Stroboscopic Vision as a Treatment for Retinal Slip Induced Motion Sickness

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Abstract. Motion sickness (MS) in the general population is a significant problem driven by the increasingly more sophisticated modes of transportation, visual displays, and virtual reality environments. It is important to investigate non-pharmacological alternatives for the prevention of MS for individuals who cannot tolerate the available anti-motion sickness drugs, or who are precluded from medication because of operational environments. We have used stroboscopic vision as a way to provide a simple, easily managed treatment for MS. Specifically, a five part study was designed to investigate the effect of stroboscopic vision (either with a strobe light or LCD shutter glasses) on MS while: (1) using visual field reversal, (2) reading while riding in a car (with or without external vision present), (3) making large pitch head movements during μ-g phase of parabolic flight, (4) exposed to rough seas in a small boat, and (5) seated and reading in the cabin area of a UH60 Black Hawk Helicopter during provocative flight patterns. A total of 69 subjects participated in selected phases of the study. Fewer subjects suffered from MS under stroboscopic conditions. Stroboscopic illumination prevents retinal slip, thereby treating MS symptoms. Shutter glasses with a cycle frequency of 4 or 8 Hz and a short dwell (glasses clear) time (10–20 msec) are as effective as a strobe light, producing a useful adaptation during either self or surround motion without the penalty of using disabling MS drugs.

Introduction

Previous NASA studies have suggested that during space flight functional difficulties with motion sickness (MS) and motor control may have a common root in retinal slip (Somers, *et al*., 2002). Retinal slip occurs when an object in the visual environment is not, or cannot be stabilized during either an eye movement or a coordinated eye and head movement.

Retinal slip under these conditions is directly related to vestibular system gain. When the gain is optimal (i.e., an eye movement in the skull is equal and opposite to the head movement) an object of interest in the environment is captured and held without substantial movement on the retina of the eye. An example of unity gain during a coordinated head and eye movement is the

vestibular-ocular reflex (VOR). As the head rotates, the eye (fixated on a target) rotates equally and opposite the head. This reflexive action ensures that the target will remain fixed on the retinal surface, and that the target will not race across the retina. Space flight and other factors, such as aging, disease, and medications, can modify the gain of the vestibular system.

Experimentally, gain of the VOR can be modified by using a variety of prisms. Adaptation of the VOR to extended prism wear was first studied over 25 years ago with subjects wearing prisms to reverse vision in the horizontal plane (Melvill Jones and Mandl, 1981). It was discovered that when wearing left-right reversing prisms, all of the subjects developed severe MS symptoms. However, these symptoms were prevented if the visual surround during active head/body movements was illuminated with a brief stroboscopic flash (3 µsec) to prevent retinal slip. Additionally, a unique finding emerged from this study. It was found that not only did the strobe exposure prevent MS, the subjects continued to adapt to the prisms while exposed to the strobe. Suggesting that if you could provide a way of strobing the visual environment that did not involve a strobe light, you could prevent MS evoked by retinal slip and that the subjects could possibly adapt to the MS provocative environment.

Nothing, however, was done with the information from the Melvill Jones and Mandl (1981) study until a better than normal postflight recovery (no visual decrement or postural performance) of a veteran astronaut following a 140-day stay aboard the Mir spacecraft was observed. This particular astronaut flew with a greater than normal number of square-wave jerks (SWJ), and postflight presented with SWJ intrusions of approximately 1/sec. SWJ, in this case, were typically conjugate saccades typically 0.5 to 2.0° in size, which took the eye away from the fixation position and then returned it after a period of about 200 msec. It was hypothesized that this astronaut's improved postflight performance was due to the SWJ allowing the crewmember to effectively *strobe* the visual environment (Reschke *et al*., 2004).

It is unknown to what degree MS in different environments can be attributable to retinal slip, nor is it known if preventing retinal slip by strobing the environment will prove to be an effective countermeasure in provocative situations experienced by the majority of the population suffering from MS.

This paper represents our initial attempt through one completed study and four pilot investigations to study the effectiveness of stroboscopic vision on MS in different motion environments. Specifically we have examined the effects of stroboscopic vision while (1) reading text and making head movements around the Z-axis while wearing left-right reversing prisms, (study previously reported, but included here for completeness (Reschke *et al*., 2006), (2) being exposed to rough seas in a small boat, (3) making large pitch head/body movements during parabolic flight, (4) reading in a moving car (with or without external vision present), and (5) seated and reading in the cabin area of a UH60 Black Hawk Helicopter during evasive combat maneuvers.

Study 1: Visual Field Reversal
Methods. In part I of this study, designed to repeat the original Melvill Jones and Mandl study (1981), 19 subjects (11 men, 8 women, ages 24-46) in a simple cross-over design were tested two times, once under normal light conditions (control condition), and once with a Monarch Instrument strobe light (model Nova Strobe PB, Amherst, NH) with a 4 Hz flash frequency and 30 µsec flash duration In part II, testing was repeated with an additional 13 subjects (8 men, 5 women, ages 26-48) and 6 subjects from the part I study (4 men, 2 women, ages 25-47) using stroboscopic LC glasses (developed in the investigators' laboratory) with a 4 Hz flicker frequency and 10 ms dwell time (period LCD lenses are clear). The physical limitations of the LC glasses required the

flash duration to be set to 10 ms. The constant flash frequency of 4 Hz was selected to match the Melvill Jones and Mandl (1981) stroboscopic rate, and avoid epileptogenic stimuli (i.e., visually driven epileptic seizures) in photosensitive individuals.

Subjects were fitted with goggles that contained dove prisms arranged to produce horizontal (left-right) image reversal. These goggles were worn over the LC glasses and permitted direct forward vision. Goggle fitting and prism checks for different inter-pupillary distances were done in the light with the head fixed in a chinrest to prevent head movements and thus any incongruent visual-vestibular stimulation which could induce MS symptoms prior to the initiation of the experiment.

The visual field used to provide the primary source of visual-vestibular conflict was placed exactly 1 m from the subjects' eyes (frontal plane) and centered at the line of sight (horizon). The target consisted of a short passage from *Treasure Island*. The letters were equivalent to a font (Arial) size of 125 pt, and subtended an average visual angle of approximately 1°.

Regardless of the treatment group (normal light, stroboscopic or LC), all subjects were required to make active ±20° amplitude yaw head movements at a frequency of 0.25 Hz paced with a modulated auditory signal for 30 min.

The MS score sheet used for this test was adapted from the Pensacola Diagnostic Index (PDI) Method (Graybiel, Wood et al. 1968),. Subjects were questioned every 5 min during the trials (stroboscopic, LC or normal lighting) for symptoms. The test operator recorded symptoms that the subject could not reliably observe (i.e., pallor, mild levels of sweating or salivation, reduced head motion, etc). The test was terminated when a subject reached a level of moderate malaise (MIIa), corresponding to 5 to 7 points on the PDI, or the 30 min test period ended. A non-parametric Friedman two-way ANOVA for repeated measures was used for all statistical inference.

To avoid adaptation to the provocative environment, approximately 14 days elapsed before subjects were exposed to a new illumination condition.

Results. In Part I, all the subjects that experienced symptoms, 11 of 14 exhibited lower MS scores with the strobe light while 3 subjects showed no change in MS symptoms (Figure 1). Overall the MS scores were significantly lower than in the control condition ($p<.003$). In Part II (Figure 2) similar results were obtained for the LC glasses where all but 4 subjects who experienced symptoms had lower MS scores while wearing the glasses ($p<.001$). There was no difference between the strobe flash and the glasses flicker ($p=0.180$) or no strobe and no glasses flicker ($p=0.414$).
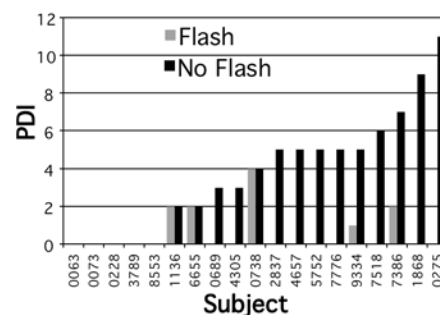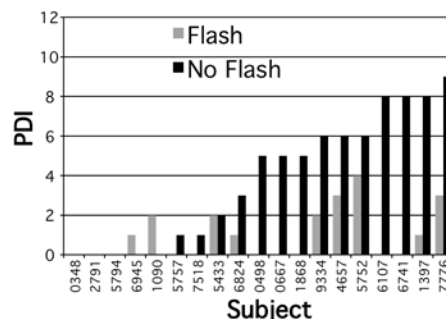

Figure 1. Strobe Light

Figure 2. Strobe Glasses

Study 2: Seasickness Pilot Study
Methods. Three subjects participated in this study (2 males, 1 female). Subjects were taken by boat out to the Aquarius Underwater Laboratory off the coast of Florida to support or activate NASA's

Extreme Environment Mission Operations (NEEMO) platform. This was a two-part experiment, consisting of an outbound and inbound portion. The subjects donned the goggles (set to flicker at 8 Hz with a 10 msec dwell time per cycle) immediately upon entering the boat. The flicker rate and dwell time used in this study differed from that used in Study 1 for the following reasons: (1) the expected frequency of head movements and motion of the boat were expected to be at a higher frequency that that used in Study 1, (2) the dwell time was increased, after verifying that there was no appreciable retinal slip when a radial line display was moved and viewed by independent observers, and (3) a higher workload and the need to see targets for longer periods of time was an operational issue.

When the boat reached its destination, the subject would either stay in the boat, or enter the water to scuba dive to NEEMO. Once all subjects were back in the boat, they would don the goggles and the boat would return to shore. The experiment was terminated upon reaching the destination regardless of the PDI score. Each trip out or inbound was roughly 30 minutes each.

Results. Two of the 3 subjects exhibited less MS symptoms while wearing the treatment glasses. No statistical analysis could be performed on this limited data set. It is worth noting that all three subjects experienced frank sickness without the glasses. With the glasses only one subject experienced frank sickness.
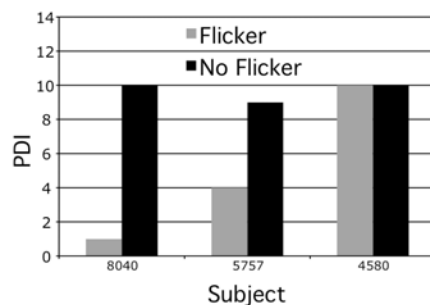

Figure 3. Seasickness (PDI) Scores

Study 3: Parabolic Flight Pilot Study

Methods. For this experiment, a total of 9 subjects were randomly assigned to two groups: (A or B). Each group participated in flying twice in this crossover design study that resulted in a total of 2 flights per subject. For the first two flights, group A wore laboratory modified ferroelectric liquid crystal glasses (Cambridge Research Systems, Ltd.) set to flicker at 4 Hz with a clear period of 10 msec, and group B (controls) wore glasses that remained clear for 4 sec and flickered dark for 10 msec. For the final two flights, the flicker treatment was reversed for groups A and B. All subjects were trained on the PDI symptoms.

The subjects, wearing soft neck braces, remained seated upright, and completely stationary during the hyper-g pullouts (approximately +1.8 Gz) with their eyes closed. Upon reaching the μg portion of the parabolas, the subjects, as trained, made *en bloc* head and upper body movements by bending at the waist and moving the head and trunk in the pitch plane approximately 40°. The *en bloc* movement, paced with an auditory tone, was completed within 2 sec (1 sec down and 1 sec up). The μg portion of each parabola lasted for approximately 20 sec, allowing for a total of 10 pitch movements per parabola. Each flight was comprised of a minimum of 35 parabolas making a total of 350 pitch movements possible barring acute MS symptoms. Testing ended when frank sickness occurred ($\geq$ 8 points on the PDI).
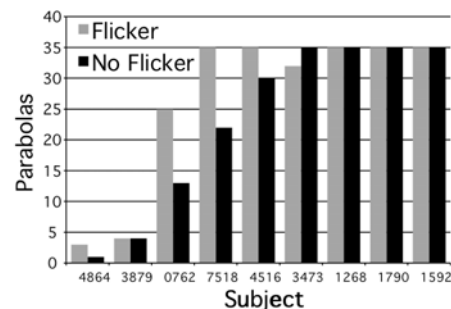

Figure 4. Number of Parabolas Completed.

Results. Five out of nine subjects did not complete the 35 parabolas during the control condition flights (Figure 4). Of those 5 subjects, 4 were capable of completing more parabolas while wearing the flicker glasses (two of the 5 completed the 35 parabolas without terminating the experiment), and 3 subjects completed all 35 parabolas regardless of the treatment afforded by the glasses.

It should be noted that the majority of symptoms occurred during the hyper-g portion of each parabola when the subject's eyes were closed and the head and body held stationary. During the *en bloc* movement when the glasses flickered the symptoms would frequently abate.

Study 4: Carsickness Pilot Study

Methods. Nineteen subjects (8 males and 12 females) ages 25–55 participated in this study. As in the previous studies, subjects gave informed consent and were briefed on the PDI Scale.
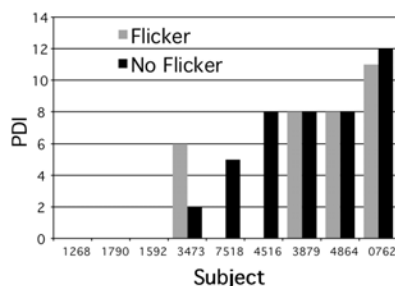

Figure 5. Final PDI Scores.

The vehicle used for the study was a 2000 Dodge Caravan. Subjects were randomly assigned to one of two visual test conditions: outside view of vehicle occluded (OCCL), or outside view of vehicle not occluded (OPEN). Within each of these two groups the subjects were further divided into a treatment (TREAT) condition that wore the stroboscopic glasses (Mac Naughton Inc., Beaverton, OR) that flickered at 8 Hz with a 20 ms clear time, or a control (CONTROL) condition that wore the same goggles, but with the lenses removed. A crossover design was used to reverse test conditions between the TREAT and CONTROL groups within the OCCL and OPEN external vehicle visual conditions.

The subjects were task to read a children's version of *Treasure Island* (Times New Roman font size 18). Two book lights (Phorm) were used to illuminate the pages of the book. The subjects' head, was stabilized with a foam cervical collar (FSA Orthopedics, Inc., Miramar, FL).

The vehicle was driven over a predetermined course that included both straight-a-ways and 90° corners at a constant speed of 5 mph for a maximum of 30 min or until the subjects reached a PDI score of MIIa. Before and after each pair of turns during testing, the subjects were prompted to report their MS symptoms. A minimum of 1 wk between tests elapsed before subjects were assigned to the opposite treatment condition

Results. Of the 9 subjects tested in the OCCL condition, four had the same tolerance time for both the TREAT and CONTROL conditions, and 5 subjects had longer tolerance times when the glasses were strobed (TREAT) (Figure 6).
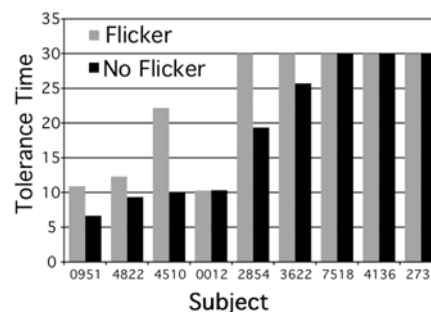

Figure 6. Outside View Occluded

Of the 10 subjects tested in OPEN condition, 4 subjects showed no change in tolerance time, 5 showed an increase in tolerance time in the TREAT condition, and 1 subject had a slight increase in time while wearing the control glasses (Figure 7). None of the vehicle MS data has been treated for

statistical significance for two reasons. First the subject population is small, and second, a sizeable portion of the population did not report any MS.
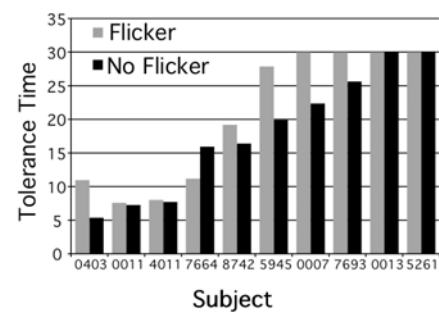

Figure 7. Outside View Not Occluded.

It is interesting to note that the majority of subjects reported that symptoms always occurred, or became more intense, during the corners. When on the straight-a-way portions of the course, symptoms would abate.

Study 5: Helicopter Pilot Study
The helicopter study allowed us to investigate the effect of stroboscopic vision on MS, and the effectiveness of flicker rate.

Methods. Six subjects participated in this study, three wearing 4 Hz strobe glasses and three wearing 8 Hz
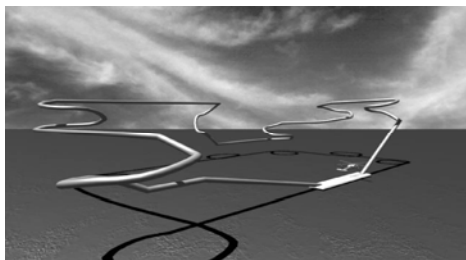

Figure 8. Helicopter Flight Path

strobe glasses. Both were set to a dwell duration of 10 msec. The subjects were required to read the text of an Army aircraft manual while seated in the cabin area of a USAARL JUH-60 Black Hawk helicopter

during 20 min of a provocative flight pattern (Figure 8). Each subject participated in 2 flights: (1) wearing the strobe glasses, and (2) no glasses. Unlike the previous four studies, for the Helicopter study, MS was scored using a written version of the Motion Sickness Questionnaire (MSQ; Kellogg, *et al*. 1965) rather than the PDI. The MSQ consists of 28 items (symptoms) that are rated by the participant in terms of severity on a 4-point scale that included three primary factors (nausea, ocluomotor disturbance, and disorientation) with yes/no answers. The total symptom severity score is an aggregate of all these symptoms
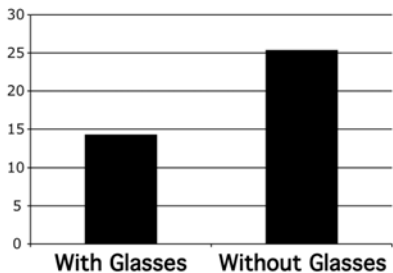

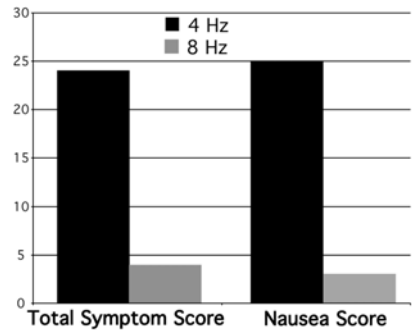Figure 9. Mean Nausea Score for both 4 Hz and 8 Hz strobe glasses.

Figure 10. Mean Total Symptom Score and mean Nausea Score for 4 Hz VS 8 Hz strobe glasses.

Results. The nausea score and total severity of symptoms score were lower for all six subjects when wearing the strobe glasses (Figure 9). In addition, the 8 Hz strobe glasses produced lower average nausea and total symptom severity scores

than the 4 Hz glasses (Figure 9). Again, the sample population was too small for statistical analysis, but the differences in the symptom scores without glasses when compared to those with the glasses is quite large.

Discussion.

The results of the five MS investigations presented in this paper strongly suggest that stroboscopic vision maybe an effective alternative to traditional pharmaceutical and adaptive anti-motion sickness countermeasures that are available today.

A primary question concerning the applicability of stroboscopic vision to different motion environments requires not only basic research, but an understanding of the what best defines the cause(s) of MS (Money, 1970; Crampton, 1989). The point on which most research in the field of MS does agree is that MS cannot be educed without an intact vestibular system. However, while unusual vestibular stimulation can elicit symptoms, self motion (passive or active) is not a prerequisite or even necessary for the development of symptoms.

Symptoms can be effectively evoked by moving the visual surround (*i.e.* optokinetic stimulation) when the visual movement is not congruent with the incoming vestibular and proprioceptive information. The resolution of this incongruency typically occurs through an adaptive process. It is interesting to consider that retinal slip, particularly at the higher frequency range of visual input (>1.0 Hz), may be one of the primary causes of the incongruency between visual-vestibular function, and it may also be at the core of the adaptative process (Melvill Jones and Mandl, 1981).

While we are not suggesting that retinal slip is the basis for all forms of MS, we are however, suggesting that it may be a primary component in those situations where there is a visual, vestibular and proprioceptive incongruency.

In this vein, there remains a question concerning retinal slip and optokinetic induced MS that must be addressed. If retinal slip is at the basis of conflict between the visual-vestibular system, why does fixation on a central point (between the eye and the moving display) prevent MS during, for example, circular-vection type displays (Flanagan *et al*., 2002) when the fixation, by its very nature, induces a primarily retinal slip? Kitazaki *et al*. (2006) have addressed this issue. They suggest that it is a matter of congruency. Specifically, when the extra-retinal and retinal eye movements were incongruent with an observer's head moving in a virtual environment (VE), MS was increased. When the head is held stationary and a central fixation point is provided, there is no conflict between the extra-retinal, the retinal, vestibular and proprioceptive inputs. Retinal slippage is anticipated and therefore, neither self-motion, nor MS is generated. Without a fixation target, the optokinetic display velocity and the ensuing pursuit eye movements may not equal a unity gain. With a gain less that unity retinal slip will be present, and MS may develop.

Conclusions

There remains a vast amount of research to be undertaken to fully investigate the efficacy of stroboscopic vision as a treatment for MS. Principal among the suggested research is: (1) definition of the most effective rate of flash or flicker, (2) determination of the most effective dwell time for each flicker, (3) adaptability to provocative environments while under the influence of stroboscopic vision (*i.e.*, do individuals adapt while wearing the stroboscopic lenses), (4) retention or capture of material or targets under stroboscopic illumination, (5) the effectiveness of stroboscopic illumination to treat sensorimotor problems other that MS (*e.g.* postural ataxia, visual vestibular challenges associated with daily living, congenital nystagmus, etc.)

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