
15	Head Movement 2: 60 bpm	standing
16	MSRS 4	sitting
17	Physiological 4	sitting
18	Head Movement 3: 80 bpm	standing
19	MSRS 5	sitting
20	Physiological 5	sitting
21	Walking Task 2	walking
22	MSRS 6	sitting
23	Physiological 6	sitting
24	One Leg Balance Test 2	standing
25	Eye-Hand Coordination Tasks 2	sitting
26	MSRS 7	sitting
27	Physiological 7	sitting
END OF SHORT SESSION		
28	Head Movement 4: 80 bpm	standing
29	MSRS 8 during last 2-1/2 minutes of HMs	standing
30	Physiological 8 during last 2 minutes	standing
31	MSRS 9 following 5 minutes of HMs	standing
32	Physiological 9	standing
33	MSRS 10	sitting
34	Physiological 10	sitting
35	Head Movement 5: 100 bpm	standing
36	MSRS 11 during last 2-1/2 minutes of HMs	standing
37	Physiological 11 during last 2 minutes	standing
38	MSRS 12	standing
39	Physiological 12	standing
40	MSRS 13	sitting
41	Physiological 13	sitting
END OF LONG SESSION		

Footnotes to Table 1

[1] Note that prior to this laboratory session each S has filled out the preliminary health questionnaire, Statement of Informed Consent, the Motion Experience Questionnaire, and the Pensacola Motion Sickness Rating Scale. Details are described below.

[2] MSRS 1: Motion Sickness Rating Scale; given 7 or 13 times.

[3] Helmet: Helmet with plain acrylic (Baseline/Control Condition) or with up-down reversing prism (Experimental Condition) were put on by S; S's field of view was restricted to 115° x 28° in the horizontal x vertical plane and worn by S from Step 3 to end of session.

[4] Physiological responses (skin temperature, pulse, GSR, EMG) pre-experimentation hook-up or 2 minute recording, measured 7 or 13 times.

[5] Six Eye-Hand Coordination Tasks performed with the dominant hand only; given twice.

[6] Head Movement: (HM) 1. Up-down and right-left tilt onto the shoulder; Head Movement/Eye Movement task that was done for 5 minutes at 40, 60, 80, or 100 beats per minute (bpm) to a metronome; given 3 or 5 times.

[7] Walking Task I: without shoes; given twice.

Information/Pretraining Session. At least 24 hours prior to testing, all Ss were informed as to the rationale of the research and filled out our preliminary health questionnaire, Statement of Informed Consent, the Motion Experience Questionnaire (Miller & Graybiel, 1970, Appendix A), and the Pensacola Motion Sickness Questionnaire (Moore, Lentz, & Guedry, 1977; Reason & Brandt, 1975). Ss also received pretraining on our 5-point Motion Sickness Rating Scale (MSRS), making judgments of bodily comfort-discomfort as described in detail below, and on the Head Movement/Eye Movement Task. Ss then received a pre-experiment instruction sheet that included asking Ss to abstain from the intake of alcoholic beverages for 24 hours, food for 3 hours, and to reschedule if they ingested any medication 24 hours prior to either of their two sessions.

Videotaping. We used a camera (RCA CKC 020) set on a tripod in a fixed position relative to S and a cassette recorder (RCA VKP 900) to record both Baseline and Experimental sessions. The videotaping served the following 5 functions: (1) independent confirmation of all timings recorded by the experimenter during the study, including the One Leg Balance Test and the 6 Eye-Hand Coordination Tasks; (2) confirmation that Ss met the criteria for head movement precision; one S did not and thus did not contribute to the data pool; (3) confirmation that Baseline and Experimental sessions were conducted as nearly identically as possible; (4) a rich source of data for analyzing individual behavioral components during all phases of the study; and (5) preservation of post-session interview data.

Data Transfer and Computer Analysis. We transferred the data from the physiological monitoring equipment to a Cyber mainframe computer (located at Vogelback Computing Center, Northwestern University, Evanston, IL). Correlational, Chi Square, and several forms of MANOVA analysis were then made possible by the expertise of a Vogelback Computing Center staff member.

Baseline Session

The purpose of the Baseline Session was to familiarize Ss with (1) wearing the 1.35 kg (2 lbs, 14 oz.) helmet; (2) looking through a restricted 115° horizontal x 28° vertical field of view; (3) reporting perceptions of comfort-discomfort on our Motion Sickness Rating Scale (MSRS) from different body parts; (4) having sensors attached for recording 4 autonomic changes; (5) performing the One Leg Balance Test; (6) performing 6 visually guided Eye-Hand Coordination Tests; (7) executing the Head Movement/Eye Movement Tasks to 40, 60, 80, and 100 metronome beats/minute; (8) walking normally through the laboratory and hall; and (9) video/audio (VCR) taping of the experiment (13 of 15 baseline and 15 of 15 experimental sessions were recorded).

The Baseline Session consisted of the following 27 (Short Session) or 41 (Long Session) steps:

(1) Ss gave pre-session MSRS ratings to determine if they could serve; rating any body region as a "number 3" (moderate discomfort) necessitated rescheduling to avoid the possibility that S's results from then on were confounded with pre-existing discomfort (e.g., a headache). The MSRS was used several times, each time preceding 2 minutes of physiological recordings, in order to evaluate the magnitude and direction of a relationship between Ss' perceptual judgments of motion sickness discomfort and applicable physiological indicators. Ss were asked to rate, on a 5-point scale, the intensity of discomfort they perceived, associated with various body regions.

Motion Sickness Rating Scale: Body Regions: 1-3. Head: rate perception of dizziness; headache; drowsiness; 4. Throat: rate discomfort; 5. Chest Region: rate discomfort; 6. Stomach: rate queasiness; 7-8. Body Temperature: rate change to warmer or colder during the performance of any protocol tasks; 9. Muscles: rate degree of tenseness; and 10. Body: rate unsteadiness. Ss were also encouraged to make spontaneous verbal report whenever a change was noticed. Intensity Dimension: 1 = no discomfort ("I feel fine"); 2 = slight discomfort, dizziness, headache, queasiness, change in temperature, or tenseness, etc.; 3 = moderate discomfort, etc.; 4 = high discomfort, etc.; 5 = extreme discomfort, etc. On perceived body unsteadiness 1 = steady; and 2-5 = slightly, moderately, highly, and extremely unsteady, respectively.

_S_s' behavior and MSRS ratings were closely observed to detect any incipient unease so that testing could be terminated before any _S_ reached a level of frank sickness with vomiting. _S_s who reached "4" and "5" levels on the MSRS were asked to stop the ongoing activity, to sit down, maintain a stationary head and to close their eyes until they felt better and their ratings of discomfort, especially "head dizzy", "stomach queasy" and "body unsteady," returned to a moderate level.

(2) _S_s' level of compliance with pre-experimental instructions was monitored by the Pre-Experimentation Questionnaire (Graybiel & Miller, 1970, Appendix B), given minutes prior to serving in both the Baseline and Experimental Session.

(3) The control helmet, adjustable to any head size, was then put on by each _S_ and worn by 7 _S_s for 65-75 minutes (Short Session) and by 8 _S_s for 85-100 minutes (Long Session). The helmet contained a rectangular, plain (nonreversing) block of clear acrylic. This helmet was worn only in the Baseline (Control, No Prism) condition.

(4) The four sensors that detect autonomic changes were then attached to _S_. Repeated measurements of 4 physiological variables were made to assess whether any changes were reliably associated with the effects of engaging in the Head/Eye Movement Task with and without up-down reversing prisms. These indicators included electromyographic (EMG) activity, electrodermographic (EDG) activity, pulse rate and skin surface temperature. The EMG and EDG monitors were J & J's models M-52 and R-72, respectively. The J & J EDG Model R-72 provides two modes for measuring the electrical activity of the skin: Skin Conductance and Skin Potential. We measured Skin Conductance, traditionally called the Galvanic Skin Response (GSR). Blood pressure was monitored by an Industrial and Biomedical Sensors Corporation automated blood pressure and pulse rate monitor, model SD-700A. Skin surface temperature was measured by a Bio-Medical Instruments/Self Regulation System model 1820 monitor. All autonomic signals fed into a control unit and then into an Apple II Plus computer. A program computed means, standard deviations, low, high, and slope values for all four physiological variables every 20 seconds, 6 consecutive times during each 2 minute recording session, and printed this data.

Skin surface temperature was measured by taping the sensor to _S_'s nondominant (left hand for all _S_s) little finger. Pulse was monitored by clipping the optical plethysmographic sensor to _S_'s ring finger. Skin conductance (GSR) was measured by attaching the 2 dry electrodes with velcro strips to the second underside pad of the middle and index fingers. EMG was monitored by affixing the three sensors to _S_'s left cheek, just above the jaw; _S_'s masseter muscle thus became the principal recording site. Skin surface- and EMG surface electrode preparation and attachment was affected as described in Basmajian & Blumenstein, 1980. All recording devices were checked for reliability of recording at this point, fresh batteries having been inserted prior to each session for each S.

(5) While still seated S was instructed to look straight ahead with eyes open throughout the session and to give baseline ratings on the MSRS.

(6) Physiological measures were then recorded for 2 minutes (six 20 second bins or periods) as soon as S could adjust himself comfortably and sit as still as possible without moving, including not talking, swallowing, smiling or making body adjustments of any kind to minimize EMG artifacts.

(7) The One Leg Balance Test was administered. Ss wore no shoes. Ss were asked to fixate straight ahead and to support the body first on their right leg (ipsilateral to their dominant hand) and then on their left leg for as long as they could or for 120 seconds each, whichever came first. The experimenter timed with a stopwatch the duration from the time S raised the second leg off the ground until S had to put it down because of loss of balance. Ss were allowed repeated attempts until each reported that he had given an optimal performance or until 15 false starts had occurred, whichever came first. The number of false starts was recorded. All timings by the experimenter were independently checked against the VCR recordings by a research assistant. All differences of 3 units (seconds or false starts) were reconciled.

(8) Six Eye/Hand Coordination Tasks were given to allow us to evaluate differences in visually guided, fine motor, eye-hand coordination for the reversing prism vs. no-prism condition. All Ss were seated in front of a table with a 20" x 20" surface. S used only the dominant (right) hand for all tasks. Following verbal instructions that allowed sight of the objects and task requirements, S was asked to look straight ahead and to place his hand in a constant starting position down by his side. On the experimenter's signal, S was to complete each task as quickly as possible, the experimenter recording total duration to completion in seconds. Errors were not counted against Ss and any item dropped on the floor was replaced by the experimenter to its last position on the table or was put consistently into the tray or box that had contained the item originally, whichever was most appropriate.

The order of task presentation--Task #1-#6--followed an increasing order of difficulty for all Ss. The first 3 tasks were standardized Bailey Infant Scale of Mental Development items. First, S was asked to drop 10 small 1/2" cubes singly into a small hole in the center of a container after removing the top, emptying out the cubes and replacing the top. Second, S was asked to remove 6 pegs in a pegboard, to place the pegs on the side of the pegboard furthest from him, and to replace them. Third, S was asked to build a tower of 8, 1-1/4" cubes from a pool of 12 cubes symetrically arranged in a 5" x 6-1/2" x 2-1/2" deep box. S had to place the 8 blocks on the table first before starting to build the tower. The fourth fine motor coordination task was for S to exchange one "AA" size battery in a 4-1/2" x 2-1/2" calculator for another. Under visual guidance S needed to remove the cover, replace the battery and cover and turn it on to test whether the battery had been inserted correctly. S then needed to place the calculator and battery back on the table in its original position. Fifth, S was shown a standard 13" x 13" checker board fully set up for play with round, 1" diameter, plastic black pieces closest to S, red ones furthest away. S was asked to replace these exactly, including the crown emblem facing upwards toward S. The experimenter then deposited all pieces by handful into a 5-1/4" x 6-3/4" x 2-1/2" deep box from which S needed to retrieve them. Sixth, S was asked to place, from a tray, 2-1/2" long plastic pegs into their respective holes in a "Score 4," 8" x 8" game board and then to place one plastic bead on each of the pegs. The accuracy of the experimenter's stop watch durations were independently checked by the computer operator who noted the on-off times to the nearest second that appeared on the monitor. Differences of more than 3 seconds were checked against the videotape and reconciled.

(9) The Head Movement/Eye Movement Task was next. While S stood, she moved her head up-down (chin-to-chest position), tilted her ear toward her right and then left shoulder continuously for 5 minutes to a metronone set at 40 beats/minute. S was also directed to look in the direction of each head movement. S typically completed one successful U-D-R-L head/eye movement sequence within 5-10 seconds of the start signal. Once S had established a correct rhythm as to the direction, extent, and frequency, the experimenter started the stopwatch. Every 15-30 seconds S was told the elapsed and remaining time and encouraged to maintain a correct rhythm.

(10) S then sat down to give the MSRS for a second time.

(11) Immediately thereafter, S was asked to sit still while physiological measures were taken for 2 minutes for the second time.

(12) The Walking Task followed. S was unplugged from the recording equipment and asked to walk the length of the laboratory and of the adjacent hallway, a total of 60 yards, while moving his head up and down and then to return and seat himself in his chair. (13) The MSRS followed for a third time. (14) Physiological measures were taken for a third time as in (11). (15) The Head Movement/Eye Movement Task followed, again for 5 minutes; this time the metronome was set at 60 beats/minute. (16) The MSRS was followed by (17) physiological measures for a fourth time. (18) The 5 minute Head Movement/Eye Movement Task was performed at 80 beats/minute, (19)followed by the fifth series of MSRS, and (20) physiological measures.

(21) The Walking Task followed for a second time, as in (12). (22) The MSRS and (23) 2 minutes of physiological recording followed, for a sixth time. (24) The One Leg Balance Test followed a second time, as in (7). (25) The Eye-Hand Coordination Tests followed for a second time, as in (8). The Short Session ended with a seventh taking of the (26) MSRS and (27) physiological measures.

The Long Session added 14 more steps to the Short Session. (28) First, S once again performed the Head Movement/Eye Movement Task at 80 beats/minute; (29) 2-1/2 minutes after the onset, while S continued moving her head, S gave the MSRS (for the 8th time) and immediately thereafter, (30) for the last 2 minutes of the head movements, physiological measures were taken for the 8th time. (31) As soon as S stopped her head movements and stood still the MSRS was administered a 9th time, (32) followed by the 9th, 2 minute physiological recording session. (33) Immediately thereafter, S sat down and gave the MSRS for the 10th time, (34) followed by the 10th physiological measurement.

(35) S then stood up to perform the Head Movement/Eye Movement Task at 100 beats/minute with the 11th-13th (36-40) MSRS ratings and physiological measurements following as above, (41) ending the Long Session with the 13th physiological recording while S was sitting.

Each S, whether he had served in the Short or Long session, was asked informally to describe the similarities or differences of his perceptions, thoughts, and feelings during the session with any experiences before participating in our study. If no spontaneous comparisons were made, S was asked more directly about likening his experiences to being on a boat or ship, to roller coaster, carousel, elevator, plane, or car rides, to panoramic movies, etc. Ss were also asked if they had experienced any bodily perceptions that we had not even asked about on the MSRS. Ss were asked about the differences in their experiences during and after the Head Movement/Eye Movement Tasks, comparing up-down with tilt movements, the different rates of movement, the One Leg Balance Task, 6 Eye-Hand Coordination Tasks, and Walking Task.

Experimental Session

The Experimental Session was held at least 48 hours after the Baseline Session. The range of time separating the two was 48-168 hours with a mean of 112 (4.7 days) and a median of 122 hours (5.1 days). The passage of at least 2 days ensured recovery from fatigue or other aftereffects that may have resulted from the Baseline Session. The Experimental Sessions, whether short (27 steps) or long (41 steps) were as identical to the Baseline Sessions as possible in all respects, with the exception that all Ss wore a helmet containing a glass prism that optically up-down roversed the field of view.

RESULTS

Visual Stability and Bodily Discomfort

Correlations Between Autonomic Measures and Motion Sickness Rating Scale Ratings. In order to examine these interrelationships among perceived bodily changes and autonomic reponses, the correlation matrix presented in Table 2 and in Table 3 was constructed.

Table 2

Correlation Coefficients (r) and significant p Values for Physiological and Motion Sickness Rating Scale Values for Individual Ss in Baseline (No Prism) and Experimental (Reversing Prism) Condition

		BASELINE (No Prism)			EXPERIMENTAL (Reversing Prism)		
S #	Variable	Head Dizzy r (p)	Stomach Queasy r (p)	Body Unsteady r (p)	Head Dizzy r (p)	Stomach Queasy r (p)	Body Unsteady r (p)
2	Mean GSR					.99(.001)	
	High GSR					.99(.001)	
	Mean Temp					.80(.02)	
	High Temp					.79(.02)	
3	Mean GSR				.75(.03)		
	High GSR				.72(.03)		
	Mean EMG				-.72(.03)		
	High EMG				-.77(.02)		
5	Mean GSR				.92(.002)	.88(.004)	
	High GSR				.92(.002)	.89(.004)	
6	High Pulse				-.82(.01)		
	Mean GSR		-.96(.001)	-.96(.001)			
	High GSR		-.97(.001)	-.97(.001)			.67(.05)
	Mean EMG		-.78(.02)	-.78(.02)			
	High EMG		-.76(.02)	-.76(.02)			
	Mean Temp						.90(.003)
	High Temp						.91(.002)
7	High Pulse						-.68(.05)
	Mean GSR			.96(.001)	.69(.04)		
	High GSR			.96(.001)	.68(.05)		
	Mean Temp	.78(.02)					-.69(.04)
	High Temp	.80(.02)					-.69(.04)
8	High EMG				.54(.03)		
9	Mean Temp				-.68(.005)		
	High Temp				-.85(.001)		

Table 2, cont.

S #	Variable	BASELINE (No Prism) Head Dizzy r (p)	Stomach Queasy r (p)	Body Unsteady r (p)	EXPERIMENTAL (Reversing Prism) Head Dizzy r (p)	Stomach Queasy r (p)	Body Unsteady r (p)
10	Mean Temp	-.51(.04)					
	High Temp	-.51(.04)					
11	Mean GSR				.66(.01)		
	High GSR				.66(.009)		
	Mean Temp				.75(.003)	.54(.04)	.68(.007)
	High Temp				.76(.002)	.53(.04)	.69(.007)
12	Mean Pulse			.84(.001)			
	High Pulse			.83(.001)			
	Mean GSR				.63(.01)		
	High GSR				.60(.02)		
	Mean EMG			.57(.02)			
	High EMG			.59(.02)			
13	Mean Pulse						.81(.05)
	Mean EMG			.70(.004)			
	High EMG			.70(.004)			
	Mean Temp		-.85(.001)				
	High Temp		-.85(.001)				
14	Mean Pulse			-.64(.009)			
	High Pulse			-.63(.01)			
	Mean GSR	.60(.02)			.96(.001)	.75(.03)	.85(.008)
	High GSR	.60(.02)			.96(.001)	.75(.03)	.86(.007)
	Mean EMG			-.53(.03)			
	High EMG			-.50(.04)			
15	Mean Temp						-.72(.003)
	High Temp						-.72(.003)

Table 3

Correlation Coefficients (r) and significant p Values for Physiological and Motion Sickness Rating Scale Values for Group (N=15) Data in the Baseline (No Prism) and Experimental (Reversing Prism) Condition

	BASELINE (No Prism)			EXPERIMENTAL (Reversing Prism)		
	Head Dizzy r (p)	Stomach Queasy r (p)	Body Unsteady r (p)	Head Dizzy r (p)	Stomach Queasy r (p)	Body Unsteady r (p)
Mean Pulse	.16(.03)			-.24(.002)	-.15(.04)	-.25(.001)
High Pulse	.18(.02)					
Mean GSR	.15(.03)			.22(.005)	.14(.05)	
High GSR	.15(.03)			.25(.002)	.17(.02)	.16(.03)
Mean EMG				.30(.001)	.29(.001)	.34(.001)
High EMG				.35(.001)	.30(.001)	.37(.001)
Mean Temp	.28(.001)			-.27(.001)	-.35(.001)	-.22(.005)
High Temp	.27(.001)			-.22(.005)	-.30(.001)	-.17(.02)

The covariation is described for each of the 4 autonomic measures (pulse, GSR, EMG, skin temperature) with 3 (of the 10) MSRS variables (head dizzy, stomach queasy, body unsteady) that were hypothesized to be most likely related to the physiological events measured. Each measurement period consisted of 20 seconds. Each recording session lasted 2 minutes. All 15 Ss underwent the same 7 physiological recording sessions following activities described in the protocol; the last 8 Ss underwent an additional 6 sessions (13 in all). Only Mean and High values collected during the 2nd measurement period in each of the 2 minute recording sessions were used. Data from the first measurement period had to be disregarded for two reasons. First, Ss exhibited a very high rate of body movements during the first 20 seconds after sitting down--even after indicating they were ready for sitting quietly for 2 minutes--thus creating artificially high (EMG) scores. Second, in several instances the recording equipment was not able to collect data free of artifacts. This was true following plugging S back into the recording machinery after the Walking Task which Ss did twice in each the Baseline and Experimental condition. Data from the 3rd through 6th measurement periods were deemed too far removed in time from the time Ss gave the MSRS ratings to be considered optimally valid to establish the extent to which Ss could judge their autonomic nervous system events.

Table 2 presents Pearson r correlation coefficients and their respective p values for each individual S; Table 3 shows r and p values for all Ss combined, again for both the Baseline and Experimental conditions. Two correlations were examined. First, the mean values of each of the 7 or 13 recording periods of S's pulse, GSR, EMG, and skin temperature were compared with the corresponding values for the 3 MSRS variables, head dizzy, stomach queasy, and body unsteady. Second, the same was done with the high values. Each value for each variable was baseline-corrected, that is, was arrived at by deducting from it its respective baseline value that each S achieved on the first measurement occasion within that condition (i.e., before S engaged in the Balance Test, Eye-Hand Coordination Tasks, head movements or walking). Hence the values are yielded by deducting Physiological 1 (Step 6 of the protocol) from Physiological 2, Physiological 1 from Physiological 3 and so on through 7 for Ss 1-7 and Physiological 2-13 for Ss 8-15 and by similarly deducting MSRS 1 (Step 5 of the protocol) from MSRS 2-7 and 2-13. These comparisons yielded 15 individual S, and 24 group, Pearson r correlation coefficients for each the Baseline and Experimental condition.

Visual Stability and Physiolgical Measures. Table 4 presents the autonomic

Table 4

Mean and High Values of 4 Physiological Measures (Pulse, GSR, EMG, Skin Temperature) and respective F Test for all Ss (N=15) for all Recording Periods (df=14/274) and for Baseline (No Prism) vs. Experimental (Reversing Prism) Condition (df=1/274)

	Source of Variation	
	Subject	Group (Baseline vs. Experimental)
Physiological Measures	F	F
Mean Pulse	1.82*	1.72(NS)
High Pulse	4.34***	.00(NS)
Mean GSR	19.62***	7.94**
High GSR	18.41***	5.47*
Mean EMG	2.04*	9.36**
High EMG	2.25**	14.23***
Mean Temp	10.75***	21.12***
High Temp	11.13***	15.11***

*p<.05 **p<.01 ***p<.001

measures that proved significantly different from chance by F test for differences among Ss across all recording periods (df=14/274) and for the Baseline (No Prism) vs. the Experimental (Reversing Prism) condition (df=1/274). Again, the Means and High physiological values used for the comparison were taken from each of the 7 or 13 recording periods; each value was baseline-corrected, that is, derived by deducting from it its respective baseline score: Physiological 1 (Step 6 of the protocol) from Physiological 2-7 and 2-13.

Visual Stability and Bodily Discomfort. Our MSRS was used to assess 10 parameters of Ss' perception of comparative bodily comfort/discomfort on a 5-point scale where 1 represented "I feel fine" and 5 extreme discomfort. Three of these parameters (head dizzy, stomach queasy, body unsteady) were considered, on empirical grounds, to best represent Ss' awareness of the discomfort experienced. Table 5 presents the mean baseline-corrected MSRS

Table 5

Motion Sickness Rating Scale. Mean MSRS ratings for all Ss for all Protocol Steps and respective F Test (df=1/14) for Baseline (No Prism) vs. Experimental (Reversing Prism) Condition

	Mean baseline-corrected MSRS Ratings for all Ss		F Test for Ratings in Baseline vs. Experimental condition
MSRS Parameter	Baseline	Experimental	F
Head Dizzy	.03	1.1	16.60***
Stomach Queasy	.0	.6	11.15**
Body Unsteady	.1	.7	8.61**
Total	.1	.8	15.02**

p<.01 *<.001

ratings for all Ss for all protocol steps (Steps 5, 10, 13, 16, 19, 22 and 26 for the Short Session, adding Steps 29, 31, 33, 36, 38 and 40 for the Long Session) and F ratio (df=1/14) for the Baseline (No Prism) vs. the Experimental (Reversing Prism) condition.

Visual Stability and Control of Balance

One Leg Balance Test. Duration of Standing on Either Leg. The One Leg Balance Test was used to assess Ss' comparative visually guided control of balance. The total duration Ss could support their body on the right leg and left leg in the Baseline (No Prism) vs. the Experimental (Reversing Prism) condition was compared by analysis of variance. Table 6 shows these

Table 6

One Leg Balance Test. Mean Durations (in seconds) all Ss could stand on one leg, and respective F Test (df=1/14) for Baseline (No Prism) vs. Experimental (Reversing Prism) Condition.

	Mean Duration (in Sec.) for all Ss		F Test for Durations Baseline vs. Experimental Condition
	Baseline	Experimental	F
Balance Right Leg	52	5	21.00***
Balance Left Leg	67	7	34.05***
Balance R & L Leg	119	12	28.12***

***p<.001

mean durations and one main effect that was significantly different from chance (df=1/14) (i.e., the length of time Ss stood on one leg in the Baseline vs. the Experimental condition). Ss stood significantly briefer durations (on average, only 6 seconds) while looking through the up-down reversing prism than they did while looking through plain acrylic goggles (on average, a full 59 seconds). Natural log transformation of the duration Ss were able to support themselves on either leg yielded F ratios greater than those shown in Table 6. (The analysis by F Test of the time at which the Balance Test was performed, 1st vs. 2nd occasion [Step 7 vs. Step 24 of the protocol], showed no significant differences for either the right or left leg for either the Baseline or Experimental condition. Similarly, the right leg vs. left leg differences for duration of balancing proved nonsignificant in either condition.)

One Leg Balance Test: Number of False Starts. Table 7 shows the mean number of false starts with respective F Test and the Chi Square analysis which compared how often Ss as a group put their leg down before successfully supporting their body on the other leg (number of false starts) in the Baseline (No Prism) vs. the Experimental (Reversing Prism) condition. (Additional analysis of the time at which the One Leg Balance Test was performed, 1st vs. 2nd occassion [Step 7 vs. Step 24 of the protocol] showed that in the Experimental Condition Ss as a group made significantly fewer false starts for both legs combined [F=11.16, p<.005, df=1/42] and for the right leg only during the second administration

Table 7

One Leg Balance Test. Mean Number of False Starts (FS) made by all Ss before standing still and respective F Test based on Log Transformed Data (df=1/14) and Chi Square Test for Baseline (No Prism) vs. Experimental (Reversing Prism) Condition.

	Mean # of FS for all Ss		Log Data Baseline vs. Experimental	Chi Square Test for # of FS for Baseline vs. Experimental Condition	
	Baseline	Experimental	F	Chi Sq.	df
False Starts Right Leg	1	5	25.65***	24.30**	10
False Starts Left Leg	0	3	49.69***	28.30***	9
False Starts R + L Legs	2	8	69.54***	32.83**	16

**p<.01 ***p<.001

compared with the first administration [F=15.88, p<.001, df=1/42]; also a significant difference from chance was found for the main effect of Time (F=15.03, p<.005, df=1/14), and for the Time at which false starts were made with the right leg (F=21.12, p<.001, df=1/14).) (No significant difference for either right or left leg was found in the Baseline Condition.) Natural Log transformation of these false start scores were deemed most appropriate for this analysis of variance.

Optical Disorientation and Visually Guided Fine Motor Coordination

Eye-Hand Coordination Tasks. In order to assess Ss' comparative visually guided performatory competence, 6 Eye-Hand Coordination Tasks were used. Table 8 shows the mean durations for all Ss for all 6 tasks for both Baseline and Experimental conditions; it also presents the Low, High, and Range scores across all Eye-Hand Coordination Tasks for all Ss.

The analysis of variance shown in Table 8 indicates that both main effects, Time at which the 6 tasks were performed (1st vs. 2nd occasion: Step 8 vs. Step 25 of the protocol), and Condition (Baseline vs. Experimental), as well as the Time x Condition interaction effect--the Experimental Condition showed (performatory adaptation) changes over time whereas the baseline condition did not--were significantly different from chance (df=1/14) for all tasks. A further F ratio analysis, also presented in Table 8, revealed that the duration for all task performances decreased significantly (df=1/42) only during the Experimental condition, that is, Ss took less

Table 8

Eye-Hand Coordination Tasks. Mean Durations (in seconds) to Complete all 6 Tasks for all Ss and respective F Test (df=1/42); also F (df=1/14) for Time of Performance (Time 1 of Baseline & Experimental Cond. vs. Time 2 Baseline & Experimental Cond: Step 8 vs. Step 25 of the protocol); Condition: Baseline (No Prism) vs. Experimental (Reversing Prism) Condition, and Condition x Time Interaction

Task #	Mean Duration (in sec.) for all Ss Low, High, and Range Scores across all Tasks for all Ss: Baseline Condition 1st	Baseline Condition 2nd	Baseline Condition Mean	Baseline Condition F	Experimental Condition 1st	Experimental Condition 2nd	Experimental Condition Mean	Experimental Condition F	F, for Time of Performance, Baseline vs. Experimental Condition, & Condition x Time Interaction: Time 1 vs. 2 of performance F	Baseline vs. Experimental Cond. F	Condition vs. Time Interaction F
1	17	16	16	.07(NS)	68	41	54	18.07***	12.64**	54.88***	8.72**
2	14	14	14	.00(NS)	57	29	43	37.83***	29.54***	51.46***	24.60***
3	22	19	21	.00(NS)	354	82	218	25.54***	14.04**	23.09***	13.85**
4	34	23	28	.41(NS)	118	58	88	11.34**	8.33**	17.59***	4.74*
5	54	51	52	.03(NS)	201	136	168	16.25***	16.27***	54.27***	14.39**
6	92	88	90	.03(NS)	302	203	251	28.46***	25.06***	83.91***	22.84***
Mean	39	35	37	.06(NS)	183	92	137	36.86***	26.52***	57.08***	24.12***
Low	11	10	11		28	18	23				
High	121	120	121		1188	292	740				
Range	110	110	110		1160	274	717				

*p<.05 **p<.01 ***p<.001

time to complete the 6 tasks the second time they performed them in the Experimental Condition. Natural Log transformation of the duration Ss required to complete each of the 6 Eye-Hand Coordination Tasks yielded F ratios that were significant at or beyond the levels shown in Table 8 for all comparisons of the 2 main effects, namely, Time at which each task was performed and Condition (Baseline vs. Experimental), and for their interaction (Time x Condition).

DISCUSSION

Dizziness, queasiness, sweating, changes in muscle tension and skin surface temperature, poor balance while standing, unsteady equilibrium while walking, and disorientation while moving about and during precise eye-hand coordination were all observed reliably and to a significant extent in a sample of 15 men and women under the influence of the main independent variable-cluster of this study: seen unfamiliar optical motions and movements engendered by eye-, head-, body-, leg-, and hand movements while looking through an up-down reversing prism attached to S's head.

More specifically, the following results demonstrate the prominent role played by unfamiliar and unexpected optical motion-information:

(1) We observed significant covariations for 13 of our 15 individual Ss for their ratings of dizziness, queasiness, bodily instability and the magnitude of their physiological responses including pulse, GSR, EMG, and skin surface temperature (Table 2).

(2) We found modest but significant covariations for our 15 Ss as a group for their ratings of dizziness, queasiness, and bodily instability and the magnitude of their physiological responses including pulse, GSR, EMG, and skin temperature (Table 3).

(3) Measureable changes from baseline levels were found in Ss as a group in physiological responses including GSR, EMG, and skin temperature (Table 4).

(4) Significant individual differences exist among the Ss of our sample relative to all the physiological and MSRS parameters (Tables 2 & 4).

(5) We found that as a group, Ss' perceptions of bodily discomfort differed substantially from baseline levels as reflected in ratings of dizziness, queasiness and bodily instability on our MSRS (Table 5).

(6) Ss displayed significant loss of control of visually directed body balance in the Experimental (Reversing Prism) Condition as reflected first, in the One Leg Balance Test where Ss were able to stand, on average, only 1/10th as long as in the Baseline (No Prism) Condition and, second, in the fact that Ss made an average of 4 times as many false starts while trying to stand on one leg in the Experimental Condition (Tables 6 & 7).

(7) Profound visuo-motor disorientation was documented by significant performance decrements in visually guided actions; Ss took 3-16 times as long in the Experimental (Reversing Prism) Condition as in the Baseline (No Prism) Condition to perform the 6 Eye-Hand Coordination Tasks (Table 8).

(8) We also found substantial, rapid adaptation in fine motor coordination; Ss completed the Eye-Hand Coordination Tasks on the second attempt in the

Experimental (Reversing Prism) Condition in up to 1/4 of the time; on average, only 65 minutes elapsed between the first and second try.

Ss as a group consistently and homogeneously exhibited the following behaviors:

(9) During the Experimental (Reversing Prism) Condition every S stood more shakily and for less time than they had during the Baseline (No Prism) Condition (One Leg Balance Test); moreover, every S made more combined false starts during the Experimental Condition.

(10) Similarily, all but one S took substantially more time to complete each of the 6 visually guided, fine motor coordination tasks and

(11) Ss completed each task more quickly when doing it the second time, exhibiting a quick form of learning or adaptation on the Eye-Hand Coordination Tasks.

(12) All Ss were unsteady while walking and

(13) All Ss were disoriented while visually locating their chair and while sitting down; these problems in gross motor performances were only noticeable during the Experimental (Reversing Prism) Condition.

Correlations Between Autonomic Measures and Motion Sickness Rating Scale Ratings: Individual S Data

One rationale for this study was to determine whether, and to what extent, S's perceptions of bodily discomfort corresponded to actual autonomic nervous system events that occurred closely in time. The data presented in Table 2 show that the relationship between MSRS values and values of physiological response measures was sizeable (extent) and idiosyncratic (direction). The magnitude of such relationships accounted for between 25%-98% of the variance (r values ranged from -.50 to .99; respective p values ranged from .05 to .001. The suggestion is clear: S's high or low values on the MSRS (head dizzy, stomach queasy, and body unsteady) were reliably associated with high or low values on the physiological measures (pulse, GSR, EMG, and skin temperature). Generalizations about the direction of such relationships requires further analyis, however.

In the Experimental (Reversing Prism) condition, 13 of our 15 Ss displayed a significant correlational relationship between changes in one or more of their 4 physiological responses and one or more of their 3 MSRS ratings; r values ranged from .53 to .99, with significance levels ranging from <.05 to <.001, accounting for 28%-98% of the variance. Overall, 20 Mean and 23 High physiological indices proved significant, suggesting that either the Mean or High value may be used for future investigations. Two physiological indicators--GSR and skin temperature--correlated most frequently with S's MSRS ratings. 10 Mean and 11 High GSR indices proved significant. The behavior of 10 of the 15 Ss exhibited such a co-variation. For 6 Ss we found a significant, direct relationship between

(Increases In) head dizzy ratings and (Increases In) GSR values; two of these Ss also exhibited increases in GSR along with increases in stomach queasy ratings, and one of them also showed increases in body unsteady scores along with increases in GSR. One S showed only a correlation between GSR and body unsteadiness. In summary, 8 Ss displayed a direct covariation of GSR with their MSRS values: electrodermal activity increased along with an increase in their head dizzy (n=6), stomach queasy (n=3), and body unsteadiness (n=2) ratings. Thus, GSR showed itself as a reliable predictor of perceived bodily discomfort and vice versa.

The second most frequently found co-variate under conditions of optical disorientation proved to be skin surface temperature (for 6 Ss). The behavior of 4 Ss exhibited a correlation between skin temperature and judged body unsteadiness. Two Ss showed a direct relationship, two an inverse relationship, with skin temperature decreasing as body unsteadiness increased, suggesting perhaps, cold sweating. Two other Ss showed a direct relationship between (increases in) skin temperature and (increases in) queasiness. Finally, 2 Ss produced a correlation between (increases in) dizziness and skin temperature; one of these was an inverse relationship where skin temperature decreased with corresponding increases in dizziness values. In summary, 6 Ss displayed a relationship of skin temperature with their MSRS values: along with increases in MSRS values went increases or decreases in skin temperature; dizzy (n=2), queasy (n=2), unsteady (n=4). Third, pulse co-varied directly with increased body unsteadiness values in one S, and inversely (pulse decreased) with (increases in) dizziness in one S, and with (increases in) body unsteadiness in one S. Fourth, EMG values increased in one S as his dizzy values increased and decreased in another S as her dizzy ratings increased.

These results suggest the likelihood of (1) characteristic motion sickness susceptibility profiles which further implies, when also considering Table 4 results, that (2) our physiological indicators--GSR, skin surface temperature, EMG, and pulse--and our Motion Sickness Rating Scale may well be good predictors of motion sickness susceptibility. Much more data is available from this study and remains to be analyzed; for example, we focused on 3 of the 10 MSRS parameters and on only 2 of the 5 available computer generated physiological summary statistics and on only 1 of 4 additional measurement periods during which summary statistics were collected. Thus the 70% remaining MSRS scores and 90% physiological values may contain further useful answers.

One hypothesis that emerged from the correlational data for individual Ss in the Experimental(Reversing Prism) Condition is that a given S responds characteristically to the novel, unfamiliar, and disconcerting optical information produced by the up-down reversing prism condition, both in terms of that person's perception of bodily discomfort and actual physiological changes. Such covariations suggest that individuals or distinct subgroups of flight personnel and astronaut trainees may need tailor-made training schedules that fit their profile of responding. Perceptual and physiological pre-adaptation training procedures could then be designed for optimal results.

One application of the data on physiological indicators to microgravity is to collect relevant baseline data for a given trainee and provide each trainee with a simple (e.g., wristwatch) monitor that would thus signal and predict incipient SMS in time for the trainee to decrease or discontinue eye-, head-, or body movements, and to stabilize himself visually relative to the craft to obviate SMS onset. What we need to know here is (1) how great a change in a given physiological indicator can be safely ignored and (2) how much time does the individual have before his performance will be affected by SMS. Future research needs to define in further detail what constitutes such relevant baseline data for specified trainees and the contiguity relationship between physiological indicators of motion sickness and disorientation, performance decrement, and perceived bodily discomfort.

The following questions warrant further analysis of our data. What proportion of Ss who reported increases in dizziness, queasiness, and/or unsteadiness, showed corresponding changes in pulse, GSR, EMG, and/or skin temperature? Another question of interest for future analysis is the consistency-relationship between S's physiological behavior and MSRS judgments during the Baseline (No Prism) Condition relative to the Experimental (Reversing Prism) Condition. Finally, a closer look needs to be given to potential changes that occurred in the physiological measures of two groups of Ss: first, Ss who almost fell down while walking and who were visibly unsteady, especially during the Balance Test, yet provided #1 ("I feel fine") ratings throughout on all 3 MSRS indicators (the experimenter had to physically support the entire body of one of these Ss while walking, otherwise he would have fallen down); are some Ss less aware than others of physiological events? Are some culturally "prohibited" from expressing moderate or high discomfort under circumstances such as ours? Second, we need to look carefully at the physiological behavior of those Ss who seemed steadier throughout and also consistently gave #1 ratings.

Correlations Between Physiological Measures and Motion Sickness Rating Scale Ratings: Group Data

Table 3, as Table 2, describes the covariation of each of the 4 physiological measures (pulse, GSR, EMG, and skin surface temperature) with 3 (of the 10) Motion Sickness Rating Scale variables (head dizzy, stomach queasy, body unsteady) except that it does so for all 15 Ss as a group. The extent of the correlation coefficients and their corresponding levels of significance suggest that Ss' perceptions of bodily discomfort did, indeed, correspond to actual autonomic nervous system events that occurred closely in time. The data of Table 3 show that the magnitude of such relationships between MSRS values and values of physiological response measures was modest: r values ranged from .14 to .37 (respective p values ranged from .05 to .001), accounting for between 2%-14% of the variance. Group r values were low even for the Experimental (Reversing Prism) Condition because first, all computations included 3 Ss who reported zero change in their MSRS scores, regardless of their autonomic nervous system behavior and second, because individual Ss responded idiosyncratically. The direction of the relationship between MSRS scores and physiological measures showed a consistent pattern for our sample, even though individual Ss displayed both direct and inverse correlations on a given combination of variables.

In the Experimental (Reversing Prism) Condition, Ss as a group produced Mean Pulse values that correlated significantly and inversely with all 3 MSRS values. Thus, as Ss as a group reported high dizziness, queasiness, and unsteadiness scores, their mean pulse rate decreased. The extent of these correlation coefficients was modest, r=-.24, -.15, and -.25, but statistically significant at the .002, .04, and .001 levels and accounted for 2%-6% of the variance. Similarly, Ss as a group produced Mean and High skin temperature values that correlated significantly and inversely with all 3 MSRS scores. Thus, as Ss as a group reported higher dizziness, queasiness, and unsteadiness scores, their Mean and High skin temperature decreased. The extent of these correlation coefficients ranged from r= -.17 to r=-.35; they were significant at the .02 to .001 levels and accounted for 3%-12% of the variance.

All group values for both Mean and High EMG values were positive and significantly correlated with all 3 MSRS measures during disorientation. Their extent ranged from r=.29 to r=.37; all were significant at the .001 level and accounted for 8%-14% of the variance. Thus, as dizziness, queasiness, and judged body unsteadiness increased, so did muscle tension. Finally, all but one group r value for both Mean and High GSR values were positive and significantly correlated with all 3 MSRS measures during disorientation. Their extent ranged from r=.14 to r=.25; they were significant at the .05 to .002 level and accounted for 2%-6% of the variance. The exception was mean GSR and body unsteady scores.

Perhaps the most remarkable finding is the fact that of 24 possible correlations between our 4 physiological indices, represented by Mean and High values, and our 3 MSRS scores, 20 were significant, 10 at the .001, 2 at the .002, and 3 at the .005 level. (It also appears that either Mean or High values adequately represent our physiological parameters; 11 Mean and 9 High values proved useful.) The conclusion appears warranted that all 4 physiological measures are good predictors of perceived bodily discomfort in our visual disorientation paradigm. A comparison of Tables 2 and 3 strengthens the conclusion that pulse, GSR, EMG, and skin temperature all are useful in assessing perceived bodily discomfort, typically associated with motion sickness and SMS, be it dizziness, queasiness, or bodily unsteadiness, and vice versa. Consequently, both our physiological indicators and Motion Sickness Rating Scale represent useful cross-check tools. Other group similarities and differences for physiological-MSRS correlations will require additional (Rounds 2 and 3) analyses of the available but untapped data base.

Visual Stability and Physiological Measures

Another rationale for this study was to find out whether any physiological indicators were reliably associated with disorientation, bodily instability, nausea, and performance decrements typically reported by some astronauts and flight personnel and which we successfully simulated by our optical disorientation paradigm. The analysis presented in Table 4 shows that 3 of the 4 parameters are indeed useful: Mean and High scores for GSR, EMG, and skin surface temperature found in the Experimental (Reversing Prism) Condition differed significantly from those in the Baseline (No Prism) Condition. Data presented in Table 4 also confirms our previous conclusion that individual Ss responded differently from one another on all physiological variables. Mean and High GSR responses, Mean and High Temperature scores and High Pulse scores were all significant at $p < .001$. High EMG responses also differentiated Ss at the <.01 level and Mean EMG and Mean Pulse scores did so at the <.05 level. Overall, it is clear that all 4 physiological measures were confirmed to be useful tools in future investigations for profile-analysis of individual trainees.

Visual Stability and Bodily Discomfort

The results of Table 5 show that as a group and across all rating opportunities, Ss responded significantly different in the no prism Baseline and reversing prism Experimental Condition on all 3 of the 10 MSRS parameters we chose to look at. Indicators of the novel optical motion-information during and following S movements were dizziness (<.001 level of significance), queasiness ($p < .01$), and perceived unsteadiness ($p < .01$). Table 5 also shows overall means for the 2 conditions of the study. The Baseline (No Prism) condition mean was computed on 138 scores for each parameter, the Experimental (Reversing Prism) condition mean on 124 scores each. The MSRS scores appear low because they are baseline-corrected, that is every rating had deducted from it its respective baseline rating score. Nevertheless, the differences between the Baseline (No Prism) vs. Experimental (Reversing Prism) condition proved to be statistically significant for all MSRS parameters (head dizzy, stomach queasy, body unsteady). The data show that even as a group Ss consistently judged themselves to be dizzier, queasier, and more unsteady, relative to the no prism control situation, during the visual disorientation and instability created by head-, body-, and limb movements while looking through an up-down reversing prism.

The conclusion seems warranted that our Motion Sickeness Rating Scale is a useful tool for assessing the types of bodily discomfort characteristically associated with motion sickness and with SMS. As such, it represents a helpful adjunct to the use of physiological and performatory indices, such as those we have already shown to be reliable in any SMS pre-adaptation or training program for flight personnel and astronauts. Given that the MSRS was given 7 times (Short Session) and 13 times (Long Session), additional statistical analyses are desirable to discover which protocol condition affected S's perceptions of bodily discomfort least and which most and how these differences compared to physiological changes over time.

Visual Stability and Control of Balance

One Leg Balance Test. Maintaining one's equilibrium in relation to the immediate environment is a vital component of maintaining visual stability. When optical motions were generated by an unfamiliar relationship between head movements and their initially unpredictable seen consequences, body balance was compromised and instability resulted. Table 6 shows that standing on one leg proved so difficult while looking through the up-down reversing prism that Ss stood, on average, only 6 seconds on either leg (range=1-34 seconds) in the Experimental (Reversing Prism) Condition compared with an average of 59 seconds (range=8-120 seconds, our selected maximum) in the Control (No Prism) Condition. This difference was significant at the <.001 level. The data indicate that the One Leg Balance Test is an effective method for differentiating our optical disorientation condition from an environment in which the seen rate and direction characteristics of optical motions and movements are familiar and predictable.

Another method we used for assessing visually guided stability was to count false starts, that is, the number of times Ss stepped back on the ground with the second leg before they were able to support themselves and assert that they had maintained their balance on one leg as long as possible. Table 7, as Table 6, shows a significant (p <.001) between-groups difference for the log transformed data. In the Baseline (No Prism) Condition Ss made a mean of 2 false starts (range=0-6) whereas in the Experimental (Reversing Prism) Condition Ss made a mean of 8 false starts (range=0-15, our selected maximum). The Chi Square analysis also confirms the Control-Experimental group differences at the <.01 level of significance. In the Experimental Condition Ss as a group made fewer false starts the second time the balance test was administered. The implication here too is that counting false starts is one useful and reliable ancillary method to the One Leg Balance Test to assess trainees' capacity to initially respond and later adapt to conditions of disorientation that create visual instability. The rate of adaptation to regain control of equilibrium and bodily balance that optimizes performatory competence can thus be objectively measured.

Optical Disorientation and Visually Guided Fine Motor Coordination

Eye-Hand Coordination Tasks. Undoubtedly the most life-threatening and consequently most pressing problem facing flight personnel and astronauts is not experiences of bodily discomfort *per se*, such as nausea, but destabilization of the self that is so severe and/or long lasting that the performance of vital, inflight tasks is adversely affected. Tasks that require quick and accurate coordination are of special interest. Accordingly, we chose tasks that simulate--in the reversing prism condition--the novel demands for visual guidance in locating (e.g., a specific switch on a complex display), and in manipulating small objects during repair jobs while moving freely, unpredictably, and in any possible orientation in the spacecraft in microgravity. Movements made by the astronauts yield unexpected physical and hence at first also unexpected seen results, not perceptually and motorically unlike the effects the reversing-spectacle wearer experiences as a result of formerly normal up-down, tilt, and diagonal head movements: it took longer to locate, identify, and to manipulate objects. Overall, for the prism wearer, competent visuo-motor activities were hard to execute and control; hand movements especially were hard to repeat and predict, and seeing them produced additional visuo-motor disorientation. The data presented in Table 8 are unequivocal. For example, the range is 10 times greater (110 vs. 1160 seconds) for the Experimental (Reversing Prism) Condition when compared with the Baseline (No Prism) Condition for the mean durations for all 6 tasks combined, when considering the first time the tasks were performed in each condition. As a group, Ss took from between 15-39 seconds (median=20 seconds) to stack 8 cubes in the Baseline (No Prism) Condition and then needed from 1-20 minutes--from 55-1188 seconds (median=313 seconds)--while looking through the up-down reversing prism. Each of the 6 visually guided fine motor coordination tasks differentiated Ss' coordination skills with and without optical up-down reversal: each task took significantly longer to complete when Ss were optically disoriented. Overall, the F Test proved significant at the <.001 level when comparing the Baseline (No Prism) and Experimental (Reversing Prism) condition; all tasks combined, reliably differentiated Ss' Baseline and Experimental condition performances at the <.001 level of significance.

The degree of optical disorientation initially produced by reaching, and manipulating relatively small objects while looking through an up-down reversing prism, may be appreciated by a description of the first 3 tasks Ss performed. All three are items from the standardized Bailey Scale of Mental Development. First, putting 10 small square beads in a box that has a lid with a hole in it that just accommodates the beads, is a task a typical 12.9 months old infant (range 10-17 months) can perform. During the Baseline (No Prism) Condition our Ss took a mean of 17 and 16 seconds during the 1st and 2nd administration, respectively, to complete the tasks. During the Experimental (Reversing Prism) Condition Ss took 68 and 41 seconds during the 1st and 2nd administration, respectively. Second, placing 6 pegs as fast as possible on the table and replacing them in the pegboard is a task a typical 16.4 month old toddler (range 13-20 months) performs in 70 seconds, a typical 17.6 months old (range 14-22 months) does in 42 seconds, a typical 20 months old (range 16-29 months) does in 30 seconds, and a typical 26.6 months old (range 19-30 months) completes in 22 seconds. During the Baseline (No Prism) Condition our Ss needed a mean of 14 seconds during each administration to complete the task. No S needed longer than 20 seconds. During the Experimental (Reversing Prism) Condition Ss needed 57 and 29 seconds during the 1st and 2nd administration, respectively. 6 Ss needed longer than 70 seconds (mean=86 seconds) the 1st time. Third, stacking 8 cubes is a task a typical 30 months old (range 22-30+) can perform successfully. During the Baseline (No Prism) Condition our Ss needed a mean of 22 and 19 seconds in the 1st and 2nd administration, respectively. During the Experimental (Reversing Prism) Condition Ss needed a mean of 354 and 82 seconds in the 1st and 2nd administration, respectively.

Rapid Perceptuo-Motor Adaptation During Optical Disorientation In Spite of Motion Sickness

Use of the 6 Eye-Hand Coordination Tasks also helped answer the question whether motion sickness produced by optical disorientation affects speed (as an index of accuracy and smoothness) of performance. An analysis by time revealed that there were no significant differences for any of the 6 Eye-Hand Coordination Tasks, when the first and second administrations were compared in the Baseline (No Prism) Condition. Only 2 seconds separated all tasks, averaged over all Ss. On the other hand, significant differences existed for each of the 6 tasks in the Experimental (Reversing Prism) Condition; when comparing how much more quickly Ss as a group completed any given visual coordination task on the second administration, compared to the first, mean durations decreased by at least 32% and by as much as 77%, with an improvement of 50% averaged over all 6 tasks. Some individual Ss made gains of up to 89% on some tasks. These results taken together clearly indicate fast learning or perceptuo-motor adaptation even under conditions of extreme optical disorientation. Note that only 65 minutes separated, on average, the 1st and 2nd time Ss attempted the Eye-Hand Coordination Tasks in the Experimental Condition.

One of the most interesting findings of the study was that several Ss gave high and extreme (#4 and 5) dizzy, queasy, and/or body unsteady MSRS ratings, and two of these requested or were requested not to perform further Head Movement or Walking Tasks to prevent frank sickness; when this group of Ss then performed the 6 Eye-Hand Coordination Tasks, they too improved their task performance dramatically even though they continued to report high or extreme motion sickness ratings. S #14 was typical of this group. Prior to attempting the 6 tasks the second time he reported extreme dizziness, queasiness, and unsteadiness; immediately following completion of the tasks he reported extreme dizziness, and high queasiness and unsteadiness. Nevertheless, his performance improved by 46% (mean duration went from 184 sec. to 99 sec.), very close to the improvement mean for all Ss. These Ss noticed their enhanced competence and reported it during and/or following the session, expressing surprise that they could do so well despite their high or extreme malaise. These findings suggest that measureable adaptation during optical disorientation occurs even if motion sickness symptoms are experienced, provided individuals continue to work on the tasks at hand as best they can.

While some Ss were doing their performance routines we continued to measure physiological indicators to see if there were any physiological changes during the process of adaptation. Data yet to be analyzed includes looking at the differences between some S's pulse, GSR, EMG, and skin temperature during the head movement sequences, following the head movement sequences, while standing and then while sitting. Such comparisons of the long (41 steps) and short (27 steps) protocol session should yield information about physiological differences during peak periods of stress (as measured by our MSRS indicators, especially head dizzy, stomach queasy, body unsteady), immediately following peak stress periods, and during subsequent periods of quiescence.

Qualitative Data: Post Session Interviews from Video Recordings

Video taping the study provided valuable confirmation of the data we analyzed statistically, especially data recorded by the experimenter during the experiment. All timings and false starts documented during the One Leg Balance Test and the 6 Eye-Hand Coordination Tasks were checked against the video tape independently, for accuracy. The videotape also confirmed that only one S did not meet the criteria for head movement precision and that Baseline and Experimental Sessions were conducted as nearly identically as possible. The qualitative data recorded on tape of the post-session interviews point out the idiosyncratic perceptions Ss had relative to the conditions of the Experimental Session. Further analysis is needed to determine if patterns exist in the individualistic perceptions of how our Ss responded and adapted.

Some Ss reported that "balancing took a lot of concentration;" "I was concentrating on seeing." One described the experience by saying: "When I was looking straight ahead, I felt like I was falling off inside. I couldn't keep my head from falling off." Another response was, "I didn't feel unsteady on balancing; I just couldn't do it."

Eight of the 15 Ss said that stacking the 8 cubes was the hardest Eye-Hand Coordination task and during the tasks 8 of the 15 Ss felt mostly "frustrated." (These were not the same 8 who chose the block task as the hardest.) One admitted to not following instructions: "Tense and frustrated with blocks. Would catch myself doing things by touch, especially the pegs." (This S had the fastest time, most comparable to her Baseline speed.)

The experimenter asked regarding head movements, "What was the most difficult," and "How did you feel?" 7 of the 15 Ss said that the fast head movements (80 or 100 bpm) were the most difficult, disconcerting, or disorienting. Of those who found the fast head movements most difficult, some attributed the difficulty to dizziness, some to nausea, and one to dizziness and nausea. One S said: "Stopping the head movements helped as far as feeling sick but I was still nauseous." Another said: "I stopped focusing on head movements. I just went inside, stopped paying attention. Two or three times during head movements, I found myself watching, and it was kind of disorienting and confusing." (This S reported only #1 ratings [i.e., "I feel fine"] on all MSRS judgments considered in our analysis.)

Six of the 15 Ss said they felt maximal unsteadiness during the walking portion of the session. Even those who agreed, however, reported idiosyncratic perceptions.

Other factors reflected in the data are the degree of difficulty or frustration experienced, the order in which problems occurred, the immediate aftereffects of each task, and the manner in which each S reported himself/herself to be making attempts at adaptation. Clearly, additional analysis is desirable of our approximately 50 hours of VCR tapes and of notes the experimenter took during the sessions.

REFERENCES

Ambler, R.K., & Guedry, F.E., Jr. The validity of a brief vestibular disorientation test in screening pilot trainees. BuMed Project MR005.13-6001 Subtask 4, Report No. 122. Pensacola, Fla.: Naval School of Aviation Medicine, 1965.

Ambler, R.K., & Guedry, F.E., Jr. Validity of a brief vestibular disorientation test in screening pilot trainees. Aerospace Medicine, 1966, 37, 124-126.

American Psychological Association. Ethical Principles of Psychologists American Psychologist, 1981, 36[6], 633-638.

Basmajian, J.V., & Blumenstein, R. Electrode Placement in EMG Biofeedback Baltimore: The Wilkins & Wilkins Co., 1980.

Benfari, R.C. Perceptual Vertigo: A dimensional study. Perceptual Motor Skills, 1964, 18, 633-639.

Berry, C.A., & Homick, G.L. Findings on American astronauts bearing on the issue of artificial gravity for future manned space vehicles. Aerospace Medicine, 1973, 44, 163-168.

Bock, O.L., & Oman, C.M. Dynamics of subjective discomfort in motion sickness as measured with a magnitude estimation method. Aviation, Space, and Environmental Medicine, 1982, 53[8], 773-777.

Brown, G.G. Perception of depth with disoriented vision. British Journal of Psychology, 1928, 19, 117-146.

Clark, B., & Stewart, D. Vestibular and nonvestibular information in judgements of attitude and coriolis motion in a piloted flight simulator. Aerospace Medicine, 1967, 38, 936-940.

Clark, B., & Stewart, J.D. The relationship between motion sickness experience and tests of the perception of rotation in pilots and nonpilots. Aerospace Medicine, 1973, 44[4], 393-396.

Cohen, M.M. Disorienting effects of aircraft catapult launchings: II. Visual and postural contributions. Aviation, Space, and Environmental Medicine, 1976, 47, 39-41.

Cohen, M.M. Disorienting effects of aircraft catapult launchings: III. Cockpit displays and piloting performance. Aviation, Space, and Environmental Medicine, 1977, 48, 797-804.

Collins, W.E. Vestibular responses from skaters. Aerospace Medicine, 1966, 37, 1098.

Collins, W.E., Schroeder, D.J., & Elam, G.W. A comparison of some effects of three antimotion sickness drugs on nystagmic responses to angular accelerations and to optokinetic stimuli. Aviation, Space, and Environmental Medicine, 1982, 53[12], 1182-1189.

Cowings, P.S., & Toscano, W.B. The relationship of motion sickness susceptibility to learned autonomic control for symptom suppression. Aviation, Space, and Environmental Medicine, 1982, 53[6], 570-575.

Davies, P., & Melvill Jones, G. An adaptive neural model compatible with plastic changes induced in the human vestibulo-ocular reflex by prolonged optical reversal of vision. Brain Research, 1976, 103, 546-550.

Dichgans, J., & Brandt, T. Optokinetic motion sickness and pseudo-coriolis effects induced by moving visual stimuli. Acta Otolaryngologica, 1973, 76, 339-348.

Dix, M.R., & Hood, J.D. Observations upon the nervous mechanism of vestibular habituation. Acta Otolaryngologica, 1969, 67, 310-318.

Dolezal, H. Living in a world transformed: Perceptual and performatory adaptation to visual distortion. New York: Academic Press, 1982.

Dolezal, H. Living in a world transformed: Perceptual and performatory adaptation to visual distortion: Implications for space travel and sleep research. Paper presented at the Midwest Psychological Association Conference, Chicago, April 1983.

Dolezal, H., & Held, R. Two components of visually-induced tilt during rotary field motion. Paper presented at the meeting of the Eastern Psychological Association, New York, April, 1975.

Dowd, P.J. A useful test in selecting motion-sick-prone individuals. Space Life Sciences, 1973, 4, 391-401.

Duncker, K. Ueber induzierte Bewegung. Psychologische Forschung, 1929, 12, 180-259.

Ewert, P.H. A study of the effects of inverted retinal stimulation upon spatially coordinated behavior. Genetic Psychology Monographs, 1930, 7, 177-363.

Gibson, J.J. Visually controlled locomotion and visual orientation in animals. British Journal of Psychology, 1958, 49, 182-194.

Gibson, J.J. The senses considered as perceptual systems. Boston: Houghton Mifflin, 1966.

Gibson, J.J. On theories for visual space perception: A reply to Johansson. Scandinavian Journal of Psychology 1970, 2, 75-79.

Gibson, J.J. Outline of a theory of direct visual perception. In J.R. Royce & W.W. Rozeboom [Eds.], The psychology of Knowing. New York: Gordon & Breach, 1972.

Gibson, J.J. The ecological approach to visual perception. Boston: Houghton Mifflin, 1979.

Gonshor, A., & Melvill Jones, G. Changes of human vestibulo-ocular response induced by vision-reversal during head rotation. Journal of Physiology, 1973, 234, 102P-103P.

Gonshor, A., & Melvill Jones, G. Extreme vestibulo-ocular adaptation induced by prolonged optical reversal of vision. Journal of Physiology, 1976, 256, 381-414.

Graybiel, A. Vestibular sickness and some of its implications for space flight. In W.S. Fields & B.R. Alford [Eds.], Neurological aspects of auditory and vestibular disorders. Springfield, Illinois.: Thomas, 1964.

Graybiel, A. Prevention and treatment of space sickness in shuttle-orbiter missions. Aviation, Space, and Environmental Medicine, 1979, 50[2], 171-176.

Graybiel, A. Space motion sickness: Skylab revisited. Aviation, Space, and Environmental Medicine, 1980, 51[8], 814-822.

Graybiel, A., & Knepton, J. Sopite Syndrome: A sometimes sole manifestation of motion sickness. Aviation, Space, and Environmental Medicine, 1976. 47, 873-882.

Graybiel, A., & Lackner, J.R. Comparison of susceptibility to motion sickness during rotation at 30 rpm in the earth-horizontal, 10 deg. head-up, and 10 deg. head-down positions. Aviation, Space, and Environmental Medicine, 1977, 48, 7-11.

Graybiel, A., & Lackner, J. R. A sudden-stop vestibulovisual test for rapid assessment of motion sickness manifestations. Aviation, Space, and Environmental Medicine, 1980, 51[1], 21-23.

Graybiel, A., & Lackner, J.R. Motion sickness: Acquisition and retention of adaption affects compared in three motion environments. Aviation, Space, and Environmental Medicine, 1983, 54[4], 307-311.

Graybiel, A., Miller, E.F. II, & Homick, J.L. Experiment M131: Human vestibular function. In Proceedings of the skylab life sciences symposium, 1, 169-220. NASA TMX-58154, 1974.

Graybiel, A., & Miller, E.F. II. A z-axis recumbent rotating device for use in parabolic flight. Aviation, Space, and Environmental Medicine, 1976, 47, 893.

Grose, V.L. Deleterious effect on astronaut capability of vestibulo-ocular disturbance during spacecraft roll acceleration. Aerospace Medicine, 1967, 38, 1138-1144.

Guedry, F.E. Habituation to complex vestibular stimulation in man: Transfer and retention of effects from twelve days of rotation at 10 rpm. Perceptual and Motor Skills, 1965, 21, 459-481.

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

Guedry, F.E., Jr. Conflicting sensory orientation cues as a factor in motion sickness. In Fifth symposium on the role of the vestibular organs in space exploration, Pensacola, Fla., August 1970, [NASA SP-314], 45-51.

Guedry, F.E., Jr., & Benson, A.J. Coriolis cross-coupling effects: Disorienting and nauseogenic or not? Aviation, Space, and Environmental Medicine, 1978, 49[1], 29-35.

Guedry, F.E., Kennedy, R.S., Harris, C.S., & Graybiel, A. Human performance during two weeks in a room rotating at three rpm. Aerospace Medicine, 1964, 35, 1071-1082.

Homick, J.L. Space motion sickness. Acta Astronautica, 1979, 6, 1259-1272.

Homick, J.L. Validation of predictive test and countermeasures for space motion sickness. In S.L. Pool, Johnson, Jr., & J.A. Mason [Eds.], Shuttle OFT medical report: Summary of medical results from STS-1, STS-2, STS-3, and STS-4., NASA Technical Memorandum 58252. Houston, Texas: Lyndon B. Johnson Space Center, 1983, 11-15.

Howard, I.P. Orientation and motion in space. In E.C. Carterette & M.P. Friedman [Eds.], Handbook of Perception, [Vol.III]. New York: Academic Press, 1974.

Howard, I.P. Effects of exposure to spatially distorted stimuli. In R.D. Walk and H.L. Pick [Eds.], Perception and Experience. New York: Plenum, 1978.

Howard, I.P., & Templeton, W.B. Human spatial orientation. London: Wiley, 1966.

Johnson, W.H., & Jongkees, L.B.W. Motion sickness. In H.H. Kornhuber [Ed.], Handbook of Sensory Physiology [Vol. VI/2]. Berlin: Springer-Verlag, 1974.

Kohler, I. Ueber Aufbau und Wandlungen der Wahrnehmungswelt: Insbesondere Ueber Bedingte Empfindungen. Vienna: Rohrer, 1951.

Kohler, I. The formation and transformation of the perceptual world [H. Fiss, Trans.]. Psychological Issues, 1964, 3, 1-173, [Monograph].

Kottenhoff, H. Situational and personal influences on space perception with experimental spectacles. Acta Psychologica, 1957, 13, 19-97; 151-161.

Lackner, J.R. Influence of abnormal postural and sensory conditions on human sensorimotor localization. Environmental Biology and Medicine, 1976, 2, 139-177.

Lackner, J.R., & Graybiel, A. Variations in gravitoinertial force level affect the gain of the vestibulo-ocular reflex: Implications for the etiology of space motion sickness. Aviation, Space, and Environmental Medicine, 1981,52[3], 154-158.

Lackner, J.R., & Graybiel, A. Etiological factors in space motion sickness. Aviation, Space, and Environmental Medicine, 1983, 54[8], 675-681.

Lackner, J.R., & Teixeira, R.A. Optokinetic motion sickness: Continuous head movements attenuate the visual induction of apparent self-rotation and symptoms of motion sickness. Aviation, Space, and Environmental Medicine,1977, 48,[3], 248-253.

Lee, D.N. The functions of vision. In H.L. Pick, Jr. & E. Saltzman [Eds.], Modes of perceiving and processing information, Hillsdale, N.J.: Lawrence Erlbaum, 1978.

Leger, A., Money, K.E., Landolt, J.P., Cheung, B.S., & Rodden, B.E. Motion sickness caused by rotations about Earth-horizontal and Earth-vertical axes. Journal of Applied Physiology, 1981, 50[3], 469-477.

Levy, R., Jones, D.R., & Carlson, E.H. Biofeedback rehabilitation of airsick aircrew. Aviation, Space, and Environmental Medicine, 1981, 52[2], 118-121.

Melvill Jones, G. Origins, significance and amelioration of coriolis illusions from the semi-circular canals: A non-mathematical appraisal. Aerospace Medicine, 1970, 41, 483-490.

Melvill Jones, G. The vestibular system for eye movement control. In R.A. Monty & J.W. Senders [Eds.], Eye movements and psychological processes, Hillsdale, N.J.: Lawrence Erlbaum, 1976.

Melvill Jones, G., & Davies, P. Adaptation of cat vestibulo-ocular reflex to 200 days of optically reversed vision. Brain Research, 1976, 103, 551-554.

Melvill Jones, G., & Gonshor, A. Extreme vestibular habituation to long-term reversal of vision during natural head movements. Proceedings of the annual scientific meeting, Aerospace Medical Association, Bal Harbour, Fla., May, 1972.

Melvill Jones, G., & Gonshor, A. Goal-directed flexibility in the vestibulo-ocular reflex arc. In G. Lennerstrand & P. Bach-Y-Rita [Eds.], Basic mechanisms of ocular motility and their clinical implications. Oxford: Pergamon Press, 1975.

Miller, E.F. II, & Graybiel, A. A standardized laboratory means of determining susceptibility to coriolis [motion] sickness. BuMed Project MR005.04-0031-3, Pensacola, Fla.: Naval Aerospace Medical Institute, 1969.

Miller, E.F. II, & Graybiel, A. Comparison of five levels of motion sickness severity as the basis for grading susceptibility. BuMed MF12-524.005-5024B Pensacola, Fla.: Naval Aerospace Medical Institute, 1970. [a]

Miller, E.F. II, & Graybiel, A. A provocative test for grading susceptibility to motion sickness yielding a single numerical score. Acta Otolaryngologica, 1970, Supplement 274. [Appendix A]. [b]

Money, K.E., & Oman, C.L. Medical monitoring and therapy of space motion sickness. Published in Space 2000. Downsview, Ontario.: Defence and civil institute of environmental medicine, 1983, 311-326.

Moore, H.J., Lentz, J.M., & Guedry, F.E. Nauseogenic visual-vestibular interaction in a visual search task, BuMed MF51.524.004-5001 Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1977.

Osterhammel, P., Terkildsen, K., & Zilstorff, K. Vestibular habituation in ballet dancers. Advances in Oto-Rhino-Laryngology, 1970, 17, 158-166.

Parker, D.M. A psychological test for motion sickness susceptibility. Journal of General Psychology, 1971, 85, 87-92.

Peterson, J., & Peterson, J.K. Does practice with inverting lenses make vision normal? Psychological Monographs, 1938, 50, [whole No. 225].

Pitblado, C., & Mirabile, C.S., Jr. Relationship between visual orientation and susceptibility to motion sickness. Perceptual and Motor Skills, 1977, 44, 267-273.

Pitman, J.R., & Yolton, R.L. Etiology and treatment of motion sickness: A review. American Optometric Association Journal, 1983, 54[1], 31-38.

Potvin, A.R., Sadoff, M., & Billingham, J. Motion sickness and otolith sensitivity: A pilot study of habituation to linear acceleration. Aviation, Space, and Environmental Medicine, 1977, 48, 1068-1075.

Reason, J.T. Man in motion: The Psychology of Travel. New York: Walker and Company, 1974.

Reason, J.T. Motion sickness adaptation: A neural mismatch model. *Journal of the Royal Society of Medicine*, 1978, *71*, 819-829. [a]

Reason, J. T. Motion sickness: Some theoretical and practical considerations. *Applied Ergonomics*, 1978, *9.3*, 163-167. [b]

Reason, J.T., & Brandt, J.J. *Motion Sickness*. New York: Academic Press, 1975.

Richards, W. Visual space perception in E.C. Carterette & M.P. Friedman [Eds.], *Handbook of perception* [Vol. V]. New York: Academic Press, 1975.

Rock, I. *The nature of perceptual adaptation*. New York: Basic Books, 1966.

Rock, I. *An introduction to perception*. New York: Macmillan, 1975.

Ryan, T.A., & Ryan, M.S. Geographical orientation. *American Journal of Psychology*, 1940, *53*, 204-215.

Ryback, R.S., Rudo, R.E., Matz, G.J., & Jennings, C.L. Motion sickness in USAF flying personnel. *Aerospace Medicine*, 1970, *41*, 672-677.

Sandstroem, C.I. *Orientation in the present space*. Stockholm: Almquist & Wiksell, 1951.

Schilder, P. *The image and appearance of the human body*. London: Kegan Paul, 1935.

Shebilske, W.L. Visuomotor coordination in visual direction and position constancies. In W. Epstein [Ed.], *Stability and constancy in visual perception: Mechanisms and processes*. New York: Wiley, 1977.

Sjoberg, A. Experimental studies of the eliciting mechanism of motion sickness. In *Fourth symposium on the role of vestibular organs in space exploration* [NASA SP-187]. Washington, D.C.: National Aeronautics and Space Administration, 1970.

Smith, D.E. A statistical examination of three approaches for predicting motion sickness incidence. *Aviation, Space, and Environmental Medicine*, 1982, *53* [2], 162-165.

Snyder, F.W., & Pronko, N.H. *Vision with Spatial Inversion*. Wichita: University of Wichita Press, 1952.

Spector, M., [Ed]. *Dizziness and vertigo: Diagnosis and Treatment*. New York: Grune and Stratton, 1974.

Steele, J.E. *The symptomatology of motion sickness* [AMRL-TR-70-86]. Wright Patterson AFB, OH: Aerospace Medical Research Lab, 1968. [AD 755 343].

Stratton, G.M. Some preliminary experiments in vision without inversion of the retinal image. Psychological Review, 1896, 3, 611-617.

Stratton, G.M. Upright vision and the retinal image. Psychological Review, 1897, 4, 182-187. [a]

Stratton, G.M. Vision without inversion of the retinal image. Psychological Review, 1897, 4, 341-360, 463-481. [b]

Toscano, W.B., & Cowings, P.S. Reducing motion sickness: A comparison of autogenic-feedback training and an alternative cognitive task. Aviation, Space, and Environmental Medicine, 1982, 53[5], 449-453.

Tschiassny, K. Perrotatory nystagmus in the ballet dancer, pigeon, and blind person. Annals of Otology, 1957, 66, 641.

Wallach, H., & Floor, L. On the relation of adaptation to field displacement during head movements to the constancy of visual direction. Perception and Psychophysics, 1970, 8, 95-98.

Wallach, H., & Frey, K.J. Adaptation in the constancy of visual direction measured by a one-trial method. Perception & Psychophysics, 1969, 5, 249-252.

Wallach, H., & Frey, K.J. Adaptation in distance perception based on oculomotor cues. Perception & Psychophysics, 1972, 11, 77-83.

Wallach, H., Frey, K.J., & Romney, G. Adaptation to field displacement during movement unrelated to the constancy of visual direction. Perception & Psychophysics, 1969, 5, 253-256.

Wallach, H., & Kravitz, J.H. The measurement of the constancy of visual direction and of its adaptation. Psychonomic Science, 1965, 2, 217-218.[a]

Wallach, H., & Kravitz, J.H. Rapid adaptation in the constancy of visual direction with active and passive rotation. Psychonomic Science, 1965, 3, 165-166. [b]

Wallach, H., & Kravitz, J. Adaptation in the constancy of visual direc on tested by measuring the constancy of auditory direction. Percepti 1 & Psychophysics, 1968, 4, 299-303.

Welch, R.B. Perceptual modification: Adapting to altered sensory environments. New York: Academic Press, 1978.

Wong, S.C., & Frost, B.J. The effect of visual-vestibular conflict on the latency of steady-state visually induced subjective rotation. Perception & Psycophysics, 1981, 30[3], 228-236.

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