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Motion Sickness Prevention by Stroboscopic Environment during Simulated Military Transport

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14. ABSTRACT

Previous studies have shown stroboscopic illumination to reduce the severity of motion sickness symptoms when retinal slip is a significant factor. The present study assessed the use of a 4 and an 8 Hz stroboscopic environment as a countermeasure for visually-induced motion sickness. The motion profiles of an Army UH-60 Black Hawk helicopter and a Marine AAVC7A1 Amphibious Assault Vehicle were produced using the U.S. Army Aeromedical Research Laboratory's Multi Axis Ride Simulator. Participants who experienced the UH-60 motion profile subjectively reported the 8 Hz condition as significantly more effective in controlling motion sickness symptoms than the 4 Hz condition. In addition, the same participants reported a greater mean number of motion sickness symptoms (regardless of severity) after the no strobe condition than the 8 Hz condition; however this difference was not significant. Although there was no conclusive evidence of stroboscopic illumination as a motion sickness countermeasure in the objective performance measures, there was evidence of its effectiveness in subjective reports.

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Introduction

Dizziness, nausea, vomiting, drowsiness, pallor, sweating, and overall malaise that are triggered by travel in a boat, car, train, or plane all fall into the category of motion sickness (Lawther & Griffin, 1988; Griffin & Mills, 2002a, 2002b; Howarth & Griffin, 2003). Motion sickness has been well known for thousands of years. Ancient seafaring nations were very familiar with this malady. Motion sickness has become increasingly prevalent in the modern world with the development of many forms of vehicular travel. The syndrome appears to arise from a disturbance in the vestibular apparatus, organs used to maintain balance and sense orientation and movement. The most widely accepted theory concerning the cause of motion sickness focuses on sensory mismatch between the visual and vestibular systems (Eyeson-Annan et al., 1996). For example, passengers on cruise ships are far more likely to get seasick when below deck because their vestibular apparatus detects motion while their visual system does not (Gordon et al., 1994). Standard advice for such seasickness is to go up on deck where vestibular and visual inputs agree. Similarly, studies have shown that children are less likely to become car sick when elevated in a seat that provides a good outside view (Fischer, 1998).

Evidence of current problems has been well documented. Rickert (2000) found that 74% of the Marines being transported in an amphibious assault vehicle reported moderate to severe motion sickness symptoms after working at computer work stations. Cowings et al. (1999) examined Soldier health and performance in a command and control vehicle (C2V) in an operational environment and found motion sickness was reported by 100% of the subjects with 55% indicating moderate to severe symptoms. The authors also report that 15% of the participants experienced vomiting and that drowsiness was the most frequently reported symptom. These undesirable effects were comparable to blood alcohol equivalencies at or above 0.08% in 35% of the Soldiers during movement and 22% during short halts.

Airsickness can be more problematic than motion sickness occurring on the ground. An outside view doesn't necessarily help in aviation, because flight constantly presents sensory conflicts. During a coordinated turn, for example, the visual scene is that of a tilted horizon while the vestibular sense indicates a perfectly upright position. Uncoordinated maneuvers and turbulence provide even more complex conflicts. In a cloud, many vestibular sensations may be received while the visual system reports a featureless, horizonless void. Passengers are far more prone to motion sickness than are pilots (DeHart & Davis, 2002). This is not surprising considering that motion sickness is often triggered by discrepancies between anticipated orientation and actual orientation. For pilots at the aircraft controls, knowledge of upcoming flight movements seems to offer some protection against acquiring the symptoms of airsickness as compared to passengers and crewmembers (DeHart & Davis).

Treatment of motion sickness

Nausea and vomiting (Stern, 2002) are the most common complaints of motion sickness and are mediated by central neurotransmitters. In response to visual and vestibular input, increased levels of dopamine stimulate the medulla oblongata's chemoreceptor trigger zone, which in turn stimulates the vomiting center within the reticular formation of the brain stem. The vomiting

center also is directly stimulated by motion and by high levels of acetylcholine. Therefore, most drugs that are used to prevent or ameliorate motion sickness symptoms target these neurotransmitters. While the precise action of these medications in preventing motion sickness is not known, most of these drugs fall into three classes: antidopaminergics, anticholinergics, and antihistamines (Drug Facts and Comparisons, 1999; Physician's Desk Reference, 2001). Alternative remedies such as acupuncture, acupressure, acustimulation, and hypnosis are becoming increasingly popular and many have been recommended for treatment of motion sickness (Blumenthal, Goldberg, & Brinkmann, 2000; Cummings & Ullman, 1997; Dobie & May, 1994; Ernst & Pittler, 2000; Brendley, Marti, & DiZio 2003; Yen, Fleur, Golding, & Gresty, 2003; Young, Chiang, Huang, Pan, & Chen, 2002).

The focus of this study was the assessment of one such alternative remedy: the use of stroboscopic vision as a countermeasure when retinal slip is a significant factor in eliciting the motion sickness. Studies have shown that retinal image velocity (retinal slip) contributes to space and terrestrial motion sickness (Bos & Bles, 2004; Han et al., 2005). Melvill-Jones and Mandl (1981), in a research project exploring adaptation of the vestibulo-ocular reflex, employed optically reversing prisms which induced motion sickness symptoms. They discovered what they term a "particularly interesting" finding: "none of the subjects ever experienced nausea or associated symptoms" in stroboscopic light (strobe-light conditions). The results of a study by Reschke, Somers, and Ford (2006), comparing the efficacy of strobe lighting and shutter glasses (both at 4 hertz [Hz] or cycles per second) as a treatment for motion sickness, were very similar to those of Melvill-Jones and Mandl. Reschke, Somers, and Ford reported that stroboscopic illumination, both by ambient illumination or by shutter glasses, reduced the severity of motion sickness symptoms and "appears to be an effective countermeasure where retinal slip is a significant factor in eliciting motion sickness due to either self- or surround-motion." A review of these studies provides compelling evidence that stroboscopic technology may provide a method of preventing motion sickness in the mounted Warfighter. Estrada (2007), in a preliminary, but suggestive, airborne test of the stroboscopic shutter glasses in the U.S. Army Aeromedical Research Laboratory's (USAARL) research helicopter, found the results to be consistent with the reports by Reschke, Somers, and Ford (2006) and Han et al. (2005). Although efficacy of the shutter glasses as a countermeasure for motion sickness was not implied by Estrada's test, the results did indicate that stroboscopic technologies, such as the shutter glasses, demonstrated promise and should be explored as a non-pharmacological motion sickness prevention strategy. Instead of using shutter glasses, the current study explored the potential of turning the cabin area (passenger section) of military vehicles into an ambient stroboscopic environment as a motion sickness countermeasure.

Flicker vertigo and photosensitive epilepsy

Despite the research reporting the benefits of stroboscopic vision as a countermeasure for motion sickness, it should be noted that a small percentage of the population is adversely affected by flickering or flashing light. For most people, viewing such a light can be distracting, annoying, or both (DeHart & Davis, 2002, p. 233). However, two very rare maladies known as flicker vertigo and photosensitive epilepsy have been reported.

Rash (2004) described flicker vertigo as an imbalance in brain cell activity caused by exposure to low-frequency flickering or flashing of a relatively bright light such as a rotating beacon, strobe light, or sunlight seen through a turning propeller or rotor. It is said to occur at flashing/flicker rates of 4 to 20 Hz (Headquarters, Department of the Army, 2000; Heinle, 2001) and to result in nausea, dizziness, a spinning sensation, headache, panic, confusion, and, in rare cases, seizures and loss of consciousness (Rash).

According to the National Society for Epilepsy (NSE) (n.d.) and the Epilepsy Foundation (n.d.), photosensitive epilepsy (sometimes called flicker-induced epilepsy) has been reported in about 3 to 5% of the people who have epilepsy (1 in 200) and is more common in children and adolescents between the ages of 5 and 19 years. Binnie and Jeavons (1992) report that photosensitivity is most often detected at the age of 12 to 14 years, although the history often suggest that it may have been present for some years before it is recognized. In addition, the authors report that two-thirds of the patients are female. The NSE lists the most common triggers of photosensitive epilepsy as visual fire alarm strobe lights, television screens, video games, computer monitors, and exposure to string environmental lights. A study of the widely-reported *Pokemon Phenomenon,* in which many Japanese children and some adults developed various degrees of neurologic problems, including seizures, while watching the popular animated television show, found that "individuals in whom definitive seizures were induced had some predisposition to seizures" (Furusho et al., 2002). The rarity of this condition is documented in a study by Doose and Waltz (1993) where only 2 to 10% of individuals possessing electroencephalogram (EEG) markers of seizure liability (photoparoxysmal response) developed seizures due to photic stimulation. The frequency range at which seizures are induced varies according to the information source. According to the NSE and Epilepsy Foundation, seizures are generally triggered by flashes between 5 and 30 Hz while DeHart and Davis (2002), suggest the triggering frequencies are between 8 to 14 Hz. As expected, the critical frequency varies from person to person although it is uncommon to have photosensitivity to flashes below 5 Hz (NSE).

Military significance

Soldiers must be ready to execute missions at any time during or following transportation, therefore minimizing the symptoms of motion sickness such as nausea, fatigue, and apathy is critical. In the operational environment, motion sickness should be treated with the most effective countermeasures which yield the fewest negative side effects. Many of the currently available pharmaceutical countermeasures must be given in high doses to be effective. Unfortunately, high doses of antiemetics often produce sedation, which is unacceptable in terms of mission effectiveness. Hence, the development of nontraditional, non-pharmacologic motion sickness and nausea remedies would be of great benefit to the operational military community.

Research objective and hypothesis

The objective of this study was to determine the effectiveness of 4 and 8 Hz stroboscopic environments for alleviating airsickness symptoms and ameliorating performance declines. It

was hypothesized that symptoms of motion sickness would be reduced under the two stroboscopic conditions (i.e., 4 and 8 Hz) compared to a no strobe condition (0 Hz).

Methods

Study population

Eligible participants included both men and women (military and civilian) between the ages of 19 and 40 years. The upper limit age range of the participants was restricted to 40 years based on age-related vision problems, such as presbyopia (Mayo Clinic, n.d.). Interested females were screened to exclude pregnancy due to the risks of whole body vibration on a developing fetus (Seidel, 1993). In addition, participants were screened for a history of epilepsy. There were no occupational or skill restrictions. A power analysis indicated a total of 18 participants were needed for the study.

Equipment

The motion profiles of an Army UH-60 Black Hawk helicopter and a Marine AAVC7A1 Amphibious Assault Vehicle were produced using the USAARL's Multi Axis Ride Simulator (MARS). The MARS duplicates the vibrations, movements, thrusts, and jolts of various military vehicles. In general, the MARS is described as a seat secured to a movable platform (see figure 1). All motion profiles were within exposure limits defined by the International Organization for Standardization (ISO) standard 2631-1 (ISO, 1997).

Figure 1. The Multi Axis Ride Simulator

For the purposes of this study, the MARS was surrounded by a black curtain to prevent participants from seeing stabilizing, outside visual references. A 750 watt strobe light provided the ambient stroboscopic effect (4 or 8 Hz). The strobe light measured 220 equivalent candelas at the intensity setting used for the experiment. A 90 watt bulb provided the ambient reading light for the 0 Hz condition. Both light sources were mounted overhead.

In order to induce retinal slippage, all participants were asked to read a passage from a military novel and answer questions regarding the material. The passage was presented on 8.5 x 11 paper with 20 point Times New Roman font.

Data collection instruments

Motion History Questionnaire

Developed by Kennedy and Graybiel (1965), the Motion History Questionnaire (MHQ) was used to ask participants about their experiences in environments that may engender motion sickness-like symptoms; judged susceptibility to motion sickness, nausea and dizziness; and likes and dislikes for activities which produce such symptoms in some persons. Participants' responses on the MHQ were used to compute a "Perceived Susceptibility" score ranging from 0 to 15, where a higher score indicates a greater susceptibility to motion sickness (Kennedy, Lane, Grizzard, Stanney, Kingdon, & Lanham, 2001).

Psychomotor Vigilance Task

In order to test for changes in alertness, basic reaction time was tested through the Psychomotor Vigilance Task (PVT). Participants were required to monitor a screen on which an LED stimulus was presented randomly every 1 to 10 seconds. The participant responded by pressing a microswitch. Reaction time (RT) and lapses (responses over 500 milliseconds [msec]) were recorded for each stimulus.

Motion Sickness Questionnaire

Subjective sickness symptoms were measured using the Motion Sickness Questionnaire (MSQ) (Kellogg, Kennedy, & Graybiel, 1965). The MSQ (Appendix A) is a self-report form consisting of 28 items that are rated by the participant in terms of severity on a 4-point scale. The MSQ yields four scores: nausea, oculomotor, disorientation, and total motion sickness. Nausea scores are derived from the self-assessment of general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, and confusion. Oculomotor disturbance scores are derived from self assessment of general discomfort, fatigue, headache, eyestrain, difficulty focusing and concentrating, and blurred vision. Disorientation scores combine reports of focusing difficulties, nausea, fullness of the head, blurred vision, dizziness with eyes open and/or closed, and vertigo. The total symptom severity score is an aggregate of all of the symptoms.

Postural Balance Assessment

One symptom of motion sickness is dizziness, which can affect balance (Benson, 2002). To test for this affect, the Postural Balance Assessment (PBA) was employed. It is a 5-minute postural equilibrium test consisting of three parts (Gower & Fowkles, 1989). The first part is referred to as "walk on floor with eyes closed" (WOFEC) and requires the participant to take 12 heel-to-toe steps with her/his eyes closed and arms folded across her/his chest. The participant is scored on a scale of 0 to 12 based on how many steps she/he is able to make without side-stepping or losing balance. The second part of the PBA is the "standing on preferred leg with eyes closed" (SOPLEC) test which requires the participant to stand on her/his preferred leg for 30 seconds with her/his eyes closed and arms folded across her/his chest. The participant is scored on the number of seconds she/he is able to remain upright (to within 5 degrees) without losing balance. The third part is the "standing on non-preferred leg with eyes closed" (SONLEC) test which is the same as SOPLEC except that the participant stands on the opposite leg. The three parts of the PBA were completed three times, and the scores from all three were averaged.

Effectiveness Questionnaire

Participants' opinions regarding the effectiveness of the stroboscopic lighting conditions in reducing motion sickness were captured with the Effectiveness Questionnaire. (Appendix B). The responses were on a visual analog scale of 60 mm to allow analysis with parametric tests.

Procedure

The study protocol was approved prior to the start of the study by the USAARL's Human Use Committee. Written informed consent was obtained from all participants. In addition, participants viewed a safety video outlining the safety features of the MARS. All volunteers were medically screening prior to taking part in the study. Also, participants completed the MHQ during the in-processing procedures.

The present study used a repeated measures design. Each participant attended three experimental sessions; one on Monday, one on Wednesday, and one on Friday within the same week. The independent variable was frequency of the stroboscopic light (0 Hz, 4 Hz, and 8 Hz). The participants experienced one of the three lighting conditions per session, and the order of presentation was counterbalanced.

When participants first arrived at the testing facility, they completed the PVT, MSQ, and PBA. Next, participants experienced the 20 minute session on the MARS. Half of the participants (n = 9) were exposed to the UH-60 Black Hawk motion (the airborne group) and the remaining participants (n = 9) were exposed to the Marine AAVC7A1 Amphibious Assault Vehicle motion (the terrestrial/aquatic group). During the MARS session, participants read selected passages to induce retinal slippage. After completion of the MARS session, participants again completed the PVT, MSQ, PBA, and Effectiveness Questionnaire. Before being released

from the study each day, participants met with the study physician to ensure there were no lingering effects of the stroboscopic and/or motion environments.

Results

All statistical analyses were conducted using SPSS® 12.0 with significance set at an alpha level of .05. For all dependent measures, the airborne group was analyzed independently from the terrestrial/aquatic group. Data from one participant from the terrestrial/aquatic group were excluded from all analysis due to failure to complete all testing sessions. In addition, data from the Effectiveness Questionnaire from one participant in the airborne group were not included in the analysis as the participant chose to abstain from completing the survey.

Demographic data

Data were collected on 17 participants (12 male, 5 female). No special populations were included in the sample. Participants were active duty military and DOD civilian employees. Of the nine participants in the airborne group, five were males and four were females. The average age of the participants was 29.00 years (SD = 5.98 years). Of the eight participants in the terrestrial/aquatic group, there were seven males and one female. The average age of the participants was 29.63 years (SD = 4.27 years).

Motion History Questionnaire

With regard to motion sickness susceptibility, both groups of participants scored low on the MHQ, thus indicating a low susceptibility to motion sickness. The mean Perceived Susceptibility score for the participants in the airborne group was 4.22 (SD = 2.54). For those participants in the terrestrial/aquatic group, the average score was 2.62 (SD = 2.20). The difference in perceived susceptibility between the two groups was not significant as revealed by an independent samples t test ($t(15) = 1.38$, $p = 0.19$).

Psychomotor Vigilance Task

Participants were asked to complete the PVT before and after each exposure to the MARS, and data were recorded regarding mean reaction time and number of lapses. Tables 1 and 2 present the respective data before and after the MARS exposure for the airborne and terrestrial/aquatic group by lighting condition. Difference scores were calculated by subtracting the scores from the post-administration from scores of the pre-administration. The data were analyzed using a one-way repeated measures ANOVA across the three lighting conditions (0 Hz, 4 Hz and 8 Hz). No significant differences were found among the lighting conditions for mean reaction time or lapses for the airborne group or the terrestrial/aquatic group.

Table 1.
Psychomotor Vigilance Task Mean Reaction Time (msec) Data and standard error (SE)

Motion	Administration	Lighting Condition					
		0 Hz		4 Hz		8 Hz	
		Mean RT	SE	Mean RT	SE	Mean RT	SE
Airborne Group	Pre	280.25	8.84	263.09	12.91	276.53	10.08
	Post	294.28	23.97	262.73	11.35	277.05	8.20
Terrestrial/Aquatic Group	Pre	251.40	13.37	237.39	10.09	252.02	16.96
	Post	246.43	13.79	239.14	11.30	249.98	13.77

Table 2.
Psychomotor Vigilance Task Mean Lapses Data and standard error (SE)

Motion	Administration	Lighting Condition					
		0 Hz		4 Hz		8 Hz	
		Mean lapses	SE	Mean lapses	SE	Mean lapses	SE
Airborne Group	Pre	1.11	0.20	1.11	0.51	1.11	0.54
	Post	3.33	2.11	1.00	0.53	1.11	0.31
Terrestrial/Aquatic Group	Pre	0.50	0.27	0.25	0.16	0.63	0.26
	Post	0.50	0.27	0.38	0.18	0.75	0.37

Motion Sickness Questionnaire

Participants were asked to complete the MSQ before and after each exposure to the MARS. Figure 2 presents the four MSQ scores before and after the MARS exposure for the airborne and terrestrial/aquatic group by lighting condition. Difference scores were calculated by subtracting the scores from the pre-administration from scores of the post-administration. The data were analyzed using a one-way repeated measures ANOVA over the three lighting conditions (0 Hz, 4 Hz or 8 Hz). No significant differences were found among the three lighting conditions for any of the four scores for the airborne group or the terrestrial/aquatic group. Although not significant, exposure to the 4 Hz stroboscopic environment resulted in greater changes in all four MSQ scores (pre- to post-MARS exposure) compared to the 8 Hz environment (i.e., the MSQ differences scores were larger after exposure to the 4 Hz stroboscopic environment than those after exposure to the 8 Hz stroboscopic lighting).

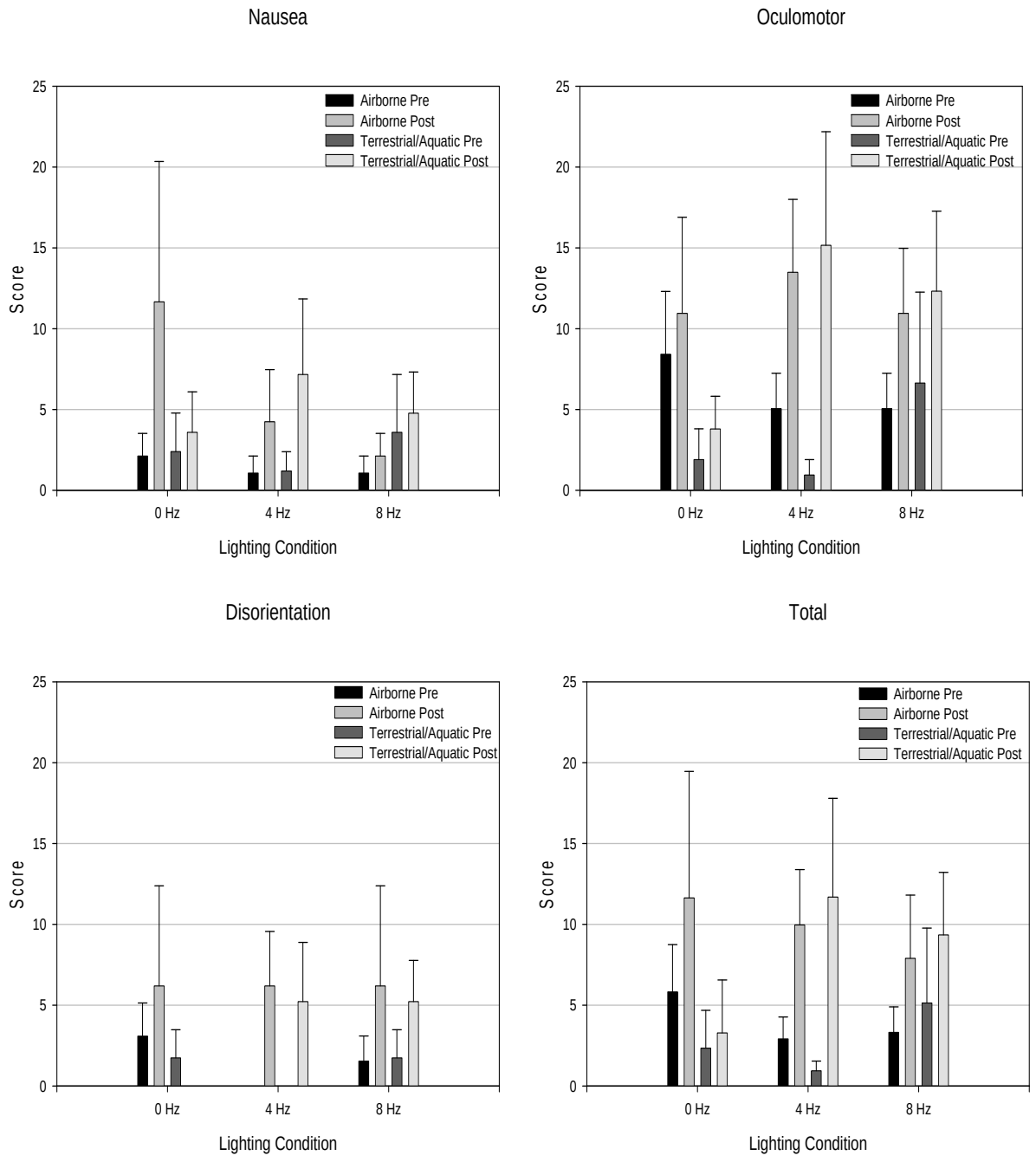


Figure 2. Mean ± SE MSQ scores

Interestingly, when the number of symptoms reported (on the MSQ) after MARS exposure were analyzed (regardless of severity), the participants in the airborne group reported a greater mean number of symptoms after the 0 Hz condition (M = 2.89) than the 8 Hz condition (M = 2.22). However, this difference was not significant, as revealed by a one-way repeated measures ANOVA over the three lighting conditions ($F(1.23, 9.87) = 0.18$, $p = 0.73$). The most commonly reported symptoms after exposure to the MARS are presented in figure 3.

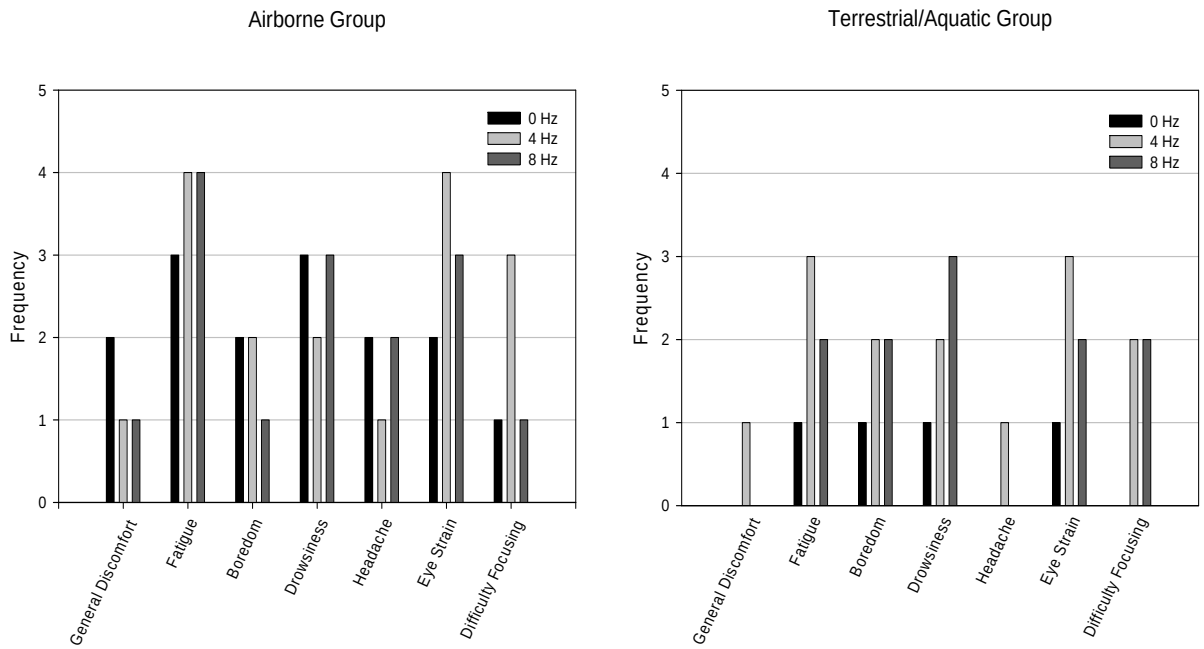


Figure 3. Frequencies of MSQ symptoms reported

Postural Balance Assessment

Participants were asked to complete the PBA before and after each exposure to the MARS. Difference scores were calculated by subtracting the scores from the pre-administration from scores of the post-administration. The data were analyzed using a one-way repeated measures ANOVA over the three lighting conditions. No significant differences were found among the three lighting conditions for any of the three PBA tests for the airborne group or the terrestrial/aquatic group.

Upon further analysis of the PBA data, it was discovered that there were practice effects, regardless of the motion profiles. A 3 x 2 repeated measures ANOVA revealed a significant practice effect for the WOFEC test ($F(2, 32) = 26.88$, $p < .001$). Figure 4 illustrates that over the three days, participants WOFEC performance increased both before and after the MARS exposure. Participants also improved on the other two tests in the PBA over the course of the study, but the differences were not significant.

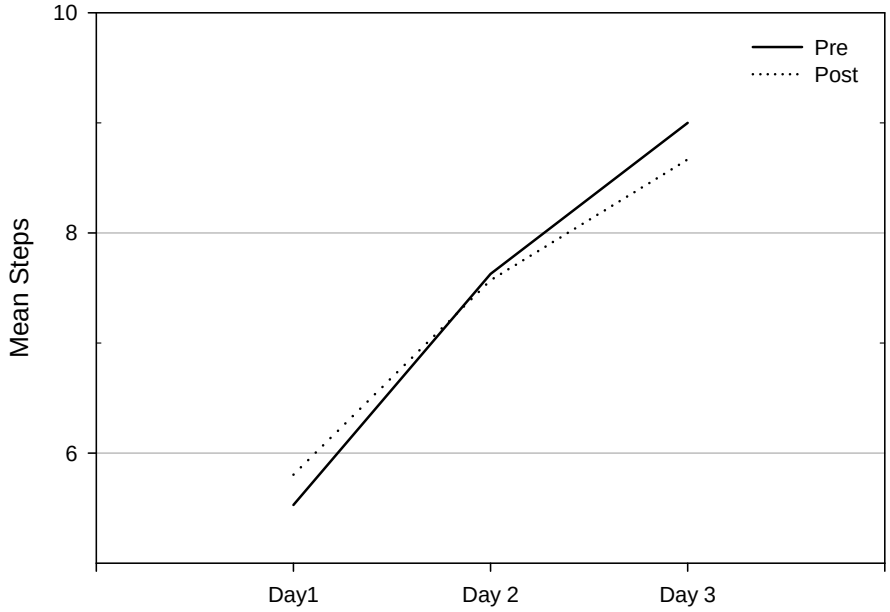
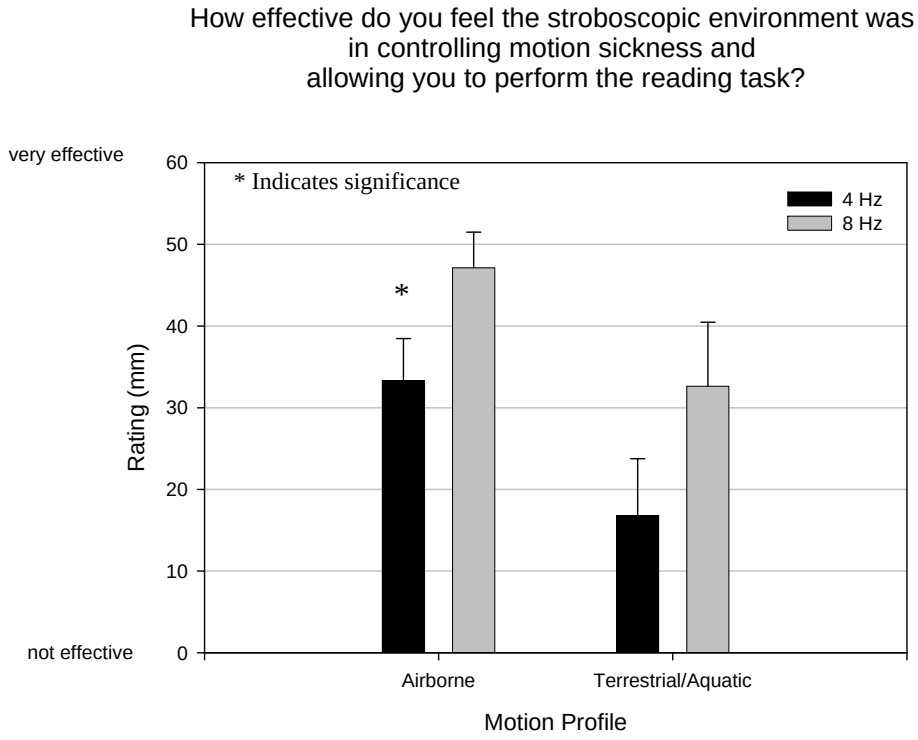


Figure 4. Practice effects during the WOFEC test

Effectiveness Questionnaire

The Effectiveness Questionnaire measured how effective and distracting the 4 and 8 Hz stroboscopic environments were to each participant. Figure 5 presents the mean ratings for the airborne and terrestrial/aquatic groups by lighting condition. A paired samples *t* test revealed participants in the airborne group reported the 8 Hz condition as significantly more effective in controlling motion sickness symptoms than the 4 Hz condition ($t(7) = -2.15$, $p = 0.03$). Participants in the terrestrial/aquatic group also reported the 8 Hz stroboscopic environment as more effective with the difference approaching significance ($t(7) = -1.85$, $p = 0.054$). With regard to how distracting the stroboscopic conditions were to the participants, those in the airborne group felt the 4 Hz condition was more distracting, whereas the terrestrial/aquatic group felt the 8 Hz environment was more distracting. These differences were not significant.

Study volunteers were also encouraged to provide comments regarding the effectiveness of the stroboscopic environment in reducing motion sickness. Several participants indicated that the 8 Hz condition produced less eye strain and allowed for easier reading in comparison to the 4 Hz condition.



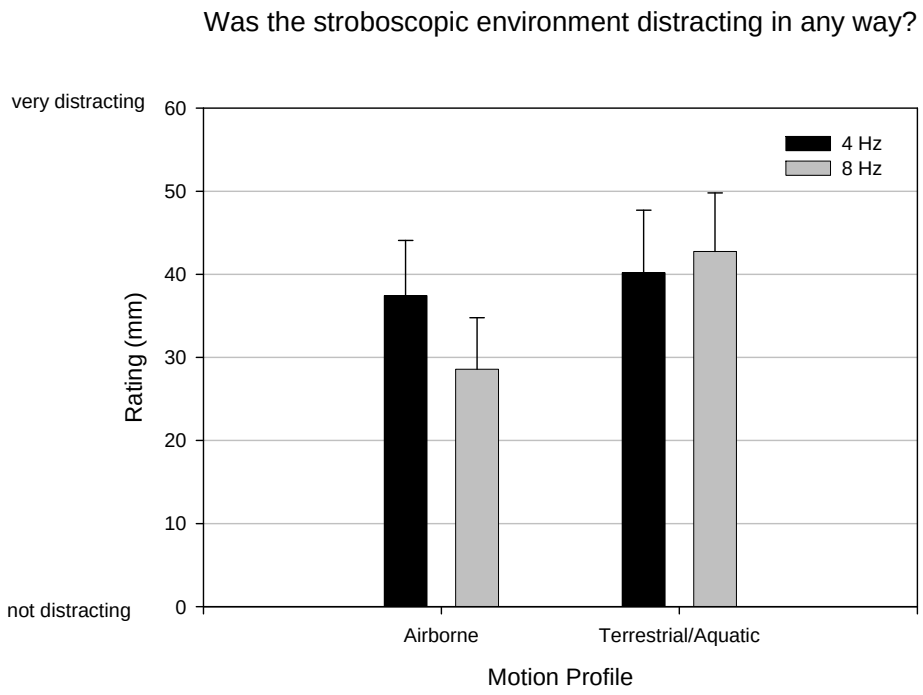


Figure 5. Effectiveness Questionnaire results (Mean ratings ± SE). Note: the higher the rating the more effective and the more distracting, respectively

Discussion

Demographic data

The two groups of participants were similar in composition with regard to age; however the terrestrial/aquatic group was predominantly male (i.e., 7 of 8). Some research suggests that females are more susceptible to motion sickness (Turner, Griffin, & Holland, 2000), and this may have impacted study results. While participation was open to both soldiers and civilians, the majority of the study population was active duty military personnel.

Motion History Questionnaire

With regard to motion sickness histories, both the airborne and terrestrial/aquatic groups tended to score low on the MHQ. Future studies examining the effectiveness of stroboscopic illumination in reducing motion sickness should focus on a motion sickness-susceptible population. The PVT, MSQ and PBA data were further analyzed using only those participants with the highest MHQ scores (i.e., those most susceptible to motion sickness). These analyses failed to find a significant effect of the stroboscopic illumination; however, the statistical power was very low due to the small sample size ($n = 4$). It should be noted that two of the four participants most susceptible to motion sickness reported less nausea after exposure to the MARS under the 8 Hz condition compared to the 0 Hz condition. A similar trend was found in the PBA data; all four of the motion sickness-susceptible participants were able to take more steps in the WOFEC after MARS exposure under the 8 Hz condition compared to the 0 Hz condition.

Psychomotor Vigilance Task

The PVT is an objective measure of performance and has been used to document the effects of various stressors on alertness and performance. The present study was the first to include this objective test in the assessment of stroboscopic lighting as a countermeasure for motion sickness. Other studies examining stroboscopic lighting have mainly relied on subjective reports of participants symptoms (Reschke, Somers, & Ford, 2006; Estrada, 2007). There is literature that suggests that motion sickness does not have any measureable effect on performance because motivation is such an important factor. Motion sickness has been said to affect one's proclivity, not ability, to perform a task (Johnson, 2005). This claim may account for the results in the present study.

Motion Sickness Questionnaire

Although not statistically significant, exposure to the 8 Hz condition reduced all four MSQ scores more than the 4 Hz condition for both the airborne and terrestrial/aquatic groups (see Figure 3). This is consistent with the preliminary findings reported in Estrada (2007), where participants reported more motion sickness symptoms with 4 Hz shutter glasses than 8 Hz in a flight environment.

It should be noted that Reschke, Somers, and Ford (2006) used a modified version of the Miller and Graybiel Questionnaire which is scored differently from the questionnaire used in the present study. In addition, Reschke, Somers, and Ford did not test participants' motion sickness scores prior to exposure, as they only analyzed participants' motion sickness scores after exposure to the motion sickness stimuli. In the present study, difference scores were calculated and analyzed. Perhaps these differences in scoring and analysis contributed to the inability of the present study to find significant evidence of stroboscopic illumination as a motion sickness countermeasure.

Postural Balance Assessment

Analysis of the PBA data provided no evidence of the efficacy of stroboscopic illumination as a motion sickness countermeasure. However, the analysis showed significant practice effects. The participants in the present study were not given time to practice any of the tests in the PBA. More practice time could have prevented the practice effects. Other studies using the PBA have also found learning effects for tests similar to the WOFEC and SOPLEC for up to as many as ten practice sessions (Hamilton et al., 1989). This practice effect prevents any conclusions from being drawn about the effectiveness of the stroboscopic environment in reducing disequilibrium related to motion sickness.

Effectiveness Questionnaire

Participants judged the 8 Hz stroboscopic environment as more effective than the 4 Hz in controlling motion sickness. This finding is similar to that found in Estrada (2007). In addition, participant comments indicated the 8 Hz environment produced less eye strain and allowed for easier reading. Reschke, Somers, and Ford (2006) used only 4 Hz stroboscopic lighting for their experiment. Although the prismatic motion sickness stimuli used by Reschke et al. were different from those used in the present study, it would be interesting to replicate their study using both 4 and 8 Hz stroboscopic lighting to further examine the differences in effectiveness between the two lighting conditions. Furthermore, measures of oculomotor functioning may help explain the reasoning behind the subjective preference.

Limitations

As with many efforts examining the application of novel technologies, funding of this project was very limited. This prevented a more robust research methodology and limited the potential for discovery. For example, increased funding would have allowed for the study to be conducted using actual air and ground vehicles. While the MARS was a cost effective alternative, it was unable to reproduce low frequency vibrations (i.e., below 1 Hz) which are most nauseogenic (Cheung & Nakashima, 2006). Another limitation is that the study population, as a group, was not susceptible to motion sickness based on their MHQ scores. Perhaps, for this sample population, the 20 minute exposure on the MARS did not elicit sufficient motion sickness symptoms for the stroboscopic environment to counter. However, it is interesting to note that one participant discontinued participation due to unpleasant motion sickness symptoms. The strength of motion sickness stimuli is an important variable in motion sickness research, as there are great

individual differences in motion sickness susceptibility (Benson, 2002). A final limitation is that there was insufficient power for all of the statistical tests. The highest statistical power was obtained in the analysis of disorientation MSQ scores for the terrestrial/aquatic group, which was approximately .40, clearly not the desired .80. The variance of the study population as well as their lack of motion sickness susceptibility most likely contributed to the inability to detect a significant effect of the stroboscopic environment.

Conclusion

The present study was an examination of the potential for stroboscopic illumination to serve as a countermeasure for visually-induced motion sickness by using both objective and subjective measures. The results of this research demonstrated the limitations associated with research involving such great individual differences in susceptibility. Clearly examination of a susceptible population will be required for any future research examining stroboscopic illumination as a motion sickness countermeasure. Although there was evidence of the effectiveness of stroboscopic illumination in reducing motion sickness in the subjective reports of the participants, especially for the 8 Hz condition, this study did not provide the conclusive evidence required to recommend this promising technology for operational applications.

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Appendix A

Motion Sickness Questionnaire

For each symptom, please circle the rating that applies to you **RIGHT NOW**.

	1	2	3	4
General discomfort	None	Slight	Moderate	Severe
Fatigue	None	Slight	Moderate	Severe
Boredom	None	Slight	Moderate	Severe
Drowsiness	None	Slight	Moderate	Severe
Headache	None	Slight	Moderate	Severe
Eye strain	None	Slight	Moderate	Severe
Difficulty focusing	None	Slight	Moderate	Severe
Increased salivation	None	Slight	Moderate	Severe
Decreased salivation	None	Slight	Moderate	Severe
*Sweating	None	Slight	Moderate	Severe
Nausea	None	Slight	Moderate	Severe
Difficulty concentrating	None	Slight	Moderate	Severe
Mental depression	No	Yes		
“Fullness of the head”	No	Yes		
Blurred vision	No	Yes		
Dizziness w/ eyes open	No	Yes		
Dizziness w/ eyes closed	No	Yes		
Vertigo	No	Yes		
**Visual flashbacks	No	Yes		
Faintness	No	Yes		
Awareness of breathing	No	Yes		
***Stomach awareness	No	Yes		
Loss of appetite	No	Yes		
Desire to move bowels	No	Yes		
Confusion	No	Yes		
Burping	No	Yes		
Vomiting	No	Yes		

OTHER: Please Specify

_____

_____

_____

* Sweating “cold sweats” due to discomfort, not due to physical exertion

**Visual flashback- illusion of movement or false sensation similar to aircraft dynamics when not in a simulator or aircraft

***Stomach awareness-used to indicate a feeling of discomfort just short of nausea

Appendix B

Effectiveness Questionnaire

For each of the following items, please rate your perceptions of the stroboscopic environment by marking a vertical mark on the line. For example:

Not effective _____|_____ Very effective

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1. How effective do you feel the stroboscopic environment was in controlling motion sickness **and** allowing you to perform the reading task?

Not effective _____ Very effective

2. Was the stroboscopic environment distracting in any way?

Not distracting _____ Very distracting

3. Based on your experience in the stroboscopic environment, do you feel the strobe effect has a practical application for military helicopter passengers?

4. Provide any additional comments

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