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Reducing Symptoms of Visually Induced Motion Sickness Through Perceptual Training

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This study examined the effect of adaptation training on simulation sickness. Ten control group participants completed a single self-propelled rotation simulation (SRS) trial and then were exposed to a virtual reality (VR) device and an optokinetic rotating drum (OKN). Ten experimental group participants were exposed to 5 trials over 5 days of the SRS and then to the VR and OKN devices. All 3 of these types of exposures (SRS, VR, and OKN) are known to produce conditions of simulation sickness. The results showed a significant main effect of adaptation training as a function of prior SRS exposure. These findings demonstrate the feasibility of developing a transfer of training paradigm for the acquisition of adaptation from one motion sickness producing condition to another.

A vexing problem within the medical life sciences is the space adaptation syndrome, which is reported to afflict about half of all space shuttle astronauts and mission specialists (Homick, Reschke, & Vanderploeg, 1984; Ishii, 1993; Nguyen, 1996; Reschke, Homick, Ryan, & Mosely, 1984; Thornton, Pool, Moore, & Vanderploeg, 1987). The symptoms of this syndrome resemble those found with other forms of motion sickness (Money, Watt, & Oman, 1984), particularly those reported in visual rearrangement studies (Kottenhoff, 1957; Welch, 1978, 2000), and in ground-based flight simulators (Kennedy, Lilienthal, Dutton, Ricard, & Frank, 1984). This article focuses on preadapting astronauts to the visual and ves-

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tibular conflicts they will be exposed to before embarkation to immunize them against experiencing the space adaptation syndrome while in flight.

Continued exposure in motion-sickness-producing environments usually results in a lessening of the symptoms. It has been suggested that the process of overcoming motion sickness has much in common with adaptation to optically induced distortions of the visual field (Cohen, 1977; Jones & Gonshor, 1972; Welch, 1978). For example, when observers wear goggles containing wedge prisms or mirrors that displace the visual field to one side or reverse it, and then interact actively in their environment, visual-motor errors decline and behavior soon becomes normal. The basis for this adaptation is a resolution of the imposed conflict between vision and proprioception-kinesthesis so that touch conforms to vision. Likewise, virtually all space travelers adapt to the conditions that produce motion sickness *during* the flight, although this adaptation may not be completed for several days (Ishii, 1993; Reschke et al., 1984; Welch, 2000).

A number of studies have demonstrated a close relation between adaptation to perceptual rearrangement and traditional situational learning (Welch, 1978). Of present interest is the evidence concerning the degree to which adaptation (a) exhibits transfer to new situations (stimulus and response generalization); (b) is retained for relatively long periods of time; (c) reveals “savings” on subsequent “relearning” sessions; (d) is subject to discriminative conditioning; and (e) can be maintained for two (or more) different distorted environments at the same time. Although the adaptive responses measured in these studies may not be identical to those occurring in space adaptation syndrome, it is felt that the research discussed in this section will suggest the issues, kinds of tasks, training regimes, and measures that will prove useful in providing astronauts and other space travelers with some degree of generalized “inoculation” against the perceptual and perceptual-motor disruptions caused by the environment of micro- and macrogravity to which they are exposed.

Traditional studies of adaptation to perceptual rearrangement have used tasks that are rather similar, if not identical, to those practiced during the adaptation period (Welch, 1978). Consequently, little is known about the degree to which adaptation might transfer to tasks that are very different from those encountered during adaptation. Likewise, there is scant information concerning whether one’s adaptation to one form of perceptual rearrangement will either transfer to or predict one’s adaptability to another form of rearrangement.

Regarding the first of these two aspects of generalization, Kinney, McKay, Luria, and Gratto (1970), using prismatic displacement, combined three exposure activities with the same three tasks used as pre- and posttests of adaptation. The tasks were (a) placing a small chess piece marker on a square within a checkerboard grid, (b) reaching under a transparent table for a target, and (c) rapidly spearing a bull’s-eye with a wooden dowel. Every participant was measured on all three tasks during the pre- and post-exposure periods, but engaged in only one of them during 5 min of prismatic exposure. The greatest amount of adaptation (about 65% of the total possible compensation) occurred for the trained task. The nontrained tasks for a given exposure condition revealed generalized adaptation, but with some decrement.

Redding (1973a, 1973b, 1975a, 1975b) examined the second issue of generalization: whether adaptation to one form of distortion will influence adaptation to another form. He found that when participants were confronted (in a single session) with a visual field that was, simultaneously, prismatically displaced and tilted, adaptation to each of these distortions occurred at the same rate as when participants were adapted to each separately. Furthermore, the magnitude of participants' adaptation to one distortion was not correlated with the magnitude of their adaptation to the other. Thus, it would appear that displacement and tilt adaptation are independent processes that do not transfer to one another. Because the perception of visual location and orientation may be based on qualitatively different processes, the preceding failure of transfer may not be too surprising. Alternatively, perhaps for transfer to occur from one type of adaptation to another it is necessary to implement a much more extensive training regime on each, perhaps alternating between the two types of distortion.

Jell, Ireland, and LaFortune (1985) reported a reduction in human optokinetic after nystagmus in one direction or another, depending on the exposure history of the individual. It is well known that optokinetic after nystagmus can be reduced due to damage or destruction of the labyrinth and by lesions in parts of the parahypoglossal nuclei or pretectum. The Jell et al. study also revealed changes, but the authors did not comment on whether this change was due to lowered arousal or mere drop-off in the values of cumulative eye displacement, duration, or slow phase nystagmus. The authors concluded that this is simple habituation and used cumulative displacement as their most sensitive parameter.

In a study by Kennedy, Berbaum, Williams, Brannan, and Welch (1987), study participants were adapted to Purkinje stimulation (Benson & Bodin, 1966) involving approximately 0.5 min of bodily rotation, followed by a head turn about an axis orthogonal to that of the preceding rotation. This situation produces dizziness, illusory visual motion, and difficulty walking. The experience is similar to the effects of Coriolis stimulation, except that with the latter the head movements take place during rotation rather than afterward. It was first hypothesized that repeated exposure would cause a decline in the experience of the effects from the Purkinje stimulation. The question was then to see whether this adaptation would transfer to a situation of so-called pseudo-Coriolis stimulation (Dichgans & Brandt, 1973) in which, instead of the participant being rotated, the surrounding visual field is turned and the participant moves his or her head.

The Kennedy et al. (1987) study was designed to evaluate whether adaptation acquired in one stimulus condition involving unusual vestibular stimulation would transfer to another condition where similar, but not identical, conflicting inputs were presented. The amount of transfer was significant, and somewhat unexpected, because in previous studies the hallmark had been the specificity of adaptation (Guedry, 1965). The training condition entailed bizarre stimulation of the cupula endolymph system from the postrotatory effects (the Purkinje stimulus). The adaptation to this bizarre stimulation transferred to a condition in which the stimuli to the canals and otoliths are the same as would occur with no physical rotation present. This implies that the transferred adaptation was not merely some form of suppression or fatigue at the sensory level, but a higher order modification within the central nervous system. Possibly this is the source of its generalizability.

Dobie, May, Gutierrez, and Heller (1990) successfully replicated the Kennedy study where they found that participants exposed to bodily rotation exhibited increased tolerance to visually induced self-vection (VISV). However, exposure to VISV did not result in greater tolerance to bodily rotation. Harm and Parker (1994) examined the relation between perceptual reports obtained during a space mission and in preflight adaptation trainer (PAT) devices. Perceptual reports from the astronauts indicated that the PAT device had features similar to those encountered in microgravity. The reports also suggested that these similarities reduced some of the symptoms of space motion sickness during space flight. More recently Welch, Bridgeman, Williams, and Semmler (1998) examined the possibility that the human vestibulo-ocular reflex (VOR) is subject to dual adaptation (the ability to adapt more completely after repeated exposure to sensory rearrangement), and adaptive generalization (the ability to adapt more easily to new sensory rearrangement because of prior dual adaptation training). These researchers showed both adaptation and dual adaptation of the VOR, but no adaptive generalization when tested with a target/head gain of 1.0 (gain is a ratio of the movement of the target to the movement of the head in degrees). Thus, there is little research on the generalizability of adaptation to perceptual rearrangement as it applies to space motion sickness. More studies are needed on this issue, particularly (given the present concern) with both short- and long-term generalization.

Because there is a crucial need to systematically address factors that may help in overcoming motion sickness when one is subjected to unusual gravitational forces, this study was designed to empirically examine the effect of adaptation training in the form of *simulated rotary stimulation* (SRS) on visually induced motion sickness. It was hypothesized that repeated exposure to SRS would lead to reduced levels of dizziness and simulation sickness in both the virtual reality (VR) and optokinetic rotating drum (OKN) environments.

APPLICATION

Space adaptation syndrome develops in conditions in which nauseogenic stimuli are present for a long period. The perceptual situation of an astronaut or pilot exposed to unusual gravitational and inertial forces for some period of time has been compared in many ways to that found in experiments involving perceptual rearrangement, such as optically induced displacement, curvature, tilt, or right–left reversal (Welch, 1978, 2000). In both instances, the observer is confronted with a variety of inter- and intrasensory conflicts that initially disrupt perception and behavior and may cause nausea (Dolezal, 1982). Likewise, in both situations people reveal an ability to adapt to these imposed conflicts, as manifested in a reduction or elimination of the initial disruptive responses. Thus, overcoming motion sickness, correcting performance, and regaining normal perception when one is subjected to unusual gravitational forces may involve many of the same processes as adaptation to perceptual rearrangement in general. The similarity between the processes of overcoming space adaptation syndrome and experimentally imposed perceptual rearrangement provides the motivation for this research. Findings from such research could demonstrate the feasibility of developing a transfer of training technique for the acquisition of adaptation from one motion-sickness-producing condition to another. Developing techniques for mitigating sickness through preadaptation has major practical implications for business, industry, the military and private sectors, and anywhere else motion sickness symptoms impact performance.

METHOD

Participants

Twenty adults (10 men and 10 women) ranging in age from 18 to 34 were selected for this study. Participants were recruited from the University of Central Florida as well as a temporary employment agency located in Orlando, Florida. All participants were screened for visual and vestibular symptoms and were paid for their participation. All 20 participants were equally divided (10 participants per group) and randomly assigned by gender to be in either an experimental or a control group. Experimental protocols were approved or specially convened for human use approval committees using national and international guidelines. Four participants were dropped from the study because of either quitting after experiencing severe motion sickness symptoms or failing to report any dizziness levels at all. Previous research indicates that between 30% and 70% of participants report being asymptomatic in flight simulators (Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1989). The data from these 4 participants were not included in the final analyses.

Test Apparatus

SRS. In the SRS, participants were asked to raise their right hands above their heads and grasp their right earlobe with their left hand, bend at the waist, and spin in a clockwise direction under self-propelled condition. The participants spun 10 times in 30 sec (20 RPMs) and this constituted a trial. One or more monitors were always available to support unsteady performers. After standing, they were asked to rate their dizziness and walk a 7-ft line on the floor. Each participant was asked to walk "heel-to-toe" consistently and rhythmically for a maximum of seven steps. The number of consistent and rhythmic steps taken by the participant, while maintaining forward motion, was counted by two observers. Once there was any departure from maintaining forward progress by the participant putting his or her foot to the side (as opposed to straight in front of the other foot), halting, or losing balance, the number of steps taken was recorded.

Virtual reality device. The virtual world used in this study consisted of an environment filmed within an OKN drum. The video output from the VCR played a "cloud" videotape that was fed into a Pentium-based PC with a TV-capable video card. The cloud videotape displayed visual scenes that were used in a previous vection-induced sickness experiment (Kennedy, Stanney, & Rolland, 2001). The video was then output to a helmet-mounted display (HMD) for the participant to view. The video was directed to the PC instead of directly to the HMD to allow modification or perturbation of the visual scene. The software was developed so that field of view, resolution, lag, asynchronies, and various other factors can be introduced or modified by the computer during the course of directing the video feed from the VCR to the HMD. A Virtual Research V6 was used as the HMD to display the virtual environment. None of this equipment was hazardous. The VR exposure lasted for approximately 20 min, during which time the participants were asked to perform 10 trials of head rotation where they rotated their head in a 120° arc 10 times. After each trial the participant was asked to rate his or her dizziness on a 1 to 10 magnitude scale. This was done in both the clockwise and counterclockwise directions. While engaged in the VR, research participants were seated in a swivel chair. During immersion, lights were dimmed to reduce glare and reflections within the HMD.

OKN drum. This device consisted of a cylindrical vection drum 7.0 ft (2.7 m) in diameter and 6 ft (1.85 m) high (cf. Kennedy, Hettinger, Harm, Ordy, & Dunlap, 1996, for a description). The drum was suspended from the ceiling such that the open ends were parallel to the ceiling and floor. On the inside surface of the drum were wallpapered clouds. During the session, the participant was asked, when experiencing vection, to tilt his or her head at a 45° angle to the left and right. At each point, the participant was asked to rate dizziness. This was done for eight trials in each direction (clockwise and counterclockwise). The bottom end of the drum was approximately 2.5 ft (0.77 m) from the floor. The drum was driven by a high-torque, variable-speed DC motor with a gear reduction; the movement was extremely quiet and did not change appreciably with different (< 1%) velocities. An adjustable chair was located in the middle of a platform mounted inside the drum that was elevated approximately 1 ft (0.31 m) from the floor. Height adjustments were made while participants were seated to ensure that the center of the drum radius passed through the vertical midpoint of the participant's line of sight and that eye level was midway between the vertical dimensions of the drum. Attached to the chair was a hand-held switch that participants used to indicate the onset and termination of circular vection (CV), defined as the sensation of self-motion in a circular direction about the body's vertical axis.

Motion Sickness History Questionnaire (MHQ). This paper-and-pencil questionnaire permits individuals to list past experience in provocative motion environments and their history of motion sickness. Scores on the MHQ are generally predictive of an individual's susceptibility to motion sickness (Kennedy, Fowlkes, Berbaum, & Lilienthal, 1992). Participants were asked to complete this questionnaire before they began virtual reality exposure. Participants who evidenced extreme past histories of motion sickness were excused from the experiment and were compensated for a minimum of 1 hr of participation.

Simulator Sickness Questionnaire (SSQ). The SSQ is a self-report checklist consisting of 27 symptoms that are rated by the participant in terms of degree of severity on a 4-point Likert-type scale (Kennedy, Lane, Berbaum, & Lilienthal, 1993) where 0 indicates no symptoms, 1 indicates slight symptoms, 2 indicates moderate symptoms and 4 indicates severe symptoms. Participants were asked to complete an SSQ before the exposure to the VR device. Participants who evidenced high preexposure scores (i.e., obtained a total SSQ score higher than 7.5) were excused from the experiment and were compensated for a minimum of 1 hr of participation. The score of 7.5 was based on a number of studies conducted while developing, validating, and using the SSQ over a number of years (e.g., Kennedy, Drexler, Stanney, & Harm, 1997; Kennedy et al., 1993).

The SSQ was also administered following VR exposure and following OKN drum exposure. In addition to a total SSQ score, the SSQ has three subscales (SSQ Nausea, SSQ Disorientation, and SSQ Oculomotor). Thousands of participants have been tested using this questionnaire and normative data are available for different represented devices and conditions (Kennedy et al., 1997).

Procedure

When participants first arrived for the experimental session, they read and signed an informed consent form. Participants were informed that all records of their participation and their performance would be held in strict confidentiality, that the data files and analyses would be anonymous, and that no individual data would be reported. Participants were informed that the data would not be used for any purpose other than the scientific goals of the experiment, and that participation in the study was voluntary and that they could withdraw from the study at any time if they chose to without penalty.

Following completion of the informed consent, each participant was given three questionnaires to evaluate his or her eligibility to participate in the research: (a) the Research Participant Information Questionnaire, (b) SSQ, and (c) MHQ.

For the experimental group, the study was conducted in five sessions over 5 days. The control group, on the other hand, only participated on 1 day. On the first 4 days, participants in the experimental group experienced five trials of the SRS that lasted for about 2 hr. In the fifth session on the final day (the only day in the control case), control and experimental participants were exposed to the VR and to pseudo-Coriolis in the OKN rotating drum. (Control participants experienced one SRS prior to that to establish their baseline.) Following each task in the study (SRS, VR, and OKN Drum) the participants were given 1 hr of posttesting (SSQ) at 0, 30-, and 60-min intervals.

On Day 5 for the experimental group and the only day for controls, participants were exposed to the VR device. The VR exposure lasted for approximately 20 min during which time the participants were asked to perform 10 trials of head rotation where they rotated their heads in a 120° arc 10 times. After each trial, each participant was asked to rate his or her dizziness level on a 1 to 10 magnitude estimation scale. This was done in both the clockwise and counter clockwise directions. While engaged in the VR, research participants were seated in a swivel chair. During immersion, lights were dimmed to reduce glare and reflections within the HMD.

After participants exited the virtual environment, they were asked to complete the post-SSQ. Participants were required to remain at the test site for at least 60 min following the VR exposure to ensure that any effects experienced because of the exposure have dissipated. During this time, the SSQ was administered at 15-min intervals. Additionally, participants were asked about their physical condition. Participants were required to stay at the experimental site until adverse feelings subsided. Before being permitted to leave the experimental site, participants could not be experiencing any characteristic symptoms of motion sickness (reported on the post-SSQ).

In the final session, participants from both groups were asked to enter the OKN drum and be seated facing forward. They were then instructed on how and when to use the response key in the drum. Participants were then asked to close their eyes until the experiment began. The participants were then told to open their eyes and gaze directly at the rotating inner surface of the drum until a perception of circular self-motion (CV) was experienced. Once CV was experienced, participants signaled its presence by pressing the hand-held button. Next, while the drum continued to turn, participants were asked to tilt their head 45° toward the left shoulder and to rate their dizziness level on a scale. This pseudo-Coriolis stimulation has been shown to induce motion sickness (Dichgans & Brandt, 1973). Each participant then turned his or her head upright and made another rating. This procedure was repeated for the right shoulder and again upright before the drum was stopped (total time was about 2 min). The drum rotated at a velocity of 120°/sec, a rate known to produce substantial pseudo-Coriolis experience at a 1-sec head tilt to 45° and then 45° return to upright in 1 sec. This procedure allowed the repetition, in a 30-min session, of this sequence enough times so that adaptation ensued without losing a substantial number of participants due to emesis.

After participants exited the OKN drum, they were asked to complete the post-SSQ. Participants were required to remain at the test site for at least 60 min following the OKN drum exposure to ensure that any effects experienced because of the exposure had dissipated. During this time, the SSQ was administered at 15-min intervals. Participants were required to stay at the experimental site until adverse feelings subsided. Before being permitted to leave the experimental site, participants could not be experiencing any characteristic symptoms of motion sickness (reported on the post-SSQ).

RESULTS

A series of multivariate analyses of variance (MANOVAs) were conducted to assess the effects of preadaptation training (SRS) on each of the dependent variables. These dependent variables included scores on: (a) perception of dizziness, (b) the SSQ total scores, (c) SSQ Nausea, (d) SSQ Disorientation, and (e) SSQ Oculomotor.

Effect of Preadaptation Training on Virtual Reality Exposure

The analysis showed a significant main effect of adaptation training on VR exposure expressed in terms of dizziness ratings, $F(1, 14) = 7.50$, $p < .05$. This significance indicates that the experimental group who had the training with SRS reported lower rates of dizziness ($M = 1.41$, $SD = 1.35$) than the control group who did not experience SRS ($M = 3.79$, $SD = 2.14$). As Table 1 shows, the mean of the dizziness rates was higher among the control group than the experimental group showing transfer of adaptation into the VR condition as a function of prior simulated self-propelled rotary stimulation exposure.

The analysis also showed the same effect of adaptation training on VR as reported in the SSQ (SSQ total score) following VR exposure, $F(1, 14) = 7.64$, $p < .05$. As Table 1 shows, higher simulation sickness ratings were reported by the control group ($M = 44.25$, $SD = 37.87$) compared with the experimental group ($M = 9.72$, $SD = 10.61$) and these values compare favorably to scores from participants exposed to space and sea sickness where similar high values are obtained. The experimental group in this study exhibited scores that resemble or are lower than the scores of experimental pilots when exposed to flight simulation and control participants exhibited higher scores than that group.

SSQ Subscale Analyses

A series of separate MANOVAs were also computed for each of the nausea, disorientation, and oculomotor ratings. The adaptation effect on disorientation, $F(1, 14) = 5.90$, $p < .05$, and oculomotor, $F(1, 14) = 9.45$, $p < .01$, were both significant. There were higher ratings of disorientation among the control group ($M = 53.50$, $SD = 60.6$) than the experimental group ($M = 7.00$, $SD = 9.9$). Similarly, the control group participants reported higher oculomotor rating ($M = 36.66$, $SD = 24.34$) than the experimental group ($M = 8.50$, $SD = 12.66$). This indicates that the participants who were exposed to SRS had reported less disorientation and oculomotor ratings immediately following the VR exposure.

Effect of Preadaptation Training on Vection Drum Exposure

The MANOVA showed a significant effect of adaptation training on vection drum exposure, $F(1, 14) = 6.63$, $p < .05$, indicating that the experimental group who had prior training with SRS and VR exposure reported lower rates of dizziness ($M =$

TABLE 1
Means, Standard Errors, and Significance Levels
of All Dependent Variables

Dependent Variable	*M*	*SE*	*Significance Level*
Dizziness post-VR	Exp = 1.41	0.42	$p < .05$
	Control = 3.78	0.87	
SSQ total post-VR	Exp = 9.72	3.36	$p < .05$
	Control = 44.25	15.46	
Disorientation score	Exp = 7.0	0.96	$p < .05$
Post-VR	Control = 53.3	24.73	
Oculomotor score	Exp = 8.5	4.00	$p < .01$
Post-VR	Control = 36.66	9.93	
Dizziness post-OKN	Exp = 1.63	0.47	$p < .05$
	Control = 3.92	0.85	
SSQ total post OKN	Exp = 17.2	4.44	$p < .05$
	Control = 61.71	23.49	
Disorientation score	Exp = 18.20	6.28	$p < .05$
Post-OKN	Control = 79	36.4	
Oculomotor score	Exp = 11.5	2.59	$p < .05$
Post-OKN	Control = 56.883	17.29	

Note. VR = virtual reality; SSQ = Simulator Sickness Questionnaire; OKN = optokinetic rotating drum.

1.63, $SD = 1.47$) than the control group who did not experience SRS and VR exposure ($M = 3.92$, $SD = 2.09$. As Table 1 shows, the mean of the dizziness rates was higher among the control group than the experimental group showing adaptation in the vection drum (OKN) condition as a function of simulated rotary stimulation and VR exposure.

Similarly, a MANOVA yielded a significant effect of adaptation training on simulation sickness (SSQ total score) following the vection (OKN) drum exposure. Higher simulation sickness ratings were reported by the control ($M = 61.71$, $SD = 7.54$) than the experimental ($M = 17.20$, SD = 14.02) group.

SSQ Subscale Analyses

Another set of MANOVAs was also computed for each of the nausea, disorientation, and oculomotor ratings following the vection drum (OKN) exposure. The adaptation effect on disorientation, $F(1, 14) = 4.47$, $p < .05$, and oculomotor, $F(1, 14) = 11.27$, $p < .01$, were both significant. As Table 1 shows, there were higher ratings of disorientation among the control group ($M = 79.00$, $SD = 89.22$) than the experimental condition ($M = 18.20$, $SD = 19.85$). Similarly, the control group participants reported higher oculomotor rating ($M = 56.83$, $SD = 42.35$) than the experimental group ($M = 11.50$, $SD = 8.18$). This indicates that the participants who were exposed to SRS and VR exposure had reported less disorientation and oculomotor ratings immediately following the vection drum exposure.

DISCUSSION

The findings reported here indicate that adaptation to sensory rearrangement in the form of training with SRS can be obtained for both virtual and vection drum environments. These findings are consistent with previous findings by Kennedy et al. (1987), who similarly reported that prior adaptation to rotary simulated or Purkinje stimulation transferred to pseudo-Coriolis as was demonstrated by the large difference in reported dizziness between the control and experimental conditions. In this study, Kennedy and his associates used only a self propelled turning test and transferred to a vection drum condition. These findings suggest that training in the form of simulated self-propelled rotary stimulation and virtual environment exposure helps reduce the level of sensory rearrangement found or experienced in certain simulation-sickness-related tasks and are consistent with the predictions made by Watt (1996).

Unlike previous findings by Guedry (1965), this study reconfirmed our previous findings that the adaptation transfer is not task specific and could be extended to tasks that are not identical. Moreover, these findings are also consistent with previous results by Dobie et al. (1990), who reported increased tolerance to VISV as a function of bodily rotation exposure. Although it is clear from these findings that exposure to bodily rotation is beneficial for reducing motion-related dizziness symptoms, it is not well understood whether this adaptation phenomenon can manifest itself in both directions. Previous studies have not extensively studied the double-direction effect of perceptual learning and adaptation in distorted environments. One reason may be that there is more “reafference” (von Holst, 1954), in the self- propelled condition and less in the more passive VR and vection conditions. This difference should be examined in future research. Understanding these issues will help alleviate the space adaptation syndrome.

Similarly, this study partially supports the results by Harm and Parker (1994) and Welch et al. (1998), who previously reported both adaptation and dual adaptation of the VOR, but failed to obtain adaptive generalization. Our findings suggest that the transferred adaptation may be a higher order modification within the central nervous system, which in turn may account for its generalizability. The results also point to the need to further examine individual differences in the rate of adaptation. Some people may be more prone to simulation sickness than others, and therefore, identifying the traits for “adaptability” would have several practical implications for space adaptation syndrome and other situations entailing perceptual adjustment. Notably, an adaptation training program in the form of virtual environment or vection drum may help alleviate the motion sickness found in other visual-vestibular conflict environments. For example, Vanderploeg, Stewart, and Davis (1985) previously reported that of the 22 space travelers who have had an opportunity for more than one flight, 11 were sick in various degrees on their first flight and 11 were not, and the 11 who were sick on their first flight subsequently were symptom-free on their second exposure. These findings clearly indicate the need for preadaptation training of those who are prone to simulation sickness-type symptoms for a variety of applications including NASA astronauts.

In summary, the results showed that preadaptation training in the form of simulated rotary Purkinje stimulation produce reduced levels of simulation sickness in both the virtual and vection drum environments. The significant differences in dizziness, nausea, oculomotor, and other related simulation sickness symptoms found between the control and experimental groups are a clear indication of perceptual adaptation. These results are consistent with the relatively enduring adaptation to prism-displaced vision demonstrated even months after the initial prism exposure. It is not well understood whether the adaptation training can be sustained and maintained over a prolonged period of time. In addition, the transfer of adaptation from one situation of visual-vestibular conflict to another situation warrants further investigation.

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