A PREDICTIVE TEST FOR SPACE MOTION SICKNESS

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Abstract — Eye torsion was examined in 13 astronaut subjects, tested during repeated episodes of 0 G and 1.8 G in parabolic flight aboard NASA's KC-135. Four findings are included. 1) A strong relationship between previous history of SMS and ocular torsional disconjugacy in novel gravitational states. 2) Responses were unchanged in 4 subjects retested a year later. 3) Ocular torsional disconjugacy scores increased as exposure to 0 and 1.8 G increased. This was particularly evident in subjects who had had SMS. 4) Torsional studies during 10 to 20 parabolas are required to accurately predict SMS. The hypothesis of otolith asymmetry, compensated in 1 G but becoming unmasked in novel gravitational states, is proposed to explain the torsional disconjugacy and ensuing SMS.

Keywords — space motion sickness; ocular counterrolling; otolith asymmetry; eye torsion disconjugacy.

Humans have been subject to space motion sickness (SMS) since the beginning of space flight. Initially, when space vehicles were small and the cosmonauts and astronauts had limited mobility, it was not a major problem. As the space vehicles have increased in size and the personnel could actually move about, SMS has affected from one-half to two-thirds of space flyers (1).

The exact numbers, duration, severity, and symptoms are estimates. A systematic analysis of SMS has not been done, in spite of NASA's frequently expressed interest in the subject. The secrecy surrounding SMS may stem from the astronauts' concern that a physical complaint during space flight might result in the possibility of not being able to participate in future flights. This concern is not difficult to understand, despite the fact that some astronauts have had severe SMS, have performed their missions successfully, and have flown again. Secrecy regarding SMS continues, has infected at least some astronaut-scientists, and has inhibited research into its cause and solution. (We should hasten to add that we have found the astronauts, payload specialists, and mission specialists with whom we have worked to be very cooperative and frank.)

What do we know about SMS? It appears to be a unique form of motion sickness. That is, there is no correlation between susceptibility to SMS and susceptibility to any form of earth-based motion sickness, whether on land, sea, or air, including in parabolic flight. In space the susceptible individuals find that SMS is triggered by head movements producing angular acceleration stimuli acting on the semicircular canals. SMS is also triggered by unusual visual scenes such as seeing a fellow astronaut "upside down" or looking out of the port and seeing the earth with the southern hemisphere "up." We interpret these findings to mean that SMS has an etiology other than simple stimulation of the semicircular canals alone, but these may certainly act as promoters.

SMS tends to begin after several hours of achieving microgravity, but occasionally may start within minutes. It usually lasts from 1 to 4 days, but sometimes continues for the duration of most NASA flights, namely 1 to 2 weeks. Symptoms may return on the first day or two after landing. One astronaut told us that several days postflight he became slightly nauseated on seeing small waves as he was dining at a restaurant overlooking Clear Lake near Johnson Space Center. Scientist-astro-
nauts Ockels and colleagues (2) experienced a full range of motion sickness symptoms after lying supine for several hours in a hyper-G environment and noted the similarity of these sensations to their own previous SMS. They also stated that prior to and during shuttle launch, the astronauts and cosmonauts are positioned on their backs for several hours.

Microgravity is the underlying element in SMS, and the otolith system is the main biological detector of gravity and other forms of linear acceleration through not the only detector — see Wiltschko and Wiltschko (3). Therefore, we look to alteration in otolith function as the major substrate of SMS. The otolith asymmetry hypothesis of SMS, as first propounded by von Baumgarten and Thümler (4) proposes that some individuals have otolith systems that are asymmetric on the two sides of the head, that compensation for this has taken place in a lifetime at 1 G on earth, but that in exposure to novel G states, there is a loss of this compensation and motion sickness is one result. Asymmetry could be due to differences in the mass of distribution of otocoria; in hair cell sensitivity, distribution or numbers; in the neural relationships between the first order afferents and the receptors; or in the brainstem connections of the first order afferents. There are still other possible explanations. The essence of the hypothesis is that there is a structural or physiological asymmetry that is compensated on earth, and this compensation is lost in novel G states.

Ocular torsion is under reflex control of the semicircular canals and of the otolith apparatus (5,6). The otolith contribution can be observed in isolation if the stimulus either does not include angular acceleration or if such acceleration is below canal threshold. This can be achieved by observing ocular counterrolling with the head in the center of the axis of rotation and rotating the subject about the naso-occipital axis (7,8) with accelerations no greater than 0.2°/s². Spontaneous ocular torsion is also under otolith control. There are small random torsional eye movements, approximately ± 0.75°, these being either conjugate or disconjugate. The amplitude of these random movements becomes progressively greater as the head is rotated about the naso-occipital axis at progressively greater angles with respect to the gravity vector (9).

Methods

Several studies are described below:

1. To test the hypothesis of disturbed otolith function as a factor in SMS, we examined spontaneous ocular torsion during parabolic airplane flight in astronauts. All had had their space flights 2 to 5 or more years earlier. Most were no longer active in the astronaut program. The testing was done in a blind fashion as follows. Before the experiment the subjects filled out a questionnaire regarding their prior SMS histories and then sealed it in an envelope. The envelope was not opened until the experiment and the data analysis were completed. At that time, the written histories were converted to a widely used motion sickness rating system by Davis and colleagues (1).

During the experiment, the subjects were seated in a special chair, fixed to the floor and over the wings of NASA's KC-135 aircraft, and facing aft. Each subject's body was restrained with velcro straps and the head held firmly by means of a preformed dental bite bar. A 35-mm motor-driven single lens reflex camera was rigidly mounted on the chair about 11 inches in front of the subject's face. Both eyes were included in each image. Three to five photos were taken at each episode of 0 G and of 1.8 G. The first 9 astronauts were tested for 10 to 20 parabolas. At a later date, 8 astronaut subjects were tested, 4 having served as subjects on the previous flight.

Data analysis took place at UCLA some weeks after flight. A photographic superimposition technique was used, in which ocular torsion was measured in all frames of one eye. When this eye was completed, the other eye was similarly measured. We calculated the difference in ocular torsion between the two eyes at each episode of 0 G and 1.8 G (see Figure 1 for the steps in the data analysis).
TORSIONAL ASYMMETRY
(mean right eye amplitude minus mean left eye amplitude)
Astronaut A-7, Parabola 1

right eye amplitude

<table>
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<tr>
<th>1.8 G</th>
<th>1.5°</th>
<th>1.4°</th>
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<tr>
<td>2.5°</td>
<td>1.9°</td>
<td></td>
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<tr>
<td>2.6°</td>
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<td>mean 2.2°</td>
<td>mean 1.6°</td>
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left eye amplitude

<table>
<thead>
<tr>
<th>1.8 G</th>
<th>1.5°</th>
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<td>1.5°</td>
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<td>1.8°</td>
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<td>0 G</td>
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<td>0.6°</td>
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<td>mean 0.6°</td>
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right minus left
2.2° - 1.6° = .6°

0 G

right minus left
1.6° - 0.6° = 1.0°

Figure 1. Steps in data analysis of torsional asymmetry. Ocular torsion was measured by an iris superimposition technique, using 3 to 5 images (3 each in present example) at each episode of 0 G and 1.8 G. In the first parabola of Astronaut A-7, the mean torsion of the left eye at 1.8 G was subtracted from the mean of the right eye. The same was done for the values obtained at 0 G. These differences were then plotted and a slope obtained (right side of figure). The same was done for each parabola (not shown), and a “mean slope” was calculated for the subject.

Results

Each subject was described by a single measure of torsional disconjugacy, the “mean slope,” this being obtained by averaging the slopes from the 10 to 20 parabolas he had undergone. The mean slope scores of the astronaut-subjects were ranked, and the envelopes containing the SMS histories were then opened. It was found that 4 astronauts having the lowest scores had not experienced SMS. The 5 with the highest scores had all had SMS. The mean scores of the two groups were significantly different (P = 0.01, two-tailed Wilcoxon rank sums test) (10).

Within the group who had SMS, the severity of SMS paralleled the magnitude of torsional disconjugacy scores. For example, astronaut A-5 flew on 2 missions. On the first he had no malaise but experienced a single episode of vomiting after dinner on the 1st day of flight. Using the scale of Davis and colleagues (1), we considered his SMS to be mild. Astronaut A-6 flew 5 missions and had nausea and vomiting for 2 to 3 days on each mission. We considered his symptoms to be severe (nausea, he performed his duties in an exemplary fashion). When similar measures of torsional asymmetry were performed at 1 G on the ground, there were no differences between subjects. See top of Figure 2. For further details, see Diamond and Markham 1991 (11). Based on these results, we were encouraged to think we might have identified a long-sought predictive test of SMS.

2. The following year, we performed another series of parabolic flight experiments.
We tested 8 astronauts, 4 of whom were new to us. Each was examined for 20 parabolas. One of the questions we asked was whether the 4 new astronaut subjects would yield the same results as the prior study. We were blinded to their prior histories of SMS as described above. As before, we ranked the torsional asymmetry scores from the least to greatest. Those two astronauts who had the lower scores did not have SMS, and those who had the higher scores both had SMS (see Figure 3). A one-tailed t test found that the mean scores in these groups differed at $P = 0.015$. A one-tailed Wilcoxon rank sums test of the significance of the difference in scores in these very small groups resulted in $P = 0.06$, the lowest $P$ value this test can produce with only 4 subjects. This finding gives support to our previous assertion that changes in ocular disconjugacy during parabolic flight are related to SMS.

3. In 1992 we retested 4 of the 5 astronauts tested in 1991 who had previously had SMS. All continued to have high scores of ocular disconjugacy in parabolic flight. The responses thus appear to be stable.

4. We had hypothesized that in certain subjects the utricles might be angulated differently to each other, that a loss of compensation induced by parabolic flight causes ocular torsional disconjugacy, and that increasing the gravity vector to 1.8 $G$ when the head is tipped in certain head positions might result in a "nulling" or lessening or other alteration in disconjugacy. We tested 8 astronauts upright...
Predicting SMS

TORSIONAL ASYMMETRY IN GROUND-BASED 1G
FIVE POSITIONS

TORSIONAL ASYMMETRY IN HYPO- AND HYPERGRAVITY
FIVE POSITIONS

mean = 0.30 (0.05)  p = 0.015  mean = 0.85 (0.15)

Figure 3. Four new former astronaut subjects are arranged in order of increasing scores of torsional disconjugacy in hypogravity and hypergravity of parabolic flight. The 2 with lowest scores, shown in black bars, did not have SMS in space; the 2 with the higher scores, shown in grey bars, did get sick on their Shuttle missions. The top of the figure shows their torsional disconjugacy scores in 1 G; all had similar very low scores.

for 4 parabolas, 4 parabolas with the chair tilted 5° right ear down, 4 at 10° right ear down, 4 more at 5° left ear down, and then 4 at 10° left ear down. We found that in all tilted positions there was increased torsional disconjugacy. This is the same finding we reported at 1 G many years before (9). In the present study, the increased disconjugacy related to the tilted head position may have masked any other changes, and we could not confirm that tilting the subjects had any effect on equalizing a utricular asymmetry.

5. We asked the question whether fewer than 10 or 20 parabolas could serve as a predictive test for SMS. We were able to include data from both the 1991 and 1992 studies using a total of 13 astronaut-subjects, grouping the results in sets of 4 parabolas (see Figure 4). Torsional disconjugacy increased in 0 G with increasing number of parabolas in all subjects (0.001 ≤ P ≤ 0.02), and far more in those who had had SMS. Repeated measures ANOVA found the effect significant at P = 0.001 in the SMS group and at P = 0.02 in the non-SMS group. The finding with repeated episodes of 1.8 G is not as clear (see Figure 4).

We concluded that 10 to 20 parabolas are needed to induce sufficient ocular torsional disconjugacy to predict SMS.

The most likely substrate for both SMS and ocular torsional disconjugacy, as described in this paper, is a structural or functional asymmetry of the otolith apparatus on the two sides of the head in certain individuals. Future testing of more astronauts and of prospective astronauts, and the more ready availability of data on SMS itself will lead to a better understanding of its cause and prevention.
TORSIONAL DISCONJUGACY IN 0 G AND 1.8 G

Figure 4. Torsional disconjugacy in 0 G increased significantly \((0.0001 \leq P \leq 0.02)\) with increasing number of parabolas in all subjects, more markedly in those who had SMS on their space mission. Disconjugacy in 1.8 G was less than in 0 G.
REFERENCES