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Visual Occlusion Decreases Motion Sickness in a Flight Simulator

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Abstract
Sensory conflict theories of motion sickness (MS) assert that symptoms may result when incoming sensory inputs (e.g., visual and vestibular) contradict each other. Logic suggests that attenuating input from one sense may reduce conflict and hence lessen MS symptoms. In the current study, it was hypothesized that attenuating visual input by blocking light entering the eye would reduce MS symptoms in a motion provocative environment. Participants sat inside an aircraft cockpit mounted onto a motion platform that simultaneously pitched, rolled, and heaved in two conditions. In the occluded condition, participants wore "blackout" goggles and closed their eyes to block light. In the control condition, participants opened their eyes and had full view of the cockpit's interior. Participants completed separate Simulator Sickness Questionnaires before and after each condition. The posttreatment total Simulator Sickness Questionnaires and subscores for nausea, oculomotor, and disorientation in the control condition were significantly higher than those in the occluded condition. These results suggest that under some conditions attenuating visual input may delay the onset of MS or weaken the severity of symptoms. Eliminating visual input may reduce visual/nonvisual sensory conflict by weakening the influence of the visual channel, which is consistent with the sensory conflict theory of MS.

Keywords
simulator sickness, sensory conflict, visuo-vestibular interactions, nausea

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Anyone who has ever experienced motion sickness (MS) can attest to the unpleasantness resulting from a range of symptoms. Dizziness, headache, nausea, and even vomiting are not uncommon. Passengers in cars, boats, aircraft, and in other situations involving passive self-motion may experience MS symptoms. Actual self-motion relative to Earth is not required to elicit MS-like symptoms. It has been well documented that even subjects that are stationary relative to Earth may experience MS-like symptoms when self-motion is visually induced, as when vection occurs (Bonato, Bubka, & Thornton, 2015). Although pharmaceutical treatments for MS such as Scopolomine are available and often effective, they also can result in unwanted side effects (Spinks & Wasiak, 2011). Therefore, effective nonpharmaceutical methods for avoiding or reducing MS would be welcome. However, some proposed remedies, such as bracket-like devices that are worn around the wrist that supposedly stimulate pressure points, may result in nothing more than a placebo effect (Miller & Muth, 2004). The current study tested the effect of a different nonpharmaceutical method on MS, specifically, restricting visual input.

Although numerous theories have been developed to account for MS, including those based on canal overstimulation (Money, 1970), postural instability (Riccio & Stoffregen, 1991) and nystagmus eye movements (Ebenholtz, Cohen, & Linder, 1994), sensory conflict theories, such as that proposed by Reason and Brand (1975) remain the most commonly cited explanation for MS. According to sensory conflict theories, MS occurs when sensory systems (in the brain), such as visual and vestibular systems, receive contradictory information. For instance, passengers in an airplane receive vestibular information indicating that they are in motion; however, a visually stationary cabin interior may indicate they are in fact still. One version of the sensory conflict theory asserts that what is sensed as "vertical" is what is important and subjective vertical mismatches are what lead to MS symptoms (Bles, Bos, de Graaf, Groen, & Wertheim, 1998). Sensory conflict theory would predict that eliminating one of the sensory input channels should prevent the onset of MS.

The few studies that have directly manipulated visual input in various paradigms found contradictory results both in support of and against the effect of attenuating the visual channel. For instance, participants in a slow rotation room (Oosterveld, Graybiel, & Cramer, 1972), ship motion simulator (Bos, MacKinnon, & Patterson, 2005), and moving enclosed cabin (Mills & Griffin, 2000) experienced more MS when their eyes were open rather than closed or blindfolded. In addition, when participants were seated in a chair enclosed in a moving, patterned drum MS was more severe when the lights were on than off (Eyeson-Annan, Peterken, Brown, & Atchison, 1996). However, Graybiel (1970) found that both blind and sighted individuals reported MS symptoms in a slow rotation room. In that study, a modified version of the Dial Test (Kennedy & Graybiel, 1965) was used as a means of facilitating head movements that yielded Coriolis accelerations associated with MS. Similarly, participants placed in a rotary device experienced MS regardless of whether their eyes were open or closed (Leger, Money, Landolt, Cheung, & Rod, 1981).

We designed the current study to examine the role of the visual channel in MS and to expand upon the inconsistent findings of previous research. Our hypothesis was that visually restricted individuals would not experience MS. In the current study, we used a within-subjects design to determine whether attenuating conflicting input from one sensory system (vision) would lead to a decrease in MS symptoms in a motion-based flight simulator. The method of attenuating visual input in the current study was chosen in an attempt to reduce visual input.

Method

Subjects

Eleven individuals (seven women and four men) volunteered for the experiment. Their mean age was 27.7 years (range = 19.0–50.3 years). All subjects had normal or corrected-to-normal vision and no one reported any neurological, vestibular, or gastrointestinal problems. The institutional review board of Saint Peter's University approved the project, and informed written consent was obtained from each subject prior to participation.

Equipment and Materials

As shown in Figure 1(a) and (b), a flight simulator manufactured by InMotion Simulation (Prescott, AZ) was used for the experiment. The flight simulator consisted of an enclosed ultra light aircraft cockpit mounted onto a three degrees-of-freedom motion platform. An adjustable five-point harness system was used to stabilize the participant. Simulator cockpit motion could occur for three degrees of freedom (pitch, roll, and heave). The pitch and roll capabilities were $\pm 25^{\circ}$ and heave capabilities were ± 25 cm. From the subject's vantage point, the entire front interior of the cockpit was visible, including the instrument panel. Also visible were three large (131 cm diagonally) Samsung HL-T50755X/XAA display screens mounted in front of the cockpit to form a panoramic display that covered the entire visible area outside the front of the cockpit. Viewing distance to the center screen was 155 cm. The display screens were turned on in the control condition but remained homogeneous (white) to create a visual array analogous to flying through a cloud. In the occluded condition, the subjects wore a pair of military surplus opaque blackout goggles and the display screens were turned off.

The Simulator Sickness Questionnaire (SSQ) was used to assess MS symptoms (Kennedy, Lane, Berbaum, & Lilienthal, 1993). Scored according to published guidelines, the SSQ yields four scores: a total SSQ score and three subscores corresponding to nausea, oculomotor effects, and disorientation. Sixteen items on the questionnaire (general discomfort, fatigue, headache, eye strain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of the head, blurred vision, dizziness with eyes open, dizziness with eyes closed, vertigo, stomach awareness, and burping) contribute to the SSQ scores. Subjects indicate the level at which each symptom is experienced both pretreatment and posttreatment by circling one of four choices (0 = *none*, 1 = *slight*, 2 = *moderate*, or 3 = *severe*).

Procedure and Design

The subject was given instructions regarding the SSQ before filling out the pretreatment page of the SSQ form. The subject was then seated in the flight simulator's cockpit and strapped in with the five-point harness. In the control condition, the subject was instructed to look forward for the entire length of the trial. In the occluded condition, the subject was fitted with the blackout goggles and instructed to close their eyes and sit in the cockpit as it moved (see Figure 1(c)).

The simulator's motion was completely automated for this experiment; pitch, roll, and heave movements were sinusoidal in nature. Previous research has shown that multiple axes of motion are likely to cause MS symptoms rather than one axis (Bonato, Bubka, & Palmisano, 2009). The amplitude of pitch movement was 10° with a frequency of 0.2 Hz. Roll movement amplitude was 10° at a frequency of 0.1 Hz. Heave amplitude was 13 cm at a

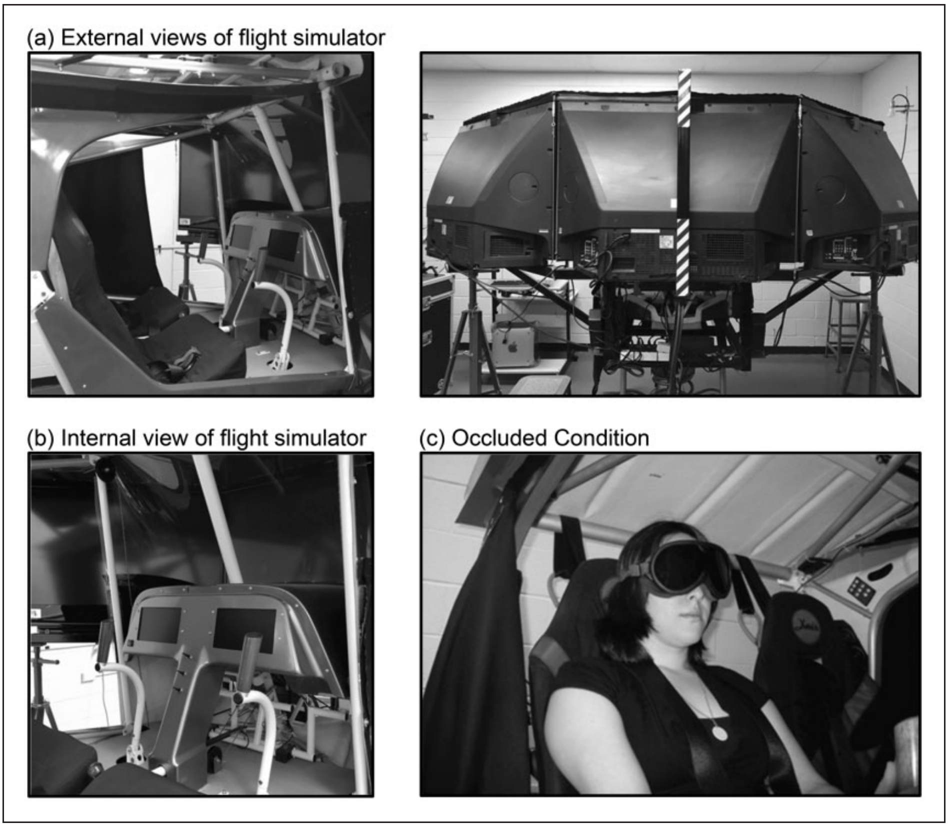

Figure 1. (a) External and (b) internal views of flight simulator on the motion platform and (c) a participant in the occluded condition wearing blackout goggles in the cockpit.

frequency of 0.16 Hz (see Golding, 2006 for a review of frequencies likely to cause MS). In addition, pilot trials suggested that this combination of motion components would be provocative enough to lead to MS symptoms.

Each trial lasted 10 minutes, after which the subject was immediately given the posttreatment portion of the SSQ form to complete while still in the flight simulator. Each subject participated in both the control and occluded conditions. Five participants completed the occlusion condition first to control for possible order effects including adaptation. At the conclusion of each trial, the subject rested until the severity of any symptoms subsided. After participating in the first condition, the subject participated in a subsequent condition within 48 to 72 hours.

Statistical Analysis

We subtracted participants' pre-SSQ score from their post-SSQ score to obtain an SSQ score for each participant for each condition. Note that the pre-SSQ score for each participant was 0 for each condition because participants could not start the study if they reported any problems on the pre-SSQ. Data for total, nausea, oculomotor, and disorientation SSQ scores were analyzed using one-tailed t tests for repeated measures with an alpha level of $p < .05$.

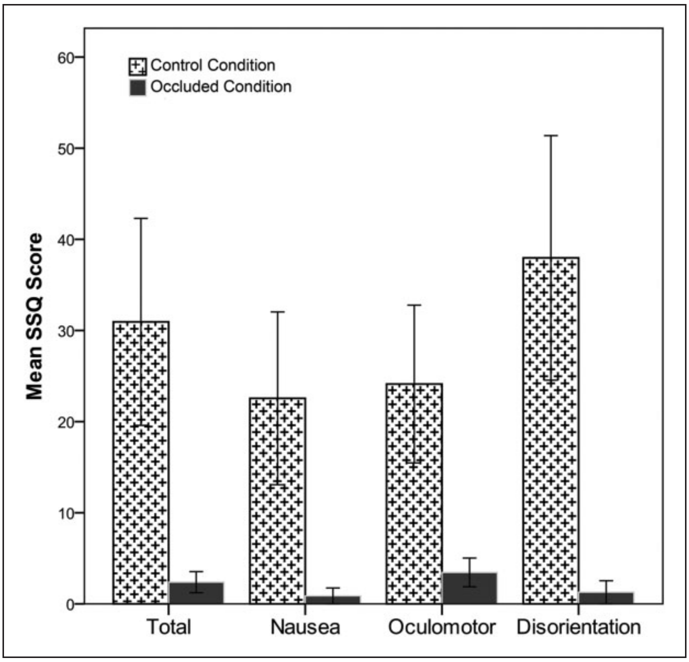

Figure 2. Mean SSQ total scores and subscores for nausea, oculomotor symptoms, and disorientation for each condition. Error bars represent ± one standard error of the mean.

Results

As shown in Figure 2, the total SSQ score and three subscores were all higher for the control condition compared to the occluded condition. The mean total SSQ score for the control condition (30.90) was significantly higher ($t(10) = 2.44$, $p = .02$) than the mean obtained (2.38) for the occluded condition. The mean nausea subscore for the control condition (22.60) was higher ($t(10) = 2.25$, $p = .024$) than the mean obtained (0.87) in the occluded condition. The mean oculomotor subscore for the control condition (24.10) was higher ($t(10) = 2.26$, $p = .024$) than the mean (3.45) for the occluded condition. Finally, the mean disorientation subscore for the control condition (38.00) was significantly higher ($t(10) = 2.65$, $p = .01$) than the mean obtained (1.27) in the occluded condition. Seven of the 11 subjects reported no symptoms at the completion of the occluded condition.

Discussion

In the current study, participants sat in a flight simulator that rolled, pitched, and heaved for 10 minutes. We assessed the extent of MS using SSQ scores after control and occlusion conditions. The findings are consistent with our hypothesis that attenuating visual input in a motion provocative environment can reduce MS symptoms. Comparison of the overall SSQ score and subscores between the occluded and control conditions showed that the scores in the control condition were significantly higher. Moreover, our findings are in line with previous research studies that directly tested the effect of visual-vestibular conflict on MS. Similar to the current study, Bos et al. (2005), Eyeson-Annan et al.

(1996), Mills and Griffin (2000), and Oosterveld et al. (1972) showed that attenuating the visual input led to less MS symptoms.

Although this is only one experiment using a modest number of subjects, the results clearly suggest that blocking visual input can significantly reduce or even prevent MS symptoms. SSQ scores obtained in the control condition were high enough to suggest that the subjects were experiencing a substantial degree of sickness symptoms (Kennedy et al., 2003). Effect sizes were notably large in this experiment. For example, the mean total SSQ scores were 1,300% higher in the control than the occlusion condition. It should be noted that 64% of the subjects reported no MS symptoms in the occlusion condition and 74% of the participants reported that the occluded condition was also more pleasant.

Why Less MS With Occlusion?

One way of eliminating a sensory conflict is to eliminate one element contributing to that conflict—in the current experiment this was vision. The idea that eliminating one sensory input channel can reduce or eliminate MS seems reasonable given that labyrinth-defective individuals are the only subset of the population that is 100% resistant to MS (Cheung, Howard, & Money, 1991). For labyrinth defectives, the visual sensory input channel is intact, but the vestibular channel is absent. However, the general idea is the same: Eliminate one sensory input channel and reduce or eliminate sensory conflict, and as a result, reduce, delay, or prevent MS symptoms. In fact, PET research on vection shows promise toward uncovering the neurological process of MS. It has been shown that when individuals experience vection without MS, the activation of visual areas, specifically medial parieto-occipital cortex, is coupled with the deactivation of the parieto-insular vestibular cortex (Brandt, Bartenstrain, Janek, & Dieterich, 1998). Deactivation may prevent vestibular cortex from providing information that contradicts with vision. Extending the results of the study to MS, one could hypothesize that MS occurs when the vestibular cortex fails to deactivate. Therefore, in the control condition participants felt MS because the vestibular cortex was not deactivated. It will be exciting to see whether future studies uncover under which circumstances and stimulus duration vestibular deactivation does or does not occur.

Part of the reason for such clean and decisive results may be due to our method of reducing visual sensory input. Closing one's eyes, turning the lights off, and even using a blindfold can block considerable light from entering the eyes, but often such methods will fail to block light completely. Using goggles such as those employed in our experiment, sitting in an enclosed cockpit, closing one's eyes, and turning off lights in a windowless, below ground lab, resulted in significant light blockage. Hence, visual input in the current experiment was effectively reduced, resulting in a reduction of visual/vestibular sensory conflict, and subsequently little or no MS symptoms in the occlusion condition.

Furthermore, electroencephalography and functional magnetic resonance imaging research studies have found cortical differences between resting conditions of eyes closed versus open. These differences are not necessarily the same as those produced by visual occlusion with a blindfold or blackout goggles. Electroencephalography has shown differences in cortical processing of visual input when the eyes are opened or closed (Barry, Clarke, Johnstone, Magee, & Rushby, 2007). Specifically, there is a reduction in delta, theta, alpha, and beta waves when the eyes were open compared to closed. There is also more electroencephalography variability when the eyes are open compared to when they are closed (Thuraisingham, Tran, Boord, & Craig, 2007). In addition, functional magnetic resonance imaging has shown that cerebral blood flow in the primary visual cortex is less when participants' eyes were closed (Zou et al., 2015). The same study showed more neuronal activity in the primary somatosensory cortices, primary auditory cortices, and supplementary motor area when the eyes are closed. In contrast, there is more neuronal activity in the lateral occipital cortex and frontal cortices when the eyes are open. It is likely that these differences in cortical activity lead to less MS symptoms when the eyes are closed or occluded. But, it should be noted that our literature review did not reveal any reports that empirically measured cortical activity due to MS with the eyes opened or closed.

Another possible explanation for the lack of sickness symptoms in the occlusion condition relates to the postural instability theory of MS (Riccio & Stoffregen, 1991). According to this theory, MS symptoms are not the outcome of contradictory incoming sensory information but from a lack of postural stability. Specifically, MS results when individuals are in unfamiliar situations in which they do not know how to maintain balance and posture. Their body has not had enough experience to develop strategies to achieve postural stability. Thus, participants in our study may have felt MS because they had never before experienced the identical motion pattern used in the experiment and did not know how to maintain their posture. Furthermore, it is possible that when participants were in the control condition they experienced more MS because they tried to match their own body to the movement of the apparatus but were unable to predict the pattern. In contrast, perhaps when participants were in the occluded condition they did not attempt to do this and did not develop MS.

A third potential explanation for the difference between the occlusion and control conditions concerns the presence of foveal retinal slip. Previous research using a virtual optokinetic drum and controlled eye motion has shown that eliminating foveal retinal slip significantly reduces MS symptoms (Guo & So, 2012). In light of this finding, the results of the current study would suggest foveal retinal slip as a contributing factor of MS in the control condition. Compared to the occluded condition, participants in the control condition would have undoubtedly experienced retinal slip. Perhaps in the control condition, participants attempted to stabilize their vision but were not successful and developed MS. In contrast, when their eyes were occluded they did not experience retinal slip and did not feel MS.

These explanations are not mutually exclusive: It is possible that sensory mismatch, postural instability, and foveal retinal slip contributed to MS in the control condition. Although the current experiment was not designed to directly distinguish among these explanations a future study certainly could.

Contrasts With Past Research and Current Study

On the surface, our results seem to contradict those obtained by Graybiel (1970), who found that both blind and sighted individuals experienced MS. One explanation for the discrepancy may be due to the difference in exposure time between the studies. Subjects in the current study were exposed for 10 minutes, but in Graybiel (1970), individuals experienced provocative motion for up to 25 minutes in a trial. It is possible that longer exposures in our apparatus would result in significant MS symptoms in the occluded condition of the current study. A related explanation is that vision may play a larger role in MS for certain conditions, such as in the current paradigm, than in other situations such as Graybiel. Taken together, these explanations suggest a more nuanced view of the role of vision and exposure duration in MS. For short durations, vision may play a larger role, thus, blocking off the visual channel prevents the onset of MS. However, for longer exposures, blocking off the visual channel does not prevent the onset of MS because it plays a smaller role.

Another possibility is that very few individuals who are blind are incapable of detecting any light or visual patterns. A survey of middle-aged and older Americans who were visually impaired suggests that only 2% of all ''blind'' Americans aged 45 years and older are totally blind in both eyes or classified as NLP (no light perception; Lighthouse Inc., 1995). In essence, being blind is not the same as having the visual input to the brain totally turned off. Patterns of light, although degraded compared to nonblind individuals, may in some cases provide enough visual input to help blind individuals orient themselves in their environments.

Our results also contrast with those in Leger et al. (1981) who found that participants reported MS symptoms regardless of whether their eyes were closed in the darkness or were open under normal viewing conditions. There are several methodological differences that may account for the discrepancy between the findings. The current study manipulated participants' movement using a combination of the three axes of rotation at once rather than one at a time in separate conditions. Also, the movement pattern and exposure duration were different between the studies. Both studies diligently attempted to block out light by having participants close their eyes, turning off the lights, and closing the apparatus door. However, participants in the current study also wore goggles that prevented light leakage if, for instance, participants accidently opened their eyes during the occlusion condition. It is possible that these and other dissimilarities led to the different results that may be resolved in future research.

Limitations

The current study has some limitations. There is always concern that results obtained under laboratory conditions might not reflect real-world situations. Even though a flight simulator with three degrees of freedom was used, for the purpose of maintaining controlled motion across conditions, it was preprogrammed and hence artificial. However, everyday situations such as actual air travel, long-distance train journeys, escalator trips, and amusement park rides provide many passengers with similar motion patterns that may result in MS. In short, the results of the current study pertain to the motion profile used in the study. Other types of motion (e.g., off-vertical axis rotation, y-axis rotation) could lead to a different set of results.

Also, using special samples, such as college undergraduates, that are not truly representative of the general population can undermine ecological validity. Nonetheless, results from healthy, college undergraduates without any reported disorders can inform us about the mechanism and prevention of MS in the general population. In addition, the number of subjects used was small. This however would have been more of a concern if negative results were obtained. Given that the t test takes the number of subjects into account, we are confident that the results reported here represent real effects. Future research to address some of these limitations might include testing a larger number of subjects from the general population.

Conclusion

In conclusion, the results of the current study suggest that under some conditions, visual input is an important component in MS. Although more research is needed to more fully understand how vision affects MS, these results suggest that a simple practical strategy for mitigating MS symptoms may be to attenuate visual input. Under some conditions, susceptible individuals in motion provocative environments may find resistance to MS by reducing or eliminating visual input.

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