Display Color Affects Motion Sickness Symptoms in an Optokinetic Drum

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Background: Many stationary participants who view the patterned interior of a rotating cylinder (optokinetic drum) experience motion sickness (MS) symptoms. Most drum interiors have consisted of black and white patterns. An experiment was conducted to investigate the effects of chromaticity on MS onset and severity. ***Methods:*** There were 12 individuals who participated in the experiment (4 men, 8 women, mean age = 25). Keeping rotation speed constant (5 RPM), the color of vertical stripes in an optokinetic drum was manipulated. There were three conditions used: 1) alternating black and white stripes; 2) gray stripes having different luminance values; and 3) chromatic stripes (white, red, yellow, black, green, and blue) that approximately matched the luminance values of the stripes in the gray condition. Every 2 min, eight motion sickness symptoms were assessed (for up to 16 min) using a subjective scale (0 = none, 1 = slight, 2 = moderate, 3 = severe). ***Results:*** Overall, MS onset was fastest, and symptoms the most severe, in the chromatic condition. The two major MS symptoms that were significantly affected were headache and dizziness. ***Conclusions:*** Chromaticity may affect how much an observer's visual environment appears to be stationary, perhaps because chromaticity is such a common feature of the stationary environment in which our visual system evolved. In an optokinetic drum, the addition of chromaticity may increase the disparity between visual and vestibular inputs, a factor thought by many to contribute to MS onset and severity.

Keywords: color, motion sickness, optokinetic drum, vection.

MOTION SICKNESS (MS) symptoms are often experienced by individuals in moving vehicles, vehicle simulators, virtual reality environments, and zero gravity conditions. Although the constellation of symptoms can vary, MS symptoms can include headache, dizziness, pallor, bodily warmth, drowsiness, nausea, retching, and vomiting. Despite MS's widespread occurrence, its causes are far from understood. Current theories of MS are centered on sensory conflict (12,18,19), specific conflict regarding the subjective vertical (2), nystagmus eye movements (6), postural instability (20), and canal overstimulation (17). It is also possible that multiple factors (7) can contribute to MS onset. Regardless of the theory subscribed to, vision often plays a pivotal role. Given that drug treatments for MS often produce unwanted side effects, it would be beneficial if MS could be partially alleviated by controlling features of the visual field. The purpose of the present experiment was to test the effects of chromaticity on the onset and severity of MS.

Visual Display Effects on MS in an Optokinetic Drum

Visual variables that potentially affect MS onset can be effectively studied using an optokinetic drum. Under optokinetic drum conditions, a stationary observer inside a large drum views the drum's patterned interior as it rotates. Within 20–30 s, most observers experience circular vection, an illusory sense of self-motion. That is, even though the observer knows the drum is moving, it may appear stationary as the observer perceives self-rotation in the direction that is opposite of the drum's true rotation. When optokinetic drum viewing is extended for several minutes, MS symptoms often result (3,11,22,23). When a participant's head is immobilized, all forms of sensory input related to motion indicate that the participant is stationary except for vision. Therefore, by carefully altering the lining of the drum, the effects of specific visual field features on MS can be tested.

Several investigators have manipulated optokinetic drum patterns and found effects on MS. Presenting vertical stripes in an optokinetic drum, Hu and colleagues (10) found that spatial frequency plays a role as well as drum rotation velocity (11). Tilted stripes (as opposed to vertical stripes) increase gastric myoelectric activity (1), a physiological measure that is correlated with motion sickness symptoms (22). Tilting an optokinetic drum so that it rotates in a "wobble-like" fashion also hastens the onset of symptoms (3). Also, a more complex pattern, such as a checkerboard pattern, hastens the onset of vection and symptoms compared with a simple striped pattern (4). Kennedy and colleagues (14) found that stimulus patterns depicting naturalistic scenes (i.e., waves, clouds, wood grain, and dots) affected the severity of MS in an optokinetic drum.

Under some conditions, such as vehicle simulators, virtual reality environments, and optokinetic drums, vection and MS are correlated (9,21). It would be wrong to assume that vection causes MS. However, the correlation should not be ignored. When vection is experi-

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enced in an optokinetic drum, visual input that indicates self-motion is at odds with other sensory inputs. It stands to reason that any increase in vection magnitude would only serve to increase the disparity between visual and nonvisual sensory inputs.

The hypothesis that the addition of chromaticity would hasten MS onset was based on the finding that adding chromaticity to an optokinetic drum hastens the onset and increases the magnitude of vection compared with achromatic stripes. In a recent experiment (4), participants viewed the same stimulus patterns that were used in the current study during 60 s trials. The three patterns used consisted of vertical stripes that were black and white, various shades of gray, and various chromatic colors that matched the luminance values of the stripes in the gray shade condition. Rotation speed (5 RPM, $30° \cdot s^{-1}$) and illumination were the same as those in the current experiment. Results indicated that participants in the chromatic condition experienced: 1) faster vection onset, and 2) more compelling vection. Our hypothesis regarding the current experiment was that the addition of chromaticity would: 1) hasten MS onset, and 2) result in more severe MS symptoms.

METHODS

Participants

There were 12 Saint Peter's College undergraduate students and faculty members who voluntarily participated in the experiment (4 males, 8 females). The age of the participants ranged from 20–43 yr (mean = 25). Potential participants who reported no history of motion sickness susceptibility were not allowed to participate in the experiment. Persons reporting any visual, vestibular, neurological, or gastrointestinal abnormality, or any other general health problem, were not allowed to participate. Participants fasted for at least 2 h before each experimental trial. The study protocol was approved in advance by the Saint Peter's College Institutional Review Board. Each subject provided written informed consent before participating.

Apparatus

The optokinetic drum consisted of a synthetic composite cylinder 122 cm in height and 107 cm in diameter. The drum was suspended from a motor attached to a beam directly above the drum with four steel cables. Head position was maintained throughout the experiment by means of a chin rest in which the participant's chin rested in a stationary concave depression while the participant's forehead rested against a curved metal bar. Viewing took place from the drum's center, resulting in a viewing distance of 53.5 cm when the participant's line of sight was perpendicular to the drum's surface. Horizontally positioned baffles attached to the top and bottom of the chin rest restricted the participant's view so that the only surface seen through the baffles was the interior of the drum. Illumination was provided by two 32-W florescent bulbs positioned directly behind a translucent plastic diffuser panel and 102 cm directly above the top of the drum.

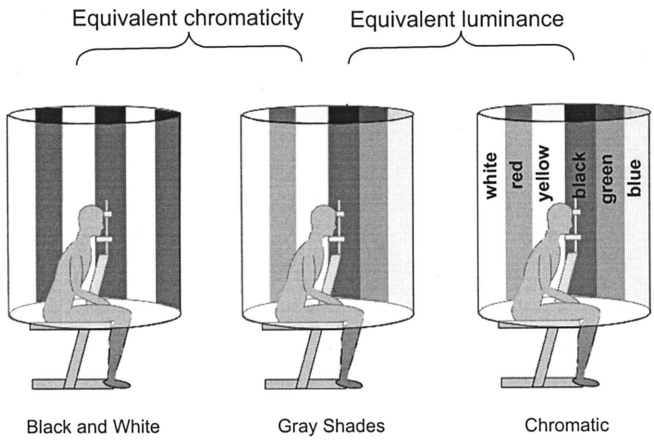

Fig. 1. The three optokinetic drum conditions with black and white, gray shade, and chromatic stripes.

Stimulus Displays

The three stimulus displays are shown in **Fig. 1**. Each display consisted of 12 vertical stripes that lined the optokinetic drum. The width of each stripe subtended 30° of visual angle. The first condition consisted of alternating black and white stripes, the second condition consisted of stripes that were black, white, and various gray shades, and the third condition consisted of stripes that were black, white, and various colors. By having black and white stripes in all three conditions, the global contrast of each display was held constant across conditions, e.g., the difference between the highest luminance value and the lowest luminance value was equated. Going from the black and white condition to the gray shade condition constituted a change in local contrast in that the degree of luminance change taking place at each edge was reduced in the gray shade condition. Furthermore, the degree of luminance change at each edge varied in the gray shade condition, whereas in the black and white condition, the degree of luminance change at each edge was always the same (± 34.4 cd $\cdot$ m^{-2}). Going from the gray shade condition to the chromatic condition constituted a change in chromaticity. That is, the global and local contrast of the gray shade and chromatic conditions were equated; the difference between these conditions was the addition of chromaticity.

In the black and white condition, the black and white stripes had luminance values of 1.6 and 36.0 cd $\cdot$ m^{-2}, respectively. In addition to black and white stripes (two each), the gray shade condition consisted of gray shades having four different shades—two for each shade. The four gray shades had luminance values of 6.6, 10.5, 11.9, and 24.6 cd $\cdot$ m^{-2}. In addition to black and white stripes (two each), the chromatic condition consisted of four different color stripes, two each of the following: red, blue, green, yellow, black, and white. The luminance value of each stripe in the chromatic condition was matched as closely as possible with the luminance value of one of the stripes in the gray shade condition. As a result, the luminance values of the red, blue, green, and yellow stripes were 6.7, 10.6, 11.8, and 25.0 cd $\cdot$ m^{-2}, respectively. The luminance matching of the gray and chromatic stripes was accomplished by choosing the

gray shades that most closely matched the luminance of the chromatic stripes from an achromatic range of Color-Aid paper. Luminance readings were obtained using a Minolta LS-110 (Konica, Mahwah, NJ) photometer from a position that approximated that of a participant's eyes during a trial. Luminance readings taken with the Minolta LS-110 photometer include a CIE spectral sensitivity correction. Because of CIE correction, the difference between corresponding stripes in the gray shade and chromatic conditions is one of wavelength, not brightness. The photometer was aimed along a line that was perpendicular to the drum's lining. Because the primary source of illumination came from above, an illumination gradient existed (brighter on top, darker on bottom). However, this gradient was slight and consistent across conditions, meaning that the luminance of each stripe varied from top to bottom by the same proportion.

Assessment Scales

Two subjective rating scales were used to assess each participant's MS symptoms throughout each trial. One scale was a 0–10 overall well-being scale (0 = I feel fine, 10 = I feel awful, as if I am about to vomit). Data analysis was not performed on the overall well-being scores; instead these scores were used to comply with the approved human subjects protocol. For the purpose of providing data for analysis, a more specific subjective symptoms of motion sickness (SSMS) scale was used to assess eight subjective MS symptoms. Each symptom was rated by the participant using a 0–3 scale (0 = none, 1 = mild, 2 = moderate, 3 = severe). The symptoms rated were spinning, dizziness, bodily warmth, headache, increased salivation, stomach awareness, nausea, and dry mouth. Unlike a study that involves assessing participants' symptoms pre- and post-treatment*, in the present study we wanted to track the development of symptoms throughout the course of each trial. In order to do so, ratings were obtained from each participant every 2 min. Therefore, a simplified scale was needed so that participants could provide ratings quickly.

Procedure and Design

The participant sat inside the stationary drum and was familiarized with the overall well-being and SSMS scales. Baseline ratings were obtained at the beginning of each trial. The participant was instructed to close his/her eyes until the drum steadily rotated at a speed of $30° \cdot s^{-1}$ (5 RPM). The participant was then instructed to open his/her eyes and overall well-being and SSMS ratings were obtained every 2 min throughout the trial. A trial concluded when the participant's overall well-being rating was a "5" or higher** or 16 min had elapsed.

Each participant served in all three conditions: 1) black and white stripes, 2) gray stripes, and 3) chromatic stripes. There were six possible orders of participation. Participation was completely counterbalanced to control for any possible order effects. At the conclusion of each trial, the participant rested until the severity of symptoms subsided. The participant was scheduled for a subsequent condition in 48–72 h. After serving in all three drum conditions, the participant was debriefed and asked to describe overall impressions of the conditions.

RESULTS

SSMS Scores

A composite SSMS score was calculated for each participant by adding the subjective ratings (0–3) for each of the eight symptoms probed (spinning, dizziness, bodily warmth, headache, increased salivation, stomach awareness, nausea, and dry mouth). Although eight symptoms were probed, realistically, the highest possible score was a "21," because it was not possible for a participant to experience increased salivation and dry mouth at the same time†. The mean number of minutes to reach the approximate midpoint of the SSMS scale (11) in the black and white, gray shade, and chromatic conditions were 8.7, 7.8, and 5.2 min, respectively (**Fig. 2**)‡. A one-way repeated measures ANOVA revealed a significant difference among conditions [$F(2,22) = 5.5$, $p < 0.011$]. Separate *t*-tests indicated that the chromatic condition was significantly different from the black and white [$t(11) = 3.5$, $p < 0.003$, 1-tailed] and gray shade [$t(11) = 2.4$, $p < 0.018$, 1-tailed] conditions; the black and white and gray shade conditions were not significantly different from each other.

Major MS Symptoms

Although the SSMS composite scores provide an overall indication of MS symptoms, not all MS symptoms are equal in severity. Some symptoms are considered to be major symptoms because they are particu-

* Unfortunately, there seems to be no standard subjective scale used to measure motion sickness symptoms. Although some are more popular than others, many investigators seem to tailor scales according to: 1) the specific questions being asked, and 2) experimental design. Nonetheless, our SSMS scale probes known MS symptoms. It is briefer than some other scales that have been used, but this is a desirable feature given the scale's frequent use throughout each trial (every 2 min).

** Participants were not informed that a trial would terminate when an overall well-being of "5" or more was reported. Frequently, participants reported ratings that were higher. We have noticed that after a rating of "5" or more is given, MS symptoms sometimes worsen at an accelerated rate. Therefore, "5" seemed like a prudent choice for the rating required to terminate a trial.

† It might seem odd at first to measure two mutually exclusive symptoms; however, individual differences in the way MS symptoms are experienced justifies the inclusion of both increased salivation and dry mouth in our SSMS list of symptoms. During MS onset, some individuals may experience increased salivation whereas other individuals may experience dry mouth.

‡ All participants attained an SSMS composite score of "11" or more in each of the three conditions they served in except for one participant in the black and white condition. That participant attained an SSMS score of "10" at the 8-min mark. In that case, the number of minutes to reach the midpoint was taken to be 10, the soonest possible time that an SSMS score of "11" or more could be attained. This approach is conservative in that it works against our hypothesis. If this participant had continued on, a score of "11" might not have been attained until a later minute mark.

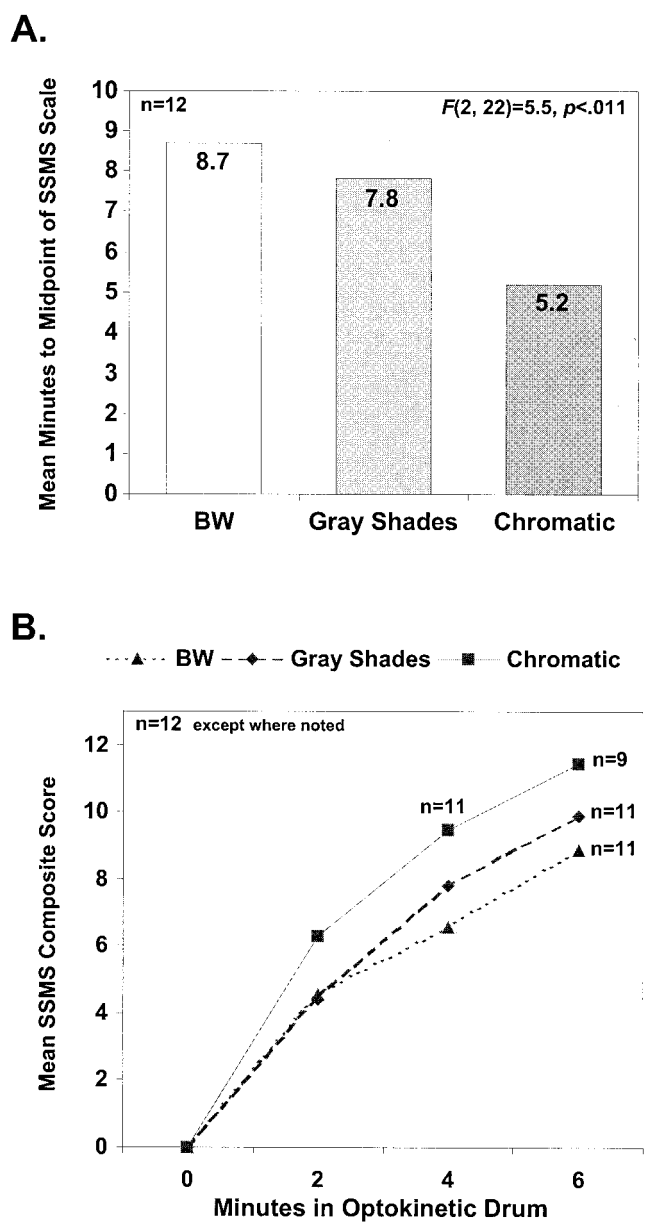

Fig. 2. The mean amount of minutes to reach the approximate midpoint (11) of the SSMS scale (A) and the mean overall SSMS ratings for the first 6 min for the three drum conditions with black and white, gray shade, and chromatic stripes (B).

larly unpleasant. Out of the eight symptoms probed in the present study, three can be considered major: dizziness, headache, and nausea. The mean SSMS ratings (0 = none, 1 = slight, 2 = moderate, 3 = severe) for dizziness, headache, and nausea attained at the 4-min mark were calculated for the black and white, gray shade, and chromatic conditions. We chose 4 min because the data from all the participants except for one were available.

The means obtained for dizziness were 0.91, 1.36, and 1.73, respectively, for the black and white, gray shade, and chromatic conditions. A one-way repeated measures ANOVA revealed a significant difference among conditions for dizziness [F (2,20) = 4.8, $p < 0.019$]. Separate t-tests indicated that the ratings obtained in the black and white and gray shade conditions were significantly different [t (10) = 2.2, $p < 0.027$, 1-tailed], as were the means obtained in the black and white and chromatic conditions [t (10) = 3.6, $p < 0.003$, 1-tailed]. Means obtained in the gray shade and chromatic conditions were not significantly different from each other.

The means obtained for headache were 0.27, 0.64, and 1.1, respectively, for the black and white, gray shade, and chromatic conditions. A one-way repeated measures ANOVA revealed a significant difference among conditions for headache [F (2,20) = 5.3, $p < 0.014$]. Separate t-tests indicated that the ratings obtained in the gray shade and chromatic conditions were significantly different [t (10) = 2.2, $p < 0.027$, 1-tailed], as were the means obtained in the black and white and chromatic conditions [t (10) = 3.1, $p < 0.006$, 1-tailed]. Means obtained in the black and white and gray shade conditions were not significantly different from each other.

The means obtained for nausea were 0.27, 0.36, and 0.91, respectively, for the black and white, gray shade, and chromatic conditions. A one-way repeated measures ANOVA did not reveal a significant difference among conditions for nausea.

DISCUSSION

The results of the current experiment suggest that the addition of chromaticity to an optokinetic drum lining significantly hastens MS onset. Dizziness and headache, two major MS symptoms, were reported significantly more often in the chromatic condition. One could argue that even though the surfaces that comprised the gray shade and chromatic conditions were matched for luminance using a photometer, even slight luminance differences or individual differences in contrast sensitivity could account for the current results. However, it seems highly unlikely that contrast caused the differences obtained in the current MS experiment. The luminance changes in the black and white condition were extreme compared with those in the gray shade and chromatic conditions and no significant differences were found between the black and white and gray shade conditions' composite SSMS scores.

The results of our color vection experiment (4) and the current experiment fit squarely with results obtained by other investigators that show vection and MS symptoms to be correlated under some conditions (9,20). It would, however, be misleading to assume that vection causes MS. The most typical forms of MS (e.g., seasickness, airsickness) occur in the absence of vection. Also, for some individuals, vection is experienced, but MS symptoms never develop. The case of vection occurring without MS is most notable for labyrinthine-defectives, individuals who have nonfunctioning vestibular systems. Labyrinthine-defectives typically experience vection, but they are immune to MS (8). Nonetheless, for many individuals vection often precedes the onset of MS symptoms, producing an illusion of causality.

It is not vection per se that causes MS, but more likely the sensory conflict that often accompanies some types of vection experiences. Such a situation typically occurs under optokinetic drum conditions. In a rotating drum,

visual input indicates that self-rotation is occurring, but the vestibular system provides information that the participant is stationary. It stands to reason that increases in the vection magnitude would be accompanied by increases in the magnitude of disparity between visual and vestibular inputs. In terms of the current results the following analysis seems to apply: 1) the addition of chromaticity to the stimulus increased the vection magnitude; 2) the disparity between vestibular and visual inputs increased; and 3) the onset of MS symptoms for susceptible individuals was hastened.

The question of why the addition of chromaticity should increase vection magnitude is more difficult to answer. Adding chromatic changes in the stimulus displays may lead to greater field stability, the perception that the visual field is stationary even if it is, in fact, moving. The result of increased field stability is an increase in the magnitude of vection. We suggest here that any increases in the complexity of the visual field will tend to lead to an increase in field stability. Any increase in scene complexity will tend to make the stimulus pattern more like the real world in which our visual system evolved, a world that is generally perceived to be "unmoving." Other evidence independently suggests that visual complexity may play an important role on the vection that is experienced in an optokinetic drum. Variables shown to affect vection include the vertical stripe spatial frequency (10), drum rotation velocity (11), stripe tilt (1), drum tilt (3), and stimulus patterns depicting naturalistic scenes (14).

Our argument regarding sensory conflict should not be construed as a claim that sensory conflict is the sole cause of MS. At this time, it seems likely to us that MS may have multiple causes (7), possibly including, but perhaps not limited to nystagmus eye movements (6), postural instability (20), canal overstimulation (17), and specific conflict regarding the subjective vertical (2). Even results from our own lab (3) support the hypothesis that conflicts regarding the subjective vertical hasten the onset of MS symptoms.

Neurological Implications

The results reported here cannot be easily explained in neuroscientific terms. It has been suggested that motion and color detection depend on separate neurological pathways (15,16). In general, it has been proposed that the magnocellular pathway is particularly sensitive to motion and contrast (luminance changes), whereas the parvocellular pathway is more sensitive to chromatic differences, but not motion. It should be noted here that there is not complete agreement regarding the roles these pathways play.

The experiment reported here was not designed to test how the magnocellular and parvocellular pathways affect MS. Instead, the current experiment constitutes a test of how the addition of chromaticity affects MS. The chromatic condition has luminance changes that are equivalent to those in the gray shade condition, and, therefore, should equally stimulate neural regions that are sensitive to contrast. Imagine taking black and white photographs of both conditions: they would appear to be nearly identical. As a result of these equivalent luminance values, the magnocellular pathway should be equally involved in processing the images corresponding to the gray shade and chromatic conditions. The parvocellular pathway, however, will be more involved in processing the image that corresponds to the chromatic condition. We choose to make no specific claims regarding the roles of these pathways as they relate to vection and MS, especially given that the exact roles that these pathways play are subjects of debate and not yet fully understood. However, the findings reported here, that the addition of chromaticity hastens MS onset, should at some point be accounted for in neuroscientific terms. Such an account may be complex given that in humans, vection may depend on high level processes such as scene interpretation.

Application of Results

Simulator sickness, or cybersickness, is a form of MS that often occurs for individuals who use vehicle simulators (e.g., automobile, tank, aircraft) or virtual reality environments (13). Optokinetic drum conditions are similar to those environments in that the self-motion experienced is created by visual input. The current results suggest that altering the color composition of the displays used may reduce MS in these environments. More research is needed to directly test this hypothesis, but the current results suggest that altering the chromatic content of simulator and virtual reality displays may at least partially alleviate MS symptoms. It would be naïve to think that altering chromaticity alone can eliminate MS in simulators and vehicles. Furthermore, eliminating chromatic information may not be practical in some situations. However, when training objectives are not compromised, using gray-scale displays may be desirable.

Can the color content of the scenes we view affect the most common forms of motion sickness, such as seasickness, airsickness, and carsickness? The present results suggest that the color composition of vehicle interiors may affect how much these environments appear to be stationary, perhaps because color is such a ubiquitous feature of the stationary environment in which our visual system evolved. Because MS in these environments is dependent on real motion, visual input that indicates the contrary (such as chromaticity) may only serve to hasten the onset of MS symptoms. Further research is needed to more fully understand the roles visual features play on the perception of self-motion and motion sickness.

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